Electrical Environment of the Proposed Northern Pass Transmission Project:
DC Electric Field, DC Magnetic Field, Air Ion Density, AC Electric Field, AC Magnetic Field, Audible Noise, and Radio Noise
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DC Electric Field,
DC Magnetic Field,
AC Electric Field,
Air Ion Density
AC Magnetic Field,
Audible Noise, and
Radio Noise

Prepared for

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Acronyms and Abbreviations

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<tr>
<td>µPA</td>
<td>Micropascal</td>
</tr>
<tr>
<td>AAL</td>
<td>Annual average loading</td>
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<tr>
<td>AC</td>
<td>Alternating current</td>
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<tr>
<td>ACGIH</td>
<td>American Conference of Governmental Industrial Hygienists</td>
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<tr>
<td>AM</td>
<td>Amplitude modulated</td>
</tr>
<tr>
<td>AN</td>
<td>Audible noise</td>
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<tr>
<td>dBA</td>
<td>Decibels on the A-weighted scale</td>
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<tr>
<td>dBµV/m</td>
<td>Decibels relative to 1 microvolt per meter</td>
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<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>ELF</td>
<td>Extremely low frequency</td>
</tr>
<tr>
<td>EMF</td>
<td>Electric and magnetic fields</td>
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<tr>
<td>FM</td>
<td>Frequency modulated</td>
</tr>
<tr>
<td>G</td>
<td>Gauss</td>
</tr>
<tr>
<td>GHz</td>
<td>Gigahertz</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>Hz</td>
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<td>ICES</td>
<td>International Committee on Electromagnetic Safety</td>
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<td>ICNIRP</td>
<td>International Commission on Non-Ionizing Radiation Protection</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<tr>
<td>kV</td>
<td>Kilovolt</td>
</tr>
<tr>
<td>kV/m</td>
<td>Kilovolt per meter</td>
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<tr>
<td>L-level</td>
<td>Exceedance level</td>
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<tr>
<td>mG</td>
<td>Milligauss</td>
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<tr>
<td>MHz</td>
<td>Megahertz</td>
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<td>Megavolt Ampere Reactive</td>
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<td>Megawatt</td>
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<td>Northern Pass Transmission</td>
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<td>PL</td>
<td>Peak loading</td>
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<td>RN</td>
<td>Radio noise</td>
</tr>
<tr>
<td>ROW</td>
<td>Right of way</td>
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<tr>
<td>V/m</td>
<td>Volt per meter</td>
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</tbody>
</table>
Limitations

At the request of Northern Pass, LLC, Exponent conducted specific modeling and evaluations of the electrical environment of the Northern Pass Transmission Project. This report summarizes and presents the findings resulting from that work. In the analysis, Exponent has relied upon transmission line design geometry, loading data, specifications, and various other types of information provided by the client. Exponent cannot verify the correctness of this input data, and relies on the client for the data’s accuracy. Northern Pass, LLC, has confirmed to Exponent that the data contained herein is not subject to Critical Energy Infrastructure Information restrictions. Although Exponent has exercised usual and customary care in the conduct of this analysis, the responsibility for the design and operation of the project remains fully with the client.

The findings presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.
Executive Summary

Northern Pass, LLC, proposes to build a transmission line with direct current (DC) and alternating current (AC) components for a total length of approximately 192 miles from the border with Québec, Canada, to Deerfield, New Hampshire, to deliver electricity from the Hydro-Québec system to New England. The Northern Pass Transmission (NPT) line is planned to be constructed as a ±320-kilovolt (kV) DC transmission line from the border to the Franklin Converter terminal. In the northern portion of the DC route, the NPT DC line is proposed to be constructed on new and existing right-of-way (ROW)—overhead in some portions and underground in others. In the central portion of the route, the overhead NPT DC line would be constructed on a ROW with existing AC transmission lines and would also have an underground section. South of the Franklin Converter terminal, the NPT line is planned to be constructed as a 345-kV AC line. For modeling purposes, the route is divided into four configurations based upon the proposed construction of the line.

1. **DC-Only**: an overhead ±320-kV DC transmission line on a new ROW.
2. **DC-Underground**: an underground ±320-kV DC transmission line.
3. **Combined-DC/AC**: an overhead ±320-kV DC transmission line on a ROW shared with existing AC lines.
4. **AC-Only**: an overhead 345-kV AC transmission line on a ROW shared with existing AC lines.

The route is subdivided in this way because the electrical environment and hence the calculation methodology varies among these four configurations. Beneath an overhead DC transmission line, the electrical environment includes static electric fields, static magnetic fields, space charge (i.e., mostly air ions and some charged aerosols), audible noise (AN), and radio noise (RN). When constructed below ground, the DC transmission line will be a source of static magnetic fields above ground, but not static electric fields, air ions, AN, or RN above ground. Beneath an overhead AC transmission line, the electrical environment includes 60-Hertz AC electric fields, AC magnetic fields, AN, and RN. When both AC and DC lines are present as in a Combined-DC/AC ROW, the static and AC electric and magnetic fields can be calculated independently.
(as well as space charge for the DC line), but the AN and RN must be calculated together in order to account for their additive effects.

**Static Electric and Magnetic Fields**

The DC NPT line will produce static electric and magnetic fields that are the same as those encountered in the natural environment, with magnetic-field levels similar to the earth’s static geomagnetic field on the ROW and electric-field levels outside the ROW similar to those produced by atmospheric phenomena, weather, and friction charging.\(^{1}\)

The median calculated static electric-field levels everywhere on the route are below the National Radiation Protection Board’s defined level of perception (NRPB, 2004a) and the static magnetic-field levels are likewise well below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Food and Drug Administration guidelines (FDA, 2003; ICNIRP, 2009) for static magnetic-field exposure or referenced values (NRPB, 2004b).

**Alternating Current Electric and Magnetic Fields**

In the AC-Only portion of the route there will be no project-related static electric field, static magnetic field, or space charge. Similar to their DC counterparts, however, AC transmission lines affect the ambient electrical environment and can be assessed in terms of compliance with environmental standards and guidelines developed by scientific and health agencies.

The AC electric and magnetic fields along all portions of the route are calculated to be below the Basic Restrictions established by ICNIRP and the International Committee on Electromagnetic Safety, which provide limits on public exposure (ICES, 2002; ICNIRP, 2010).

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\(^{1}\) Electric and magnetic fields associated with the operation of a DC transmission line are referred to in this report as static electric and magnetic fields. While the terminology differs, the phenomena referred to as static or direct current fields are exactly the same.
Corona Effects: Space Charge, Audible Noise, and Radio Noise

Transmission line corona refers to the partial electrical breakdown of the air surrounding the conductors resulting in conductor vibration, light, AN, RN, and space charge. Both AC and DC transmission lines are sources of corona and therefore AN and RN.²

**Space Charge.** Neither the federal government, nor the state of New Hampshire has standards or guidelines for the density (concentration) of electric charges in the air (space charge) notably associated with DC transmission lines. The space charge outside the ROW of the DC-Only and Combined-DC/AC sections would be within the range of levels encountered in the environment and similar to or less than the space charge from the existing ±450-kV DC line in New Hampshire.

**Audible Noise.** The fair weather AN along all portions of the NPT transmission line is below both the Environmental Protection Agency reference level (USEPA, 1987) as well as the night time level recommended by the World Health Organization (WHO 1999, 2009). The values will be higher in foul weather but the NPT line will still meet these guidelines.

**Radio Noise.** The fair-weather RN at 50 feet from the outer conductor throughout the route is well below the Institute of Electrical and Electronics Engineers guideline level (IEEE, 1971) for RN from a transmission line. In the unlikely event that radio reception at a residence is a problem due to the line, it can be mitigated by use of a directional antenna, relocation of an existing antenna, or other solutions (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

Note that this Executive Summary does not contain all of Exponent’s technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

² Both AC and DC lines are also sources of space charge, however corona on AC transmissions results in minimal space charge around the line because positively-charged air ions produced by corona during the positive half cycle of the voltage are attracted back towards the conductor during the negative half cycle and are removed from the air. The same phenomenon occurs with negatively-charged air ions.
**Introduction**

Northern Pass proposes to build an approximately 192-mile transmission line from the border with Québec, Canada, to Deerfield, New Hampshire, to deliver electricity from Hydro-Québec’s hydroelectric plants in Canada to New England. Over the majority of the route (approximately 158.3 miles) the Northern Pass transmission (NPT) line is planned to be constructed as a ±320-kilovolt (kV) direct current (DC) transmission line. A new right of way (ROW) will be needed for approximately 32.0 miles of the DC overhead line and approximately 60.5 miles will be constructed underground. In the southern portion of the route (approximately 33.7 miles) between a converter terminal in Franklin, New Hampshire, and an existing substation in Deerfield, New Hampshire, the NPT line is planned to be constructed as a 345-kV alternating current (AC) line.

This report describes the electrical environment around the existing lines on the proposed project route and the change in that environment as a result of the NPT project. Specifically, the report provides calculations of the 60-Hertz (Hz) electric and magnetic fields due to the AC transmission line, the static electric and magnetic fields and ion densities associated with the operation of the DC transmission line, and the audible noise (AN), and radio noise (RN) produced by both the AC and DC transmission lines.
Project Location and Description

Route Description

The route of the proposed NPT line is divided into 62 different sections in which there are different configurations of existing and proposed transmission lines. Diagrams showing these configurations are provided in the transmission line section of the Northern Pass Application. As described above, in some portions of the route, the NPT line is proposed to be constructed on a new ROW as an overhead DC transmission line, while in other portions it is proposed to be constructed underground or as a 345-kV transmission line. A simplified map depicting the route of the proposed NPT line is shown in Figure 1. This map identifies segments of the route in four different general configurations:

1. **DC-Only**: an overhead ±320-kV DC transmission line on a new ROW.
2. **DC-Underground**: an underground ±320-kV DC transmission line.
3. **Combined-DC/AC**: an overhead ±320-kV DC transmission line on a ROW shared with existing AC lines.
4. **AC-Only**: an overhead 345-kV AC transmission line on a ROW shared with existing AC lines.

The route is subdivided in this way because the calculation methodology and results vary among these four scenarios. Beneath an overhead DC transmission line, the electrical environment includes static electric fields, static magnetic fields, space charge (i.e., mostly air ions and some charged aerosols), AN, and RN.
Figure 1. Overview of the route of the proposed NPT line from the Canadian border to Deerfield, New Hampshire.

This map identifies locations where the proposed line is constructed as 1) an overhead DC line, 2) an underground DC line, 3) an overhead DC line with existing or rebuilt AC lines, or both, and 4) an overhead AC line with existing or rebuilt AC lines, or both.
Many of the 62 proposed configurations of the route are similar enough to one another so that the electrical environment of the entire route can be represented by a smaller subset (27 of the 62 configurations) as described below in Table 1. This subset was identified by reviewing all the cross sections and considering the location and voltage of the various lines on the cross section, their configuration, their distance from the nearest ROW edge, and relative length of the cross section along the line route. For example, Segment N2-1 is used to represent Segments N2-2, N2-3, and N2-5 because the physical line configuration in each segment precisely matches that of N2-2; it is simply in a different location. A slightly different example is Segment C2-38, which is used to represent Segments C2-37 as well. In this case the configuration of transmission lines on both sections of the ROW is identical (i.e., the proposed NPT-DC line is located 60 feet from the ROW edge and is spaced 60 feet and 115 feet, respectively from two additional transmission lines). The difference is that the total ROW width in Segment C2-38 is just 225 feet while that in Segment C2-37 is 300 feet. Therefore the results of calculations in Segment C2-38 can be considered conservative estimates of similar calculations in Segment C2-37.

In addition to the 27 configurations detailed in Table 1, 3 additional configurations outside the Deerfield Substation in Deerfield, New Hampshire, were also evaluated for magnetic fields—Segment DS-1, Segment DS-2, and Segment DS-3 were modeled as cross sections XS28, XS29, and XS30, respectively. These are AC-Only cross sections that will require only thermal-related upgrades to accommodate heavier loading due to the NPT Project. Only the AC magnetic fields for these sections would change because of the NPT Project. Alterations to the line on these sections (e.g., upgrading some structures to maintain the same conductor height under increased load as the existing circuits) will not change other aspects of the electrical environment for these sections such as AC electric field, AN, or RN. Since the conductors and their configuration are not proposed to change as part of this project, the electric field as well as levels of AN and RN will be unchanged from existing conditions in these sections. Therefore, modeling results are presented only for the AC magnetic-field level in these sections.
Table 1. Segments of NPT project route selected for modeling

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<tr>
<th>Model</th>
<th>Cross Section Number</th>
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<td>XS02</td>
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<td>XS03</td>
<td>Segment N1-UG</td>
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<td>XS27</td>
<td>Segment S1-20</td>
<td>3.6</td>
<td>--</td>
</tr>
</tbody>
</table>

*Splice vaults occur every few thousand feet at which locations cable separation increases for a short distance to allow the splicing of the cable in the vault.
Load Transmission

The NPT Project is nominally a 1,000 megawatt (MW) project with the potential transfer capability of up to 1090 MW. The current used for modeling the NPT DC line at full-rating power is based upon the transmission of 1,090 MW and 225 Mega-Volt-Ampere-Reactive (MVAR) delivered at the Deerfield Substation in Deerfield, New Hampshire. The nominal loading of the DC transmission line necessary to support this delivered load is approximately 1,133 MW (1,770 Amperes [A] DC delivered to the DC-to-AC converter station at a DC voltage of ±320 kV). On the portion of the route where the NPT circuit is proposed to be constructed as an AC transmission line, the nominal AC power will be 1,100 MW (approximately 1,840A AC delivered at an AC voltage of 345 kV). In the remainder of this report, these loading levels are referred to as full rating. Modeling of magnetic-field levels was also performed at half this level, and is referred to as half rating. The average annual loading (AAL) for other adjacent AC lines along the proposed route was determined with the project operating at full rating and half rating and was used to perform the modeling based upon an in-service date of the NPT line in 2019.

DC-Only Transmission Line Segments

The initial northern portion of the DC transmission line from Canada will be an overhead line in a horizontal configuration on a new transmission line ROW, as shown in Figure 2 (Segment N1-1). As the DC line route continues south, the DC line will go underground (Segment N1-UG-T) at multiple locations and then return to an overhead configuration, and then joins an existing AC transmission ROW (Segment N2-1). The DC line continues south along an existing AC transmission line corridor, primarily in a horizontal configuration. There is an additional underground cable section in this segment of the Project, with no AC lines, on the route to Franklin, New Hampshire. To the greatest extent possible, the NPT DC line was located at, or near, the center of the ROW.

The cross sections that only have the DC transmission line are designated Segments N1-1 (overhead) and N1-UG (underground).
AC-Only Transmission Line Segments

In the southern portion of the project route, in Franklin, New Hampshire, a converter terminal is proposed to convert the electricity from DC to AC for transport further south over a 345-kV AC transmission line. This new 345-kV AC transmission line would carry the energy to an existing substation in Deerfield, New Hampshire. Over this southern portion of the route, the 345-kV AC line is proposed to be constructed exclusively on existing ROWs with AC transmission and distribution lines of varying voltages and configurations. These configurations are designated Segments S1-1 through S1-20.

In some portions of the route, the existing lines are proposed be relocated (e.g., Segment S1-1 shown in Figure 3) to accommodate the new 345-kV AC line, while in other portions of the

---

Converter terminals and substations are not discussed separately because the highest levels of AC electric and magnetic fields at the boundary will be from the transmission lines where they enter these facilities (IEEE Std. 1127-1990)
route (e.g., Segment S1-16), the existing ROW has sufficient space to accommodate the new 345-kV AC line without rebuilding or relocating any of the existing lines. To the greatest extent possible, the 345-kV AC line was located at, or near, the center of the ROW.

Figure 3. Example of an AC-Only section of the transmission line ROW.

Segment S1-1 contains the proposed 345-kV line and two existing 115-kV transmission lines (one of which is relocated to accommodate the 345-kV AC line) on an existing 225-foot ROW.

**Combined-DC/AC Transmission Line Segments**

As described in greater detail throughout the rest of this report, the calculations and assessment of AC and DC electrical effects have many similarities, but ultimately, must be evaluated according to different criteria. This is particularly true in a scenario where both DC and AC transmission lines are present on the same ROW, such as will occur on the Combined-DC/AC sections of the ROW. This configuration is planned throughout much of the northern and central portions of the route where the NPT DC line is proposed to be constructed adjacent to
existing AC lines of various voltages and configurations (Segments N1-1 through C2-38). An example of a Combined-DC/AC ROW is shown in Figure 4. In some of the Combined-DC/AC sections the existing AC lines are proposed be relocated (e.g., Segment N2-8, shown in Figure 4) to accommodate the new NPT DC line, while in other portions of the route (e.g., Segment C1-3), the existing ROW has sufficient space to accommodate the new NPT-DC line without rebuilding any of the existing lines.

Figure 4. Example of a Combined-DC/AC section of the transmission line ROW.

Segment N2-8 contains a single 115-kV AC transmission line on an existing 150-foot ROW that has been relocated to accommodate the new NPT-DC line.
Direct Current Transmission Line

Direct Current Electrical Environment: Definitions, Sources, and Occurrence

The electrical environment associated with a DC transmission line is characterized by static electric fields, static magnetic fields, and corona phenomena. Corona on the conductors is the source of AN, RN, television interference, and space charge. Static electric fields and magnetic fields vary little over time, and thus have a frequency of ~0 Hz.\(^4\) When evaluating the electrical environment of a DC transmission line, it is important to consider that the strength (i.e., the level) of the field and corona effects diminish quickly with distance from the line.

**Static electric fields** are natural phenomena that arise from various sources. A commonly encountered source of static electric field is friction that creates static electricity (i.e., charge separation) and is experienced as “carpet shocks.” Another source of static electric fields is from atmospheric conditions such as thunder (electrical) storms. Man-made static electric fields result from voltage applied to electrical conductors and equipment that operate on DC power. Electric fields are measured in units of volts per meter (V/m) or kilovolts per meter (kV/m), where 1 kV/m is equivalent to 1,000 V/m. Electric fields are easily shielded or attenuated by most conducting objects such as fences, shrubbery, and buildings, so outdoor sources, such as transmission lines contribute little to indoor electric-field levels.

**Static magnetic fields** are also natural phenomena produced by the flow of electric currents. The earth produces a background geomagnetic field that originates from the electrical currents in the earth’s molten core and crustal sources. The geomagnetic field varies with latitude; it is highest at the magnetic poles and lowest at the equator (~700 and ~200 milligauss [mG], respectively). Man-made static magnetic fields result from a number of sources: battery-powered appliances and toys, kitchen magnets, magnetic resonance imaging (MRI) scanners,

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\(^4\) The power on a DC line is carried as a direct current and so is a source of static fields. Negligible time-varying fields can occur that may not have been entirely filtered out at the converter station. In comparison, AC transmission lines produce time-varying fields but no static fields. In North America and the majority of countries in Central and South America, transmission lines operate at a frequency of 60 Hz. In the majority of countries in Europe, Africa, and Asia, as well as Australia, AC transmission lines operate at a frequency of 50 Hz.
electrified railways, and DC transmission lines, to name a few. Magnetic fields are calculated as magnetic flux density measured in units of Tesla or microtesla according to the *International System of Units*, or more commonly in units of gauss (G) or mG, where 1 microtesla = 10 mG. In this report, units of mG or G are used. Since magnetic fields are vectors characterized by magnitude and direction, magnetic fields from a DC transmission line add to or subtract from the earth’s geomagnetic field depending on the orientation of the line with respect to earth’s geomagnetic field. Unlike electric fields, magnetic fields are not easily shielded or attenuated by most conducting objects.

**Corona** occurs around the conductors of DC transmission lines when the gradient of the electric field at conductor surfaces exceeds the insulating capacity of the surrounding air. The electric field surrounding transmission-line conductors becomes concentrated on surface irregularities such as nicks, debris, insects, or water droplets and causes the electrical breakdown of air around these points resulting in a small electrical discharge into the air. When this occurs on a transmission line, a tiny amount of energy is released and the transmission line is considered to be in corona. A transmission line in corona can create AN, RN, space charge (i.e., small air ions and charged aerosols), and trace quantities of ozone (O₃) and nitrous oxides (NOₓ). Transmission lines are designed so that ideally they would produce minimal corona. The presence of water droplets, insects, nicks, debris, or other surface roughness on the conductor, however, can initiate corona, which makes transmission line corona a weather- and seasonal-dependent phenomenon. Corona from transmission lines vary in time due to variations in the conductor environment as described above. Corona generated phenomena such as space charge, AN, or RN are therefore reported in statistical terms such as the median level or L₅₀ exceedance level.
• **Audible noise** produced by corona may be experienced near DC transmission lines as a hiss or crackling sound and is measured in relation to the sensitivity of the human ear, which perceives different frequencies with varying degrees of sensitivity. To account for the frequency-dependent nature of the human ear, the different frequencies are weighted differently when combining sounds. The A-weighted scale is a frequency-weighting applied to sound (i.e., decibel [dB]) levels that approximates the perception of human hearing at different frequencies, expressed as dBA, and referenced to the approximate threshold of human hearing (a sound pressure level of 20 micropascals).

• **Radio noise** produced by corona can occur at frequencies that are used for the transmission of radio signals. While RN from a transmission line may exist at any frequency between tenths of a megahertz (MHz) to 1,000 MHz and beyond, it more strongly affects devices operating at lower frequencies such as amplitude-modulated (AM) radio signals (520 to 1,720 kilohertz [kHz]) because the field strength of RN diminishes sharply at higher frequencies. Frequency-modulated (FM) radio stations transmitting at a frequency between 88 and 108 MHz or digitally-encoded transmissions generally are not affected by RN from a transmission line because their mode of operation is different and because their frequency of operation is much higher than the prevalent RN frequencies.

• **Television interference** was another potential effect of RN, since RN could affect the video portion of analog television signals. This is no longer the case in the United States, however, for the majority of television stations. Under the Digital Television Transition authorized by Congress in 1996, full power television stations received an additional broadcast channel to run digital and analog broadcasts simultaneously. Congress set June 12, 2009, as the deadline for full power broadcast stations to switch exclusively to digital broadcasting. The transition date for low power television stations is set for September 1, 2015; after that date, RN from transmission lines would not be expected to affect any television broadcasts.

• **Ham radios and cell phone interference**, historically, has not occurred from transmission lines, nor do they affect other electronic devices such as GPS or satellite receivers under most conditions (USDOE, 1980). Ham radios operating in the low frequencies (100s of kilohertz into the megahertz bands) very near the transmission line ROW edge may occasionally be affected by corona-type RN under certain conditions. In the unlikely event of interference, there are simple mitigation techniques such as change of location or antennae type that can be effective. Other electronic devices such as FM radios, cell phones, GPS systems, and satellite receivers operate at very high frequencies in the hundreds of megahertz or gigahertz range and are therefore not likely to be affected by the RN generated by the transmission line, which occurs most prevalently in the hundreds of kilohertz range.

**Space charge** is a collective term for small air ions and large air ions (i.e., charged aerosols) that are present everywhere in our environment from both natural and man-made sources. Air ions and charged aerosols can be created at the surface of transmission lines when the lines are in corona.\(^6\) Natural sources include space charge formed in the earth’s atmosphere by weather events such as frictional breakup of particles created by blowing precipitation or dust, and evaporation or water droplet breakup, such as from waterfalls. Boiling water in a tea kettle or running a shower can also produce space charge. Space charge levels from these sources can range from hundreds to many thousands of ions per cubic centimeter (ions/cm\(^3\)). Other sources of space charge commonly encountered are open flames from candles or gas ranges. These can produce general levels of space charge in the thousand to tens of thousands ions/cm\(^3\) range.

\(^6\) In addition, trace amounts of O\(_3\) and NO\(_x\) may be formed, but the levels are so low that they are an infinitesimally small proportion of ambient levels. Ambient levels of O\(_3\) are reported to be generally just below 85 parts per billion [http://des.nh.gov/organization/divisions/air/do/asab/ozone/levels.htm] and levels of NO\(_2\) between 1997 and 2007 are reported to be below about 17 parts per billion in New Hampshire (http://des.nh.gov/organization/divisions/air/do/asab/apoc/documents/nox_chart.pdf).
• **Trace gases**, including O$_3$ or NO$_x$ are only expected at low levels from the transmission line. The most comprehensive study to date monitored O$_3$ and NO$_x$ and weather conditions over 2.5 years, both before and after the construction of a ±400-kV DC transmission line in Minnesota. The authors stated “the increments above the background levels were very small and near the detection limits of the monitoring equipment.” An increase was only able to be detected when downwind values were compared to upwind measurements (Krupa and Pratt, 1982). Measurements on a ±450-kV DC test line in Québec did not show a relationship between corona losses on the line and O$_3$ levels measured downwind (Varfalvy et al., 1985). The DC transmission line is not expected to noticeably increase background levels or adversely impact ambient air quality. Multiple AC transmission lines operating at 345 kV and 138 kV adjacent to a 765 kV transmission line are reported to have “no measureable effect on ground levels of ozone.” (Fern and Brabets, 1974).

**Direct Current Environmental Assessment Criteria**

Several scientific and governmental agencies have established guidelines for exposure to static electric fields, magnetic fields, AN, and RN, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA). The National Radiological Protection Board of Great Britain (NRPB) has noted a threshold value for human perception, which is not a guideline. The reference and threshold values listed in Table 2 are used as criteria for the evaluation of potential line designs and their potential effects on the electrical environment around DC transmission lines.
Table 2. Environmental assessment standards and guidelines for DC transmission lines

<table>
<thead>
<tr>
<th>Electrical Parameter</th>
<th>Limit</th>
<th>Agency providing guideline (year)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static electric field</td>
<td>25 kV/m</td>
<td>NRPB (2004)</td>
<td>Threshold value above which annoying perceptions may occur</td>
</tr>
<tr>
<td>Static magnetic field</td>
<td>4,000 G</td>
<td>ICNIRP (2009)</td>
<td>Continuous exposure of the general public</td>
</tr>
<tr>
<td></td>
<td>40,000 G (infants)</td>
<td>FDA (2003)</td>
<td>Patient MRI exposure</td>
</tr>
<tr>
<td></td>
<td>80,000 G (adults)</td>
<td>FDA (2003)</td>
<td></td>
</tr>
<tr>
<td>Audible noise</td>
<td>55 dBA*</td>
<td>EPA (1974, 1978)</td>
<td>Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time (L_{dn} with 10 dB penalty at night)</td>
</tr>
<tr>
<td>Space charge†</td>
<td>-</td>
<td>-</td>
<td>No health guideline proposed</td>
</tr>
<tr>
<td>Radio noise</td>
<td>63 dBµV/m‡</td>
<td>Industry Canada (2013)</td>
<td>Measured at 15 meters (~50 feet) horizontally from the nearest conductor in fair weather</td>
</tr>
<tr>
<td></td>
<td>61 (dBµV/m)§</td>
<td>IEEE (1971)</td>
<td>Measured at 15 meters (~50 feet) horizontally from the nearest conductor in fair weather</td>
</tr>
</tbody>
</table>

* When calculating the L_{dn}, a 10 dB penalty is imposed during nighttime hours.
† No scientific or regulatory agency has determined that small air ions, ion current density, or charged aerosols pose a threat to the environment or to human health, so no exposure guidelines have been proposed. The Ministry of Health of the Russian Federation, however, recommended that positive and negative air ion levels be maintained between a minimum of 400 ions/cm³ and a maximum of 50,000 ions/cm³ for public and industrial quarters (MHRF, 2003). The scientific basis for determining the guideline levels was not described.
‡ This document addresses AC high-voltage power systems and recommends limits for RN based on nominal phase to phase voltage between the conductors.
§ The 1 MHz measurement frequency in IEEE (1971) was changed to 500 kHz by the IEEE Radio Noise Measurement Standard 430-1986. The guideline therefore has been adjusted for frequency (+7dB) and receiver (-2 dB for 9 kHz bandwidth receiver) to update the guideline to present methods of measurement and calculation (500 kHz with CISPR receiver).
Calculation Methods for Direct Current Assessment

The DC NPT line will operate with two conductor bundles (i.e., bipoles) at a nominal voltage of ±320 kV. Transmission line loading, conductor bundle configuration, conductor diameter, mid-span conductor height, conductor sag, conductor separation, and altitude were provided by NPT to Exponent for modeling.

The formulae and empirical curves used to calculate the static electric fields, magnetic fields, air ions, AN, and RN associated with the operation of the DC portion of the NPT line were developed at the Electric Power Research Institute’s (EPRI) High Voltage Transmission Research Center and formalized in the EPRI TL Workstation (EPRI 1990, 1991). Measurements from reduced scale DC models and full scale DC test lines in the northeastern United States form the developmental basis for these algorithms (Comber and Johnson, 1982; Johnson, 1983; Carter and Johnson, 1988; EPRI, 1990). The static field and air ion calculations are based on a saturated corona model and then fitted to describe the performance of a DC transmission line under various climatic and operational conditions. It should be recognized that the parameters calculated by this program represent descriptors of statistical distributions that are strongly affected by weather and season.

The static electric fields, static magnetic fields, ion densities, AN, and RN associated with the proposed cross sections were calculated along profiles perpendicular to mid-span where the conductor height above ground is lowest (30 feet) out to a distance of 300 feet on either side of the centerline of the proposed NPT DC line. Static magnetic fields, static electric fields, and ion densities were calculated at a height of 1 meter above ground, according to IEEE Standard 644-1994 (IEEE, 1994), while AN was calculated at a height of 5 feet, corresponding roughly to ear level, and RN was calculated for an antenna measurement height of 1 meter and frequency of 500 kHz, according to IEEE Std. 430-1986 (IEEE, 1986). The altitude used in modeling each segment was selected based upon the highest altitude found along that segment, which ranged

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7 In Combined-DC/AC sections, all pre-project calculations of AN and RN are made using the BPA method described in the AC transmission line section, while all post-project calculations of AN and RN are made using the EPRI/HVTRC method of calculations described in this section.

8 The IEEE design reference value for RN was extrapolated to 500 kHz for comparison to calculated values (IEEE, 1971).
from 500 feet above sea level near the southern end of the route to a maximum of 2,985 feet. Higher conductor clearances above ground or lower altitudes would produce lower calculated values for the various quantities. A 1% overvoltage was considered for the DC voltage and a 5% overvoltage was considered for all the AC line voltages.9

Since the intensity of corona varies depending on variable factors (e.g., weather and season), the static electric field, space charge, AN, and RN are variable over time, and are therefore described by the calculated median (i.e., $L_{50}$) value. The DC line was modeled with constant conductor polarity and a 1% overvoltage. To maximize computed values, calculations for the DC line were performed for hot, humid summer conditions, with no wind. This set of weather conditions results in the highest levels of calculated parameters since drier weather, some wind, or lower altitude would result in lower levels of static electric fields, ion density, AN, and RN. Levels of AN and RN decrease in foul weather for a DC line, so calculations were also performed to describe the performance of the line under this condition as well.

**Effects of the Direct Current Line on the Electrical Environment**

**Static Magnetic Fields**

Common sources of static magnetic fields are the earth’s geomagnetic field, permanent magnets, battery-driven devices and toys, some electrified rail systems, and MRI machines. The magnetic fields from these sources can range from a few hundred mG, such as the case of the earth’s geomagnetic field or the fields from some battery-driven devices, to thousands of G (i.e., millions of mG) for MRI scanners. The magnetic field associated with the NPT DC line will combine with earth’s geomagnetic field to alter the local magnetic field beneath and immediately surrounding the transmission line. The earth’s geomagnetic field along the proposed NPT route varies from approximately 527 mG in the Concord region near the southern end of the route to approximately 535 mG at the northern end of the route near the Canadian border. A value of 530 mG in Woodstock, New Hampshire, was selected as indicative of the approximate ambient static magnetic field along the entire route.

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9 Calculation of AN and RN in Combined-DC/AC Segments requires calculation of contributions from both AC and DC transmission lines
Transmission line parameters such as voltage, altitude, weather, and conductor conditions do not affect the static magnetic field associated with a DC transmission line; the only parameters that affect the magnitude of the static magnetic field produced by a DC line are conductor bundle separation, line height, current magnitude and direction. The lateral profiles of the static magnetic field at mid-span for Segments N1-1, N1-UG-T and C2-36 are plotted in Figure 5 through Figure 7, respectively. The magnetic-field levels on the ROW, at the ROW edges, and at 300 feet from the center line are listed for Segments N1-1, N1-UG-T, and C2-36 in Table 3.10 The static magnetic field from the overhead line at full load of 1,770 Amperes is 355 mG on the ROW, decreases to 46 mG (or below) at the edge of the ROW, and decreases further to 3.6 mG 300 feet from the center of the DC line. For the underground segment of the DC line, a static magnetic field of 397 mG occurs directly over the centerline of the underground cable circuit (N1-UG-T), but quickly drops to below 26 mG within 25 feet of the underground cable. Higher magnetic fields, up to 526 mG, may occur for short sections of the underground cable where splice joints occur due to wider separation of the cables (N1-UG-S).

Since the magnetic field from both the DC line and earth’s geomagnetic field are vectors (with both magnitude and direction), the static magnetic field from the DC line may add to (vector addition) or subtract from (vector subtraction) earth’s geomagnetic field. This combination may result in a static magnetic field under the line that may vary from as low as 188 mG to as high as 876 mG depending on the orientation of the DC line relative to earth’s geomagnetic field. A tabular summary of the magnetic-field levels on the ROW, at the edges of the ROW, and at 300 feet from the DC line for the other representative cross sections are provided in Annex A, Table A-1 and lateral profiles of magnetic-field levels are provided in Annex B, Figures B-1 through B-27.

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10 In Segment C2-36, the (+) ROW edge is 315 feet from the centerline, so the field values shown in Table 3 at +300 are still within the ROW.
Figure 5. Calculated static magnetic field profile for Segment N1-1.
Figure 6. Calculated static magnetic field profile for the underground trench section (Segment N1-UG-T).

There are no project-related static magnetic fields in the section prior to the construction of the project.
There is no project-related static magnetic field in the section prior to the construction of the project.
Table 3. Calculated static magnetic field level (mG) in Segments N1-1, N1-UG-T and C2-36

<table>
<thead>
<tr>
<th>Segment</th>
<th>Loading Condition</th>
<th>Distance from Centerline of NPT Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 feet</td>
</tr>
<tr>
<td>N1-1</td>
<td>Pre-project: AC lines AAL</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>3.6</td>
</tr>
<tr>
<td>N1-UG-T (Underground trench)</td>
<td>Pre-project: AC lines AAL</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>0.2</td>
</tr>
<tr>
<td>C2-36*</td>
<td>Pre-project: AC lines AAL</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>3.6</td>
</tr>
</tbody>
</table>

*An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the +ROW edge are lower than at 300 feet from the centerline of the NPT line.

**Corona Phenomena**

Corona related to electrical transmission lines refers to the partial electrical breakdown of the air surrounding the conductor.\(^{11}\) Corona activity is typically restricted to a small volume within a few inches of the surface of the conductor and occurs when the gradient of the electric field at the conductor surface reaches approximately 30 kilovolts per centimeter (kV/cm) (i.e., 3,000 kV/m). The electric-field strength needed to produce corona decreases with increasing altitude. Transmission lines typically are designed so that the electric field at the surface of the conductors will be below the corona inception value of 30 kV/cm. The NPT DC line is designed to have a conductor surface gradient of less than 17 kV/cm. Airborne debris such as pollen, vegetation, insects, or nicks on the surface of the conductor, however, will create points

\(^{11}\) There is no corona from underground transmission lines and the underground sections therefore are not discussed further in this section.
where the electric field is intensified and may produce corona. In foul weather, raindrops, or snowflakes on the conductor also will act as points for corona. Since the occurrence of corona is highly variable based on these factors, the effects of corona also are highly variable. Calculated results for space charge, AN, RN, TV interference, and enhanced electric fields therefore are presented as median calculated levels unless specifically noted.

**Ion Density (Space Charge)**

Air ions, the major contributor to space charge, are created when electrons are stripped from air molecules resulting in free electrons and free air molecules with a positive charge. The free electron quickly attaches to some other air molecule creating a negatively charged air molecule. Positively and negatively charged air molecules (air ions) can occur as a result of atmospheric conditions and other natural sources.

The voltage on each conductor of a DC transmission line is constant and the space charge or air ions formed by corona diffuse away from the conductor where they were created. The air ions migrate toward ground and to the opposite polarity conductors, where some recombine with charges of opposite polarity and some attach to aerosols. The ion density level at the ground is a function of both the height of the conductors above ground as well as number of conductors, conductor size, conductor spacing, conductor voltage, and weather conditions, all of which determine the level of corona activity.

**Segments N1-1 and C2-36**

Lateral profiles of ion density are shown for Segment N1-1 in Figure 8. Segment N1-1 contains only the DC line and the ROW varies along its length with 84 feet being the closest approach to the line on the west and 81 feet being the closest approach to the line on the east. For convenience a ROW width of 165 feet is used for Segment N1-1. An example of the ion density profile for a Combined-DC/AC cross section (Segment C2-36) is shown in Figure 9. The lateral profile of the ion density reverses polarity between the two figures because the polarity of the conductors switches position going from Segment N1-1 to Segment C2-36. The positive polarity conductor is on the southwest side of the line in Segment N1-1 in order to match the configuration of the line at the Canadian border. Once the NPT DC line joins a wider ROW corridor with an AC line, the location of the positive polarity conductor switches to the
northeast side of the DC line in order to put it farther from the nearest ROW edge to minimize corona-related AN at that location.

The figures indicate that space charge levels increase during foul weather. In both fair- and foul-weather cases, however, space charge levels diminish at the edge of the ROW and beyond. The ion densities within the ROW, at the edge of the ROW, and out to 300 feet from the DC line for both fair- and foul-weather conditions are listed in Table 4 for the DC-Only (N1-1) and Combined-DC/AC (C2-36) ROW example. The highest levels of ion density at the ROW edge and beyond occur for Segment C2-28, which has the closest ROW edge to the positive conductor (25,250 positive ions/cm³ in fair weather, 32,750 positive ions/cm³ in foul weather). The highest negative air ion levels at the ROW edge occur for Segment N2-9 which has the closest ROW edge to the negative conductor (15,250 negative ions/cm³ in fair weather, 32,650 negative ions/cm³ in foul weather). For Segment N1-1, the median ion density profile during fair weather peaks within the ROW at approximately 103,000 positive ions/cm³ and 59,000 negative ions/cm³. In foul weather, the median ion density peaks within the ROW at approximately 139,000 positive or negative ions/cm³. The ion levels for Segment C2-36 are similar to those for Segments N1-1 and C2-28 under the DC line within the ROW, but are much lower on the east side of the ROW due to the location of the DC and AC lines on the ROW and the distance between the east side of the ROW and the DC line.

**Ion Density Summary**

The highest median negative ion density within the ROW occurs in foul weather for Segment N2-1 and is approximately 142,000 negative ions/cm³; slightly higher than in Segment N1-1 due to the vertical configuration of the DC line in Segment N2-1 that has the negative polarity conductors closest to ground. All other cross sections have similar or lower levels of ion densities. These levels decrease with distance from the DC line. Fair weather ion density levels will also decrease during the winter due to decreased vegetation and insect debris on the conductors. Lateral profiles of the ion density for other DC and Combined DC/AC cross sections are provided in Annex B, Figures B-55 through B-81 and summarized in Table A-3 of Annex A.
Figure 8. Calculated median ion density profile for Segment N1-1.
Figure 9. Calculated median ion density profile for Segment C2-36.
Table 4. Calculated median ion density levels (ions/cm\(^3\)) in fair and foul weather for Segments N1-1 and C2-36

<table>
<thead>
<tr>
<th>Segment</th>
<th>Condition</th>
<th>-300 feet</th>
<th>-ROW edge</th>
<th>At Profile Peaks</th>
<th>+ROW edge</th>
<th>+300 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1-1</td>
<td>Pre-project</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>550</td>
<td>13,100</td>
<td>102,650</td>
<td>-58,900</td>
<td>-9,500</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>550</td>
<td>15,750</td>
<td>138,150</td>
<td>-138,150</td>
<td>-17,300</td>
</tr>
<tr>
<td>C2-36*</td>
<td>Pre-project</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>-350</td>
<td>-15,050</td>
<td>-55,450</td>
<td>101,400</td>
<td>000</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>-450</td>
<td>-32,550</td>
<td>-136,400</td>
<td>138,150</td>
<td>000</td>
</tr>
</tbody>
</table>

*An oddity in Segment C2-36 is that 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the +ROW edge are lower than at 300 feet from the centerline of the NPT line.

Static Electric Fields

Naturally-occurring static electric fields are routinely encountered in everyday life. The effects of static electric fields are commonly experienced as carpet shocks indoors (in which case, local electric fields can reach 100 kV/m or higher). Outdoors, the naturally occurring atmospheric electric field ranges between 120-150 V/m on a clear day, but can increase to as high as 40 kV/m or higher beneath an active thunderstorm. The static electric fields of a DC line are enhanced due to the charge of the ions produced by corona on the DC line.

Segments N1-1 and C2-36

The voltage of the energized 320-kV conductors of the NPT-DC line will produce a static electric field, but the total static electric field will be enhanced when the field from the ion space charge is added. The level of ion-enhanced electric fields is weather dependent due to the amount of space charge produced during fair or foul weather as shown in the lateral profile for the DC-Only line (Segment N1-1) and for the Combined DC/AC Segment (C2-36). The total static electric field is higher in foul weather than fair weather. Lateral profiles of the static
electric field for Segments N1-1 and C2-36 are shown in Figure 10 and Figure 11, respectively. The static electric-field levels in fair and foul weather on the ROW and at the ROW edges are listed in Table 5 for Segment N1-1 and Segment C2-36.

Segment C2-28 and C-19 have the highest static electric field at the ROW edge of all the cross sections (+5.7 kV/m in fair weather and +8.8 kV/m in foul weather) because the ROW edge is close (60 feet) to the DC line, slightly greater than in Segment N1-1. The median electric-field profile peaks within the ROW are approximately +15 kV/m and -11 kV/m in fair weather and increase to +21.kV/m and -21 kV/m in foul weather. The median electric fields for Segment C2-36 are similar to those for Segment C2-28 and C2-19 under the DC line but are much lower on the east side of the ROW (~0 kV/m) due to the location of the DC and AC lines on the ROW and the distance between the east ROW edge and the DC line.

**Static Electric Field Summary**

The highest median electric field within the ROW occurs in foul weather for Segment N2-1 and is -23.3kV/m, slightly higher than in Segment C2-28, which is due to the vertical configuration of the DC line in Segment N2-1. The enhanced static median electric fields will decrease with distance from the DC line. The fair weather levels will also decrease during the winter due to decreased corona from vegetative and insect debris on the conductors. Lateral profiles of the median electric field for the DC-Only and Combined-DC/AC cross sections are provided in Annex B, Figures B-28 through B-54 and summarized in Table A-2 of Annex A.
Figure 10. Calculated median static electric field profile for Segment N1-1.
Figure 11. Calculated median static electric field profile for Segment C2-36.
Table 5. Calculated median static electric-field level (kV/m) in fair and foul weather for Segments N1-1 and C2-36

<table>
<thead>
<tr>
<th>Segment</th>
<th>Condition</th>
<th>-300 feet</th>
<th>-ROW edge</th>
<th>At Profile Peaks</th>
<th>+ROW edge</th>
<th>+300 feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1-1</td>
<td>Pre-project</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>0.3</td>
<td>3.2</td>
<td>15.3</td>
<td>-11.4</td>
<td>-2.2</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>0.5</td>
<td>5.2</td>
<td>21.5</td>
<td>-21.5</td>
<td>-5.5</td>
</tr>
<tr>
<td>C2-36*</td>
<td>Pre-project</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>-0.1</td>
<td>-3.9</td>
<td>-11.3</td>
<td>14.5</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>-0.5</td>
<td>-8.8</td>
<td>-21.2</td>
<td>20.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the +ROW edge are lower than at 300 feet from the centerline of the NPT line.

Audible Noise

In addition to producing space charge, corona activity on the transmission line will produce AN. In contrast to AC transmission lines, however, the AN from a DC transmission line will be lower in foul weather than in fair weather. This is due to the increased space charge surrounding the transmission line conductors in foul weather, which make the diameter of the conductors effectively larger, reducing the surface gradient of the apparent conductors and thus the AN produced.

Levels of existing AN along the proposed line route were obtained during day and night hours in fair weather conditions (Sound Report 1 in Appendix 39: ‘Baseline Sound Monitoring – Proposed Transmission Line’). Existing background AN levels ranged from 41 dBA to 18 dBA for locations along the line route during night time hours and from 45 dBA to 22dBA during day time hours. These are existing AN levels during periods of fair weather, low wind, and low insect or animal activity and are extremely conservative estimates of the background AN. AN levels during foul weather conditions, such as rain, would likely be higher due to wind and rain striking objects.
AN from various sources is not simply arithmetically additive. For example, AN of 40 dBA from a source added to 40 dBA of background noise results in a total noise level of only 43 dBA, not 80 dBA. This 3 dBA change in AN level might be just noticeable, since 3 dBA is considered the just noticeable difference for a change in AN level that can be perceived by the human ear (Hansen, 2001).

**Segments N1-1 and C2-36**

The AN profiles due to only the transmission line during summer conditions for the DC-Only cross section (N1-1) are plotted for fair and foul weather conditions in Figure 12. Similar profiles are shown in Figure 13 for the Combined DC/AC cross section (C2-36). The existing 115-kV AC lines on Segment C2-36 produced some AN, but the levels were low due to the voltage of the AC line. The highest levels of AN are produced within the ROW under the positive DC conductor and then decrease with distance from the line. The highest AN (27 dBA) at the ROW edge occurs in Segment N1-1 on the west, due to the altitude of the cross section and the closest approach of the positive polarity conductor to the ROW edge (84 feet). Other DC-Only or Combined-DC/AC segments, such as Segment C2-36, will have lower levels of AN at the ROW edge due the location of the DC line within the cross section, the width of the ROW, or the altitude. The AN levels will decrease with distance from the conductors. The AN levels will also decrease, from those plotted, during the cold winter season due to reduced vegetation and insect debris on the conductors.

The AN levels due to the transmission lines within the ROW, at the edges of the ROW, and at 300 feet from the DC line are listed in Table 6. These reported levels of AN are due only to the transmission lines and do not consider existing background noise. Even considering the extremely conservative case of the lowest background noise measured along the line route (18 dBA during the night), the highest predicted AN level along the proposed route due to the line at the ROW edge in fair weather is 27 dBA (9 dBA greater than the lowest background level). Although the AN level may be perceptible under certain conditions, it would be considered as having only a marginal impact on the AN level and is still well below the EPA recommended guideline of 55 dBA $L_{dn}$ or the night time level of 40 dBA recommended by the World Health Organization (WHO).
Audible Noise Summary

Lateral profiles and a summary of the AN levels due to the transmission lines for the other representative cross sections are provided in Annex B, Figures B-139 through B-165 and Table A-6 in Annex A. The levels of AN on the DC-Only and Combined-DC/AC corridors will decrease during the winter and normal operating voltages on the lines. During foul weather, background AN will increase from wind and rain and will mask noise from the lines. The AN produced by the line along the ROW edge of the DC-Only or Combined-DC/AC sections of the line from the Canadian border to the Franklin converter terminal will be 27 dBA or less during fair weather and 28 dBA or less during foul weather and should not produce an objectionable increase in the AN level.
Figure 12. Calculated audible noise profile for Segment N1-1.
Figure 13. Calculated audible noise profile for Segment C2-36.
Table 6. Calculated median audible noise levels (dBA) in fair and foul weather for Segments N2-1 and C2-36

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Condition</th>
<th>Distance from Centerline of NPT Circuit*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 ft</td>
</tr>
<tr>
<td>N1-1</td>
<td>Pre-project in fair</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project in fair</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project in foul</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td>C2-36†</td>
<td>Pre-project in fair</td>
<td>≤ 0</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project in fair</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project in foul</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>weather</td>
<td></td>
</tr>
</tbody>
</table>

* Calculated levels of AN that are 0 dBA or less are represented in this table as ‘≤ 0’ indicating that the level of AN is below 20 μPa (approximate threshold of human hearing).
† An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the ROW edge are lower than at 300 feet from the centerline of the NPT line.

Radio Noise

RN is generated by both natural sources (ionosphere, clouds, lightning) and man-made sources (radio and TV transmission, communication systems). The corona activity on transmission line conductors that produces space charge and AN also generates RN. In this case, the corona micro-discharges release radiofrequency (RF) energy. Similar to AN, weather conditions, conductor contamination, and altitude that affect corona also affect RN levels. RN occurs across a range of frequencies—from below 100 kHz to above 1,000 MHz—but is predominantly in the 100 kHz to 2 MHz range. Radio reception in this band, particularly commercial AM radio stations, is therefore most commonly affected by RN from transmission lines. FM radio
stations, global positioning systems (GPS), and digital television typically use much higher frequencies and modulation techniques and are therefore not as susceptible to RN from transmission lines.

**Segments N1-1 and C2-36**

The calculated RN profiles at mid-span and at a frequency of 500 kHz, in fair and foul weather are plotted in Figure 14 for DC-Only Segment N1-1 and in Figure 15 for the Combined-DC/AC Segment C2-36. The highest median RN level at 50 feet from an outside conductor is 51 dBµV/m and occurs for Segment N1-1 in fair weather. Segment N1-1 has a median RN level of 61 dBµV/m under the conductors on the ROW. The median RN levels in the ROW at approximately ±50 feet horizontally from the outer conductor and at 300 feet from the centerline of the DC line are listed below in Table 7.

**Radio Noise Summary**

Segment N2-08 has the highest median fair weather RN level of 63 dBµV/m under the conductors within the ROW, but this decreases to 48 dBµV/m or below by 50 feet from an outside conductor due to the location of the DC and AC conductors on the ROW. The highest median RN levels occur under the conductors and then decrease with distance from the lines. The proposed line has been designed in a manner consistent with the IEEE Radio Noise Design Guide for High-Voltage Transmission Lines (IEEE, 1971) that references 61 dBµV/m at a distance of 50 feet from an outside conductor as a design guide. Expected RN levels from the lines are well below this level and should not pose a concern. A tabular summary of the RN levels and lateral profiles and for the other representative cross sections are provided in Annex A, Table A-7 and Annex B (Figures B-166 through B-192), respectively.
Figure 14. Calculated radio noise profile for Segment S1-1.
Figure 15. Calculated radio noise profile for Segment C2-36.
## Table 7. Calculated median radio noise levels in fair and foul weather for Segments N1-1 and C2-36 (dBµV/m)

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Condition</th>
<th>Distance from Centerline of NPT Circuit*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 ft</td>
</tr>
<tr>
<td>N1-1</td>
<td>Pre-project in fair weather</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>12</td>
</tr>
<tr>
<td>C2-36†</td>
<td>Pre-project in fair weather</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>7</td>
</tr>
</tbody>
</table>

* Calculated levels of RN that are 0 dBµV/m or less are represented in this table as “--,” indicating that the level of RN is below 1 µV/m.
† The distance of ±50 feet from the outside conductor will change from section to section and also from pre-project to post-project configurations. The RN values listed in this column therefore are not always positioned at the same location for pre-project and post-project conditions.
‡ An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of +300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the ROW edge are lower than at 300 feet from the centerline of the NPT line.

## Effect of Direct Current Line on Electronic Devices

### Navigation and Communication

The accuracy of compass readings potentially can be affected by static magnetic fields, so the static magnetic field from the NPT DC line may be sufficient to influence compass readings. The degree to which compass readings would be affected depends on the proximity of the compass to the NPT line and the orientation of the line with respect to the earth’s geomagnetic field.
field at a particular location. The impact of the NPT line on compass readings will be reduced simply by moving a short distance away from the line’s ROW.

The RN from the NPT line does have the potential to interfere with AM radio broadcasts, if the radio receiver is very close to the line. In the northern portion of the NPT route, interference from RN is expected to be a rare occurrence because there are so few residences or other buildings near the ROW in this remote region of the line. In these locations, RN from the NPT line may impact AM car radio reception at road crossings, similar to interference that occurs near AC transmission lines in foul weather, but this effect is transitory and will only occur when passing under the DC transmission line. In the southern portion of the NPT route, the line passes adjacent to and through towns and subdivisions, so the impact on AM radio reception may more likely be noticed.

Complaints related to corona-generated interference, however, have become less frequent. While the video portion of analog television signals are susceptible to interference from DC transmission lines, the advent of cable and satellite television and the move to digital television broadcasts in June 2009 has reduced the possibility of corona-generated interference. FM radio broadcasts and the audio portion of analog broadcast television station signals, which also are FM, are generally not affected by RN from a transmission line. Interference to FM radio reception, the audio portion of analog television signals (which also broadcast as FM), GPS signals, and cell phones is not expected because of the signal processing techniques and frequencies used by these devices.

A measurement study conducted in Manitoba, Canada, of high-precision GPS receivers under ±463/500 kV DC lines did not report interference to their operation using GPS, Global Navigation Satellite System technology, real time kinematic navigation systems, or other correction systems (Pollock and Wright, 2010; Plan Group, 2011). While the presence of the transmission towers themselves theoretically might attenuate satellite signals related to GPS systems, similar to the effect trees may have, this phenomena was not observed during the Manitoba testing.

In addition, transmission line RN decreases with increasing frequency. Since cell phones, GPS units, and satellite receivers typically operate at very high frequencies in the hundreds of MHz
or even GHz range, RN from the NPT DC line will have little or no impact on these devices. Satellite receivers, for example, may be affected if a receiver tries to view the satellite directly through the conductor bundle of the transmission line (Chartier et al., 1986), and if there is an obstruction or reduced signal due to proximity to transmission line, a slight shift in the GPS unit’s position is sufficient to eliminate this effect.

**Implanted Medical Devices**

**Implanted cardiac pacemakers**

The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a limit of exposure to static magnetic fields of 5,000 mG for persons with an implanted cardiac pacemaker (ACGIH, 2015). In general, compared to the ACGIH’s limit, the magnetic-field level from any DC transmission line is too low to affect a pacemaker’s performance. The magnetic-field level, even directly under the transmission line at any location on the ROW, will be far below the ACGIH’s recommended limit for a person with an implanted cardiac pacemaker. The background level of the earth’s geomagnetic field in New Hampshire is approximately 530 mG. After the NPT line is complete, the maximum magnetic-field level for the overhead portion of the DC line is estimated to be about approximately 885 mG, about 65% above the background level of the earth’s geomagnetic field, depending on the location along the project, which also is far below the field strength needed to interfere with the operation of an implanted cardiac pacemaker.

Similarly, the electric field from the NPT-DC line should not be a source of interference to an implanted cardiac pacemaker. Theoretically, an implanted cardiac pacemaker might be affected by an electrostatic discharge directly to a person’s chest from a large, very well-insulated, ungrounded vehicle, such as a tractor-trailer located directly under a DC transmission line. This is an extremely unlikely scenario, however, due to the short duration of such a discharge and the necessary insulation from the ground required to accumulate such a charge (Stuchly and Kavet, 2005). The magnitude, distribution, and conditions for the electric field under the NPT DC line

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12 Cell phones operate in the radiofrequency range of about 800 MHz to 1,900 MHz or higher; GPS units operate in the frequency range of 1.2 to 1.6 GHz; and satellite receivers operate at frequencies of 3.4 GHz to 7.0 GHz.
makes this exposure scenario less likely than exposure from the static electric field commonly associated with certain clothing (i.e., static cling) in the winter.

Neither the static magnetic field nor the static electric field from the NPT project would be a source of interference to an implanted cardiac pacemaker.

**Comparisons of Calculated Values to Environmental Criteria**

**Static Electric Fields, Magnetic Fields, and Corona Ions**

The median electric-field levels at the ROW edge and on the ROW for all configurations and operating conditions are below 25 kV/m, a level above which annoying perceptions may occur (NRPB, 2004b).

The static magnetic field from the current flowing on the conductors will combine with earth’s static geomagnetic field and may affect compass readings on the ROW. This effect, however, diminishes rapidly with distance from the ROW edge and compass deviations of more than a few degrees are not expected beyond the ROW. Static magnetic-field levels due to the transmission line and the earth are well below the 4,000 G (i.e., 4 million mG), and 40,000 G and 80,000 G limits for static magnetic-field exposure listed above in Table 2.

Neither the federal government, nor the state of New Hampshire has standards or guidelines for ion space charge associated with transmission lines. The ion space charge associated with the proposed NPT DC line would be similar or less than the ion space charge from the existing ±450-kV DC line in New Hampshire and within the range of other existing sources.

**Audible Noise**

The AN from the DC-Only or Combined-DC/AC lines is 27 dBA or below in fair weather and 28 dBA in foul weather for all the computed cross sections along the NPT route from the Canadian border the Franklin converter terminal (Segments N1-1 through C2-38). This is well below the 55 dBA L_{dn} EPA guideline even with the EPA penalty of 10 dB during the night or the 40 dBA night time level recommended by the WHO (USEPA, 1978; WHO 1999, 2009).
These levels are within the range of background noise levels measured along the route and have been calculated for conditions that will produce the highest levels of noise such as over voltage on the lines, highest altitude in the segment, and seasonal debris on the conductors. Even with these conditions and assuming the lowest background noise levels, the lines between the Canadian border and the Franklin converter terminal would only have a marginal to no impact on the AN levels. The noise contribution from the DC line should not produce an objectionable increase to the existing AN level.

**Radio Noise**

Background levels of RN due only to atmospheric sources are in the 1 MHz frequency range and vary with season and local conditions between 30 to 50 dB\(\mu\)V/m. Interference to AM radio reception from DC transmission lines from RN on the ROW would occur most likely when driving under or adjacent to the line and would be momentary. Outside the ROW, RN is not typically an issue for reception of RF signals because RN decreases rapidly with distance from the line; RN levels from the DC transmission line are near background levels and would typically fall below existing levels within about 50 to 100 feet of the line.

There are no RN limits in the United States applicable to transmission lines. The RN from the transmission line was compared to the guideline from the IEEE Radio Noise Subcommittee (IEEE, 1971) of 61 dB\(\mu\)V/m at 50 feet from the conductor at a frequency of 500 kHz.\(^{13}\) The levels of RN produced by DC-Only or Combined-DC/AC portions of the line route line fall well below the IEEE guideline level in fair or foul weather. If interference to radio reception at a residence is a problem, it can be mitigated by use of a directional antenna, relocation of an existing antenna, or other solutions (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

\(^{13}\) RN levels discussed are at a frequency of 500 kHz using a CISPR compliant receiver.
Alternating Current Transmission Line

Alternating Current Electrical Environment: Sources, Definitions, and Occurrence

Over the majority of the proposed route (approximately 158.3 miles), the proposed NPT line carries DC electricity; however, in the southern portion of the route (in Franklin, New Hampshire), DC electricity will be converted to AC at a new converter station and carried the remaining distance (approximately 33.7 miles) on a proposed 345-kV AC transmission line to the existing substation in Deerfield, New Hampshire, and from there into New England’s power grid.

Existing and rebuilt AC transmission lines will be sources of AC electrical effects over approximately 100 miles of the route.\textsuperscript{14} AC electric and magnetic fields are associated with any electrical source that generates, transmits, or uses electricity. All things connected to our electrical system—power lines; wiring in our homes, businesses, and schools; and all electric appliances and machines—are a source of AC electric and magnetic fields because, in North America, the vast majority of electricity is transmitted as AC at a frequency of 60 Hz. In addition, electricity transmitted as DC is converted to AC electricity at converting stations prior to local distribution. The fields from these AC sources are commonly referred to as power-frequency or extremely low frequency (ELF) electric and magnetic fields.

Alternating Current Magnetic Fields

The current flowing in the conductors of a transmission line generates a magnetic field near the transmission line. AC magnetic fields measurements are typically expressed as magnetic flux density in units of G or mG, where 1 G is equal to 1,000 mG. In contrast to electric fields, the strength of a magnetic field is unaffected by the voltage of the conductor but is determined primarily by the amount of current flowing in the conductor, so the magnetic-field level can change depending upon the patterns of power demand (load) on the bulk transmission system.

\textsuperscript{14} The NPT DC line is proposed to be constructed as a Combined-DC/AC line on existing AC ROWs over approximately 68 miles of the route, and as an AC-Only line (also on existing AC ROWs) over an additional approximately 34 miles of the route.
To address this variability, modeling results are presented for a variety of loading scenarios, discussed in greater detail below.

**Alternating Current Electric Fields**

Electric fields are due to voltage on conductors not the current passing through them, so electric fields are present around conductors of any voltage. Unlike magnetic fields, electric-field levels do not change with increased or decreased load (current) on transmission-line conductors.

AC electric-fields are expressed in units of V/m or kV/m, where 1 kV/m is equal to 1,000 V/m. The strength of an electric field at any location is determined by voltage applied to any nearby (unshielded) electrical equipment as well as the distance to the equipment, but is unaffected by the amount of current flow in the device. As mentioned, electric-field levels will not vary with changes in current, but will be lower near a low voltage source than near a high voltage source; in both cases, the field level will decrease with increasing distance from the source. If an appliance or equipment is connected to a power source, electric fields are present even if it is turned off; however, electric fields are effectively shielded by conducting objects such as trees, fences, and buildings.

**Corona Phenomena**

As described above in conjunction with DC electrical effects, transmission line corona refers to the partial electrical breakdown of the air surrounding conductors. The same physical mechanisms responsible for corona on DC transmission lines also produce corona on AC transmission lines. An irregularity at the surface of an AC conductor can cause the electric field at that point to exceed the insulating capacity of air and cause corona. Similar to DC lines, when corona on an AC line does occur, small amounts of energy are released in the form of conductor vibration, light, AN, and RN. In contrast to DC transmission lines, however, corona on AC transmission-line conductors results in minimal space charge around the line because the voltage of an AC conductor is constantly changing from positive to negative in a cycle that repeats 60 times per second (60 Hz). Positively-charged air ions produced by corona during the

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15 While AN and RN are primarily foul weather phenomena for AC lines, for DC lines AN and RN occur in both fair and foul weather.
positive half cycle of the voltage are attracted back towards the conductor during the negative half cycle where they are neutralized (i.e., removed from the air) due to the reversed direction of the electric field. The same phenomenon occurs with negatively-charged air ions produced during the negative half cycle.

The factors that affect corona activity include voltage of the transmission line, conductor size, bundle-spacing, altitude at various ROW locations, and often most important, weather conditions. In contrast to DC transmission lines in which corona phenomena increase during fair weather, AC transmission lines have higher corona levels in foul weather. AC transmission lines are designed to produce minimal corona during fair weather, so that corona from AC lines is essentially a foul-weather phenomenon.

The presence and magnitude of corona varies significantly with a variety of conditions along the length of a transmission line and calculations of corona-related effects, such as AN and RN, are reported in statistical terms to account for this variability.

**Audible Noise**

AN from an AC transmission line results from corona, as discussed above. The frequency spectrum of AN for an AC transmission line is primarily broadband, so it is often characterized as a hissing or crackling sound. In certain circumstances, there may also be an added component of discrete pure tones at multiples of the power frequency, which can be characterized as an accompanying 120-Hz hum.

AN is measured in decibels relative to a sound pressure level of 20 micropascals ($\mu$Pa), which is approximately the threshold of human hearing at a frequency of 1 kHz. The sensitivity of the human ear to sounds at other frequencies varies significantly between approximately 20 Hz and 20 kHz. In order to estimate how loud a sound would be, the sound is weighted to approximate

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16 Corona-related effects such as AN and RN increase with altitude. The altitude of the terrain varies throughout the route from 500 to 2,985 feet and each segment was modeled at an altitude representative of that particular segment.

17 This difference is related to the lack of space charge buildup surrounding AC conductors, which acts to suppress further corona on a DC line during foul weather.

18 Unless otherwise noted, all values of AN and RN are reported as median levels.
the sensitivity of the human ear (A-weighting) and is reported as decibels on the A-weighted scale (dBA).

Corona-generated AN from transmission lines varies in time due to variations in the environment as described above and are therefore reported in statistical measures called Exceedance levels. Exceedance levels (i.e., L-levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L₅ level, for example, refers to the sound level that is exceeded 5% of the time (a rare occurrence), while the L₅₀ level refers to the sound level that is exceeded 50% of the time and not exceeded the other 50% (i.e., the median sound level). Sound-level measurements in this report are expressed as L₅₀ (median) levels in fair and foul-weather conditions.

Radio Noise

RN levels are expressed as decibels relative to 1 microvolt per meter (dBµV/m) and are calculated at a frequency of 500 kHz as recommended by the IEEE (IEEE, 1971, 1986), as discussed in greater detail below. Similar to AN, corona-generated RN varies significantly with time due to a large extent to the strong influence of weather conditions. Statistical descriptors are used to describe RN to account for fluctuating noise levels. RN levels in this report are expressed as the L₅₀ levels during fair and foul weather conditions. RN, like AN, is also more pronounced at higher altitudes.

Alternating Current Environmental Assessment Criteria

Similar to their DC counterparts, AC transmission lines also affect the ambient electrical environment and can be assessed in terms of standards and guidelines developed by scientific and health agencies. Several agencies have published exposure limits to 60-Hz electric and magnetic fields, including the International Committee on Electromagnetic Safety (ICES) and ICNIRP. Although AC transmission lines exhibit different dependencies than DC transmission lines, levels of AC AN and RN are nonetheless compared to similar standards as DC transmission lines (i.e., those developed by EPA, WHO, and IEEE).
ICNIRP and ICES each specify both Basic Restrictions and reference levels for exposures of the general public and workers to 60-Hz electric and magnetic fields. Basic restrictions limit the maximum recommended electric fields induced in body tissues. Since levels of electric fields induced in tissues are difficult to measure, reference levels are provided as test values to ensure that basic restrictions are not exceeded. In the cases where reference levels are exceeded, both ICES and ICNIRP note that further analyses and computations are needed to demonstrate compliance with basic restrictions. In this report, exposures expected to produce internal electric fields equal to the Basic Restrictions were derived by applying mathematical modeling described by Kavet et al. (2012).

The reference values listed in Table 8 are used as criteria for the evaluation of proposed line designs and their potential effects on the electrical environment around AC transmission lines.
Table 8. Environmental assessment Basic Restriction and reference levels for EMF exposure and guidelines for AN and RN relevant to AC transmission lines

<table>
<thead>
<tr>
<th>Electrical Parameter</th>
<th>Limit*</th>
<th>Agency Providing Guideline (Year)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC electric field</td>
<td>4.2 (36.4) kV/m</td>
<td>ICNIRP (2010)</td>
<td>General public exposure</td>
</tr>
<tr>
<td></td>
<td>5.0 (26.8) kV/m†</td>
<td>ICES (2002)</td>
<td>General public exposure</td>
</tr>
<tr>
<td>AC magnetic field</td>
<td>2,000 (12.4) mG</td>
<td>ICNIRP (2010)</td>
<td>General public exposure</td>
</tr>
<tr>
<td></td>
<td>9,040 (9,150) mG</td>
<td>ICES (2002)</td>
<td>General public exposure</td>
</tr>
<tr>
<td>Audible noise</td>
<td>55 dBA‡</td>
<td>EPA (1974)</td>
<td>Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use</td>
</tr>
<tr>
<td></td>
<td>40 dBA</td>
<td>WHO (1999, 2009)</td>
<td></td>
</tr>
<tr>
<td>Radio noise</td>
<td>63 (dBµV/m)</td>
<td>IC (2013)</td>
<td>Measured at 15 meters (~50 feet) horizontally from the conductor in fair weather</td>
</tr>
<tr>
<td></td>
<td>61 (dBµV/m)§</td>
<td>IEEE (1971)</td>
<td>Measured at 15 meters (~50 feet) horizontally from the nearest conductor in fair weather</td>
</tr>
</tbody>
</table>

* For electric fields and magnetic fields, both reference levels and Basic Restrictions are shown. Reference levels quoted from the respective standard are listed first; the limits (i.e., Basic Restrictions) derived by mathematical modeling described by Kavet et al. (2012) at 60 Hz are shown in parenthesis.
† There is an exception within transmission line ROWs, where the limit is 10 kV/m, because people do not spend a substantial amount of time in ROWs and very specific conditions are needed before a response is likely to occur (i.e., a person must be well insulated from ground and must contact a grounded conductor) (ICES, 2002, p. 27).
‡ When calculating the $L_{dn}$, a 10 dB penalty is added to the measured or calculated value to compare to reference level during nighttime hours.
§ The 1 MHz measurement frequency in IEEE (1971) was changed to 500 kHz by IEEE Radio Noise Measurement Standard 430-1986. The guideline has therefore been adjusted for frequency (calculations performed at 500 kHz) and receiver (-2 dB for 9 kHz bandwidth receiver) to update the guideline to present methods of measurement and calculation (500 kHz with CISPR receiver).

Calculation Methods for Alternating Current Assessment

Many of the basic assumptions and general methodology for calculating electric fields, magnetic fields, AN, and RN levels for AC transmission lines are similar to those for calculating static fields and corona phenomena, although several differences in the behavior of corona phenomena from AC transmission lines compared to DC require different modeling methods. Therefore
calculations for the AC-Only sections were performed using algorithms developed specifically for AC transmission lines by the Bonneville Power Administration, an agency of the U.S. Department of Energy (BPA, 1991), while calculations of the Combined-DC/AC sections were made using EPRI/HVTRC methodology, as discussed in the DC section of this report. The results obtained by both methods provide consistent results.

Each transmission-line conductor is modeled as infinite in length and parallel to one another at a fixed distance above an infinite flat earth. These simplifying assumptions are made to make the calculations more tractable and to ensure that the presented values are representative of the highest field levels that might be encountered beneath the line. Although these assumptions simplify the calculations, they do not decrease the accuracy of the model and have been shown to accurately predict electric-field and magnetic-field levels measured near transmission lines (Chartier and Dickson, 1990).

The BPA algorithms also calculate AN and RN from AC transmission lines, based upon empirical formulae developed from measurements made near high-voltage AC transmission lines (Chartier and Stearns, 1981; Chartier, 1983). These formulae for corona-generated AN and RN have also been compared to measurements throughout the United States and are shown to be accurate for replicating measured results (IEEE Committee Report, 1982; Olsen et al., 1992). The AN was calculated at a height of 5 feet corresponding roughly to ear level and results are reported in units of dBA. Calculations of RN were made for a receiving antenna height of 1 meter (3.28 feet) above ground and a frequency of 500 kHz in accordance with IEEE Std. 430-1986 (IEEE, 1986) and are reported in units of dB\(\mu\)V/m.

19 There are variations in the transmission line clearance height above ground due to the sag of the transmission lines over variable-height terrain, but levels of electric fields, magnetic fields, AN, and RN beneath the transmission lines will be lower where the clearance of the lines above ground is higher.
Modeling Configurations

Data for modeling the transmission lines provided by NPT included conductor configurations and existing and proposed transmission line loading. The magnitude of the magnetic-field is proportional to loading, so levels were modeled for five separate scenarios:  

1. Pre-project annual average load (AAL) for AC lines;  
2. Pre-project peak load (PL) for AC lines;  
3. Post-project NPT at half rating; AC lines at AAL; and  
4. Post-project NPT at full rating; AC lines at AAL;  
5. Post-project NPT at full rating; AC lines at PL.

The modeling scenarios of greatest interest are those likely to apply on any particular day of the year. In the case of the existing and rebuilt AC transmission lines, loading will vary based upon load demand and so will vary during different times of the day throughout the year, so the most representative scenario is pre-project AC lines at AAL. In contrast, the purpose of the NPT line (both DC and AC portions) is to provide a consistent source of energy to the New England area. For this reason the loading of the NPT line was modeled at its full-rating. As an additional scenario for other loading conditions the NPT line is also modeled at the half- rating. These two loading levels, combined with the AAL of existing AC transmission lines are therefore used in graphical figures (shown in Annex B, Figures B-82 through B-111) and detailed analyses, while the remaining two scenarios are presented only in tabular form (Annex A, Table A-1 [DC magnetic fields] and Table A-4 [AC magnetic fields]).

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Converter terminals and substations are not discussed separately because the highest levels of electric and magnetic fields at the boundary will typically be from the transmission lines entering the substation (IEEE Std. 1127-1990)
In contrast to magnetic-field levels, electric-field, AN, and RN levels do not depend directly on loading and so are not modeled for separate loading scenarios.\textsuperscript{21} The electric-field level is primarily determined by the conductor spacing, height above ground, and the voltage of the conductors, while AN and RN depend on the same parameters and weather conditions. Electric-field levels (assuming a 5% overvoltage condition for all AC conductors) are reported for two scenarios:

1. Pre-project configuration; and
2. Post-project configuration.

AN and RN levels were evaluated for the following four scenarios: \textsuperscript{22}

1. Pre-project, fair weather;
2. Pre-project, foul weather;
3. Post-project fair weather; and
4. Post-project foul weather.

**Phase optimization**

Where two separate AC transmission line circuits are located on the same ROW, the specific arrangement of the conductors on each structure will have an effect on the calculated levels of electric fields, magnetic fields, AN, and RN. Therefore, Exponent performed a phase-optimization analysis, in which all possible phasing configurations of the new and reconfigured AC lines for a cross section were analyzed. The analysis identified the particular phasing that reduces the highest AC magnetic-field level at either ROW edge to a minimum level considering the magnetic-field contributions of all the AC lines on the ROW.\textsuperscript{23}

\textsuperscript{21} These parameters are associated with the electric field at the conductor surface, not current flow. The electric field is quite constant but the conductor height above ground will vary with loading and so will indirectly affect electric field, AN, and RN levels. To account for this variation, all calculations of electric fields, magnetic fields, AN, and RN are made at midspan for the lowest assumed conductor height under expected operating conditions.

\textsuperscript{22} In Combined-DC/AC sections, all pre-project calculations of AN and RN are made using the BPA method described in this section, while all post-project calculations of AN and RN are made using the EPRI/HVTRC method of calculations described above in the DC calculation methods section.

\textsuperscript{23} There is a tradeoff between minimizing the magnetic-field levels and minimizing the AN and RN.
optimization is one of the ways to minimize electric and magnetic field levels that is consistent with the recommendations of the WHO (2007).

**Modeling Results for Alternating Current Transmission Lines**

Of the 27 different transmission line segments evaluated, only 3 are DC-Only segments, which are addressed entirely in the “Effects of Direct Current Line on the Electrical Environment” portion of this report above.

The AC-Only sections (Segments S1-1 through S1-20 on the route as well as DS-1, DS-2 and DS-3) are addressed entirely in this portion of the report while the Combined-DC/AC sections (Segments N2-1 through C2-38) are addressed partially in this portion of the report and partially in the “Effects of Direct Current Line on the Electrical Environment” section.\(^{24,25}\)

Since a large number of configurations were modeled, graphical figures are provided in Annex B, Figure B-1 through B-192, for both the DC environment (DC magnetic field, DC electric field, air ions, AN and RN) and the AC environment (AC magnetic field, AC electric field, AN, and RN). Likewise, summary tables depicting the values of each of the environmental aspects at specific locations on the ROW are presented in Annex A, Tables A-1 through A-7. To provide insight into the nature of the results and their interpretation, however, figures and tables from three sections (Combined DC and AC Segment C2-36, and AC-Only Segments S1-1 and S1-19) are presented in this section for a more in-depth discussion.

Segment C2-36 was selected because it represents an atypical case—a Combined-DC/AC segment on a very wide ROW—that requires greater discussion. Segments S1-1 and S1-19 were chosen because the two combined segments represent more than 60% of the proposed AC-Only route. In Segment S1-1, construction of the NPT AC 345-kV line is proposed on H-frame structures near the center of a 225-foot ROW. Also proposed for Segment S1-1 is the relocation

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\(^{24}\) All calculations of DC magnetic fields, DC electric fields, and air ions are made using the EPRI/HVTRC software described elsewhere in the report.

\(^{25}\) In Combined-DC/AC sections all pre-project calculations of AN and RN are made using the BPA method described in this section, while all post-project calculations of AN and RN are made using the EPRI/HVTRC method of calculations described above in the DC calculation methods section.
of one rebuilt 115-kV transmission line to near the western ROW edge and an existing 115-kV transmission line on the eastern side of the ROW that will not be physically altered. In Segment S1-19, construction of the NPT AC 345-kV line is proposed on vertical lattice structures near the southern edge of a 150-foot ROW, with an existing 115-kV transmission line on the ROW that will not be physically altered.

The following sections describe the modeling results from Segments C2-36, S1-1, and S1-19 for AC electric fields, AC magnetic fields, AN and RN, and present the results in graphical and tabular form. The end of each section summarizes the highest modeled levels in all Segments for reference.

**Alternating Current Magnetic Fields**

As discussed above, the modeling scenarios of greatest interest for the AC magnetic-field assessment are the pre-project AC lines at AAL and the post-project NPT at full-load rating with AC lines at AAL.26 Figure 16 to Figure 18 show calculated profiles for these two scenarios, as well as for post-project NPT half-load rating, with AC lines at AAL, for reference. The two additional scenarios—pre-project AC lines at PL and post-project NPT at full-load rating with AC lines at PL—are presented in Table 9 for reference.

**Segment C2-36**

Figure 16 shows the calculated pre-project and post-project magnetic field for Combined-DC/AC Segment C2-36. The AC magnetic-field level is calculated to generally decrease on this segment as a result of the project. This decrease is due to the changing location and structure type of the 115-kV transmission lines, as well as the generally similar or decreased loading of these lines.

As shown in Table 9, the maximum magnetic-field level in Segment C2-36 at AAL is calculated to decrease from approximately 53 mG to approximately 36 mG due to the project. The magnetic field at the ROW edge and at 300 feet from the proposed NPT transmission line is also

26 Unless otherwise noted in the below discussion, all referenced calculations are pre-project AC lines at AAL or post-project NPT at full-load rating, with AC lines at AAL rating.
calculated to decrease, but the decrease is less than near the center of the ROW.\textsuperscript{27} Table 9 also shows that at a distance of 300 feet from the centerline of the proposed NPT transmission line, the AC magnetic-field levels are calculated to decrease a very small amount (0.4 mG or less) as a result of the project.

**Segment S1-1**

As expected, with the addition of new 345-kV AC line to the ROW, the highest post-project magnetic-field level for AC-Only Segment S1-1 is calculated to increase compared to the pre-project configuration for all loading scenarios, as shown in Figure 17. At the ROW edge and beyond, however, the increase in magnetic-field level is far less.

Table 9 shows that the maximum magnetic field on the ROW (for the post-project NPT at full rating with AC lines at AAL) will increase to approximately 357 mG. At the ROW, edge the magnetic-field level is calculated to increase to approximately 44 mG or less on either ROW edge. At a distance of 300 feet from the new 345-kV AC line, the magnetic field falls to approximately 6 mG.

**Segment S1-19**

Similar to Segment S1-1, the addition of the new 345-kV AC line to the ROW increases the magnetic-field level, as expected. Figure 18 shows that the highest post-project magnetic-field level for AC-Only Segment S1-19 is calculated to increase compared to the pre-project configuration for all loading scenarios, but at the ROW edge and beyond, the increase in magnetic-field level is far less.

Table 9 shows that the maximum magnetic field on the ROW (for the post-project NPT full rating with AC lines at AAL) will increase to approximately 198 mG. At the western ROW edge (nearest the proposed 345-kV AC line) the magnetic-field level is calculated to be approximately 83 mG and approximately 34 mG on the on eastern ROW edge. At a distance of

\textsuperscript{27} Comparing pre-project AC lines at AAL to post-project AC lines at AAL or pre-project AC lines at PL with post-project AC lines at PL, both indicate a decrease in magnetic-field level.
300 feet from the new 345-kV AC line, the magnetic field falls to approximately 5 mG or less for all loading scenarios.

**AC Magnetic Field Summary**

Figures and tables of AC magnetic field levels for all 27 segments (as well as for the 3 segments of the Deerfield to Scobie line) are presented in Annex B, Figures B-82 through B-111 and Annex A, Table A-4. The highest AC magnetic-field level under the lines within the ROW anywhere along the route (for post-project NPT full rating with AC lines AAL) is calculated to be 359 mG in Segment S1-4, similar to that shown in Segment S1-1. The AC magnetic field at the edge of the ROW along the NPT route generally varies from 0.1 mG to 92 mG except for approximately 2,000 feet along one segment, represented by Segment S1-13\(^{28}\), where it is calculated to be approximately 127 mG or less. At a distance of 300 feet from the proposed NPT 345-kV AC line, the highest AC magnetic-field level is calculated to be 7.5 mG or less in all segments (under any loading scenario).

\(^{28}\) Segment S1-13 is a very short segment (~2,000 feet total) with no adjacent residences.
### Table 9. Calculated AC magnetic field (mG) for Segments C2-36, S1-1 and S1-19

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Loading Condition</th>
<th>Distance from Centerline of NPT Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 ft</td>
</tr>
<tr>
<td>C2-36</td>
<td>Pre-project: AC lines AAL</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Pre-project: AC lines PL</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
<td>0.2</td>
</tr>
<tr>
<td>S1-1</td>
<td>Pre-project: AC lines AAL</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Pre-project: AC lines PL</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
<td>6.1</td>
</tr>
<tr>
<td>S1-19</td>
<td>Pre-project: AC lines AAL</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Pre-project: AC lines PL</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
<td>4.3</td>
</tr>
</tbody>
</table>

* An oddity in Segment C2-36 is that 300 feet from the centerline of the NPT circuit is still within the ROW. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the ROW edge are lower than at 300 feet from the centerline of the NPT line.
Figure 16. Calculated AC magnetic-field profile for Segment C2-36.
Figure 17. Calculated AC magnetic-field profile for Segment S1-1.
Figure 18. Calculated AC magnetic-field profile for Segment S1-19.
Alternating Current Electric Fields

Segment C2-36

Figure 19 shows the calculated pre-project and post-project electric-field levels for Combined-DC/AC Segment C2-36. The AC electric-field level is calculated to vary significantly across the ROW due to the changing location of the two 115-kV M127 and F139 transmission lines; however at the ROW edge and beyond, the change in electric-field level is minimal. In particular, the post-project electric-field level at the western ROW edge decreases because the M127 and F139 transmission lines are further from the western ROW edge, while the electric-field level on the eastern ROW edge does not change because the V182 transmission line remains in its current location nearest to the eastern ROW edge.

As shown in Table 10, the electric field at the ROW edge in the pre-project configuration is approximately 0.2 kV/m and decreases slightly to 0.02 kV/m in the post-project configuration. Table 10 also shows that the maximum value of the electric field will not change by more than 0.1 kV/m.29 Likewise, AC electric-field levels are calculated not to change on either side of the ROW at a distance of 300 feet from the centerline.

Segment S1-1

Figure 20 shows the calculated pre-project and post-project electric field for AC-Only Segment S1-1. In contrast to Segment C2-36 in which no new AC transmission line is proposed, the 345-kV AC line is proposed to be installed near the center of the ROW in Segment S1-1. In order to make room for the new 345-kV AC line, the existing F139 115-kV circuit is proposed to move nearer to the western ROW edge and to be constructed on vertical monopole structures. The maximum AC electric-field level is calculated to increase on the ROW due to the introduction of the 345-kV transmission line; however, similar to Combined-DC/AC Segment C2-36, at the ROW edge and beyond, the change in electric-field level is minimal.

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29 As shown by Figure 19, the location of the maximum electric field on the ROW will change as a result of this project, but the absolute level will not significantly change.
Table 10 shows that the maximum electric field on the ROW will increase by approximately 3.3 kV/m due to the construction of the 345-kV AC line, but at the ROW edge and beyond the electric-field level is less than 0.5 kV/m and is relatively unchanged from the pre-project condition.

**Segment S1-19**

Figure 21 shows the calculated pre-project and post-project electric field for AC-Only Segment S1-19. In this segment, the 345-kV AC line is proposed to be installed approximately 35 feet from the western ROW edge on vertical lattice structures due to the limited space on the ROW. Similar to Segment S1-1, the maximum AC electric-field level is calculated to increase significantly on the ROW due to the introduction of the 345-kV AC line; however at the ROW edge and beyond, the increase in electric-field level is small.

Table 10 shows that the maximum electric field on the ROW will increase to approximately 5.1 kV/m due to the construction of the 345-kV AC line, but at the ROW edge and beyond the electric-field level 0.5 kV/m or less and is relatively unchanged from the pre-project condition.

**AC Electric Field Summary**

Similar figures and tables for all 27 segments are presented in Annex B, Figures B-112 through B-138 and Annex A, Table A-5, respectively. The highest AC electric field calculated anywhere along the route is 5.2 kV/m and occurs in Segment S1-20. The highest edge of ROW electric-field level anywhere along the route is calculated to be 2.7 kV/m and occurs on the north side of Segment S1-13.\(^{30}\) At a distance of 300 feet from the proposed 345-kV AC line, the AC electric-field level is calculated to be less than 0.1 kV/m in all cross sections.

\(^{30}\) Segment S1-13 is a very short segment (~2,000 feet total) with no adjacent residences.
<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Condition</th>
<th>Distance from Centerline of NPT Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-300 ft</td>
<td>-ROW Edge</td>
</tr>
<tr>
<td>C2-36*</td>
<td>Pre-project</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Post-project</td>
<td>0.0</td>
</tr>
<tr>
<td>S1-1</td>
<td>Pre-project</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Post-project</td>
<td>0.0</td>
</tr>
<tr>
<td>S1-19</td>
<td>Pre-project</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Post-project</td>
<td>0.1</td>
</tr>
</tbody>
</table>

* An oddity in Segment C2-36 is that 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels are lower at a distance of 300 feet from the NPT line than at the ROW edge, in this segment, field levels at the +ROW edge are lower than at 300 feet from the centerline of the NPT line.
Figure 19. Calculated AC electric-field profile for Segment C2-36.
Figure 20. Calculated AC electric-field profile for Segment S1-1.
Figure 21. Calculated AC electric-field profile for Segment S1-19.


**Corona Phenomena**

So far in this section, it has been possible to separate the AC electrical environment from the DC electrical environment because AC electric and magnetic fields can be considered separately from their DC counterparts. When dealing with AN and RN, however, the contributions of AC and DC lines must be considered together. It is therefore necessary to analyze the AC-Only segments in a somewhat different manner than the Combined-DC/AC cross sections. In particular, while the AN and RN from AC lines are higher in foul weather than in fair weather, the AN and RN from DC lines are higher in fair weather than foul weather. For this reason the section below reviews and discusses the levels of AN and RN for the Combined-DC/AC segment in foul weather.

**Audible Noise**

**Segment C2-36**

Figure 22 shows the calculated pre-project and post-project AN levels for the Combined-DC/AC Segment C2-36, indicating that the AN level is calculated to increase on this section as a result of the project. This increase is due to the addition of the ±320-kV DC transmission line to the ROW and is more pronounced in fair weather than in foul weather.

As shown in
Table 11, the maximum foul weather AN level in the pre-project configuration for Segment C2-36 is calculated to increase from approximately 16 dBA to approximately 23 dBA in the post-project configuration. The highest foul weather AN level at the edge of ROW is calculated to be 19 dBA post-construction and approximately 12 dBA at a distance of 300 feet from the proposed NPT DC line. The levels of AN at the ROW edge and beyond would generally be within the range of background levels and have marginal to no impact on AN.

In fair weather, the AN level in the pre-project configuration in AC-Only and Combined DC/AC segments is calculated to be inaudible (less than 0 dBA) at all locations on the ROW and beyond, so the increase in AN during fair weather is calculated to increase with the addition of the DC NPT line. In the fair weather post-project configuration, the highest AN level within the ROW of Segment C2-36 is calculated to be to approximately 29 dBA, while at the edge of the ROW and at a distance of 300 feet from the proposed NPT DC transmission line, the AN level is calculated to be approximately 25 dBA and 18 dBA or less, respectively. These levels of AN are in the range of night time background AN levels that were measured (18 dBA-41 dBA) and would have only marginal to no impact on AN.

**Segment S1-1**

Since AN is determined primarily by the voltage of a conductor, it is expected that AN would increase with the construction of the AC 345-kV line. Figure 23 confirms this is the case, showing that the post-project AN levels for AC-Only Segment S1-1 are calculated to increase at all locations on the ROW compared to the pre-project configuration. As shown in
Table 11, in fair weather, the AN level is calculated to be 14 dB or less at the ROW edge and beyond. In foul weather, the AN level is calculated to increase to about 39 dBA or less at the ROW edge.

**Segment S1-19**

Similar to Segment S1-1, it is expected that the AN levels would increase with the construction of the new 345-kV AC line. Figure 24 confirms this is the case, showing that the post-project AN levels for AC-Only Segment S1-19 are calculated to increase at all locations on the ROW compared to the pre-project configuration. As shown in
Table 11, AN levels in Segment S1-19 are higher than in Segment S1-1. In fair weather the AN level is calculated to be 17 dB or less at the ROW edge and beyond. In foul weather, the AN level is calculated to increase to about 42 dBA or less at the ROW edge.

Audible Noise Summary

Figures and tables of AN levels for all 27 segments are presented in Annex B, Figures B-139 through B-165 and Annex A, Table A-6. AN from AC lines is primarily a foul-weather phenomenon while AN from DC lines decreases during foul weather. AN is typically of greater interest in fair weather. This is due in part because the public is more likely to be outdoors (and therefore exposed to outdoor AN) in fair weather conditions than in foul weather when persons are more likely to be indoors with windows closed. In addition, AN from an outdoor source during foul weather is likely to be masked by the noise from the foul weather itself (e.g., rain and wind). Guidelines and standards also typically specify fair weather for the evaluation condition.

The highest foul weather AN levels along the ROW edge of the Combined-DC/AC or AC-Only portion of the route (Segment N2-1 through S1-20) is calculated to be 43 dBA and occurs on the north side of Segment S1-13 along the AC-Only portion of the route from the Franklin Converter Terminal to Deerfield Substation. At a distance of 300 feet from the proposed 345-kV AC line, the highest foul weather AN level is calculated to be approximately 36 dBA or less in all cross sections.

AN at the edge of the ROW for the line segments between the Franklin Converter Terminal and Deerfield Substation will increase in foul weather into the mid to upper 30 dBA range and into the low 40 dBA range for Segment S1-13, S1-19 and S1-20 (43 dBA, 42 dBA and 42 dBA respectively). However, background noise will also likely increase into the 40 to 50 dBA range due to wind and rain noise and mask AN from the line. All of the foul weather AN levels from the line at the edge of the ROW are below the USEPA L_{dn} guideline of 55 dBA even when considering the night-time penalty of 10 dBA. The 40 dBA guideline of WHO at the residence would likely be met for Segments S1-13, S1-19 and S1-20 since the AN levels from the lines
have been calculated with conservative assumptions, the highest levels on these segments only occur during foul weather when higher levels of background AN from accompanying rain and wind would be expected to mask the noise, and the levels are only a few dB above 40 dBA at the ROW edge and lower levels would be expected at residences, further from the ROW edge. All other line segments between the Franklin Converter Station and the Deerfield Substation meet the USEPA and WHO guidelines and will have only marginal to no impact on the AN.
Table 11. Calculated median AN levels in fair and foul weather for Segments C2-36, S1-1, and S1-19(dBA)*

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Condition</th>
<th>Distance from Centerline of NPT Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 ft</td>
</tr>
<tr>
<td>C2-36†</td>
<td>Pre-project in fair weather</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>12</td>
</tr>
<tr>
<td>S1-1</td>
<td>Pre-project in fair weather</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>34</td>
</tr>
<tr>
<td>S1-19</td>
<td>Pre-project in fair weather</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>35</td>
</tr>
</tbody>
</table>

* Calculated levels of AN that are 0 dBA or less are represented in this table as “--,” indicating that the level of AN is below 20 μPa, the threshold of human hearing.
† An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the +ROW edge are lower than at 300 feet from the centerline of the NPT line.
Figure 22. Calculated AN profile for Segment C2-36.
Figure 23. Calculated AN profile for Segment S1-1.
Figure 24. Calculated AN profile for Segment S1-19.
Radio Noise

Segment C2-36

Figure 25 shows the calculated pre-project and post-project RN levels for the Combined-DC/AC Segment C2-36, indicating that the RN level is calculated to increase at all locations as a result of the project (and is roughly symmetric around the proposed NPT DC line so that higher levels are found near the western edge of the ROW). This increase is due to the addition of the ±320-kV NPT DC line to the ROW and is more pronounced in fair weather than in foul weather.

As summarized in Table 12, the maximum foul weather RN level in the post-project configuration for Segment C2-36 at a distance of 50 feet from the outside conductor is calculated to be 37 dBμV/m or less, and at a distance of 300 feet from the proposed NPT DC line, the RN level is calculated to be 15 dBμV/m or less.

The fair weather RN level for Segment C2-36 in the post-project configuration is calculated to be approximately 43 dBμV/m or less at a distance of 50 feet from the outside conductor, and approximately 21 dBμV/m or less at a distance of 300 feet from the proposed NPT DC line.

Segment S1-1

The addition of the new 345-kV AC line increases RN levels. Figure 26 shows that the post-project RN levels for AC-Only Segment S1-1 are calculated to increase above the pre-project configuration. As shown in Table 12, in fair weather the RN level is 30 dBμV/m or less at a distance of ±50 feet from the outside conductor while in foul weather, the RN level at this distance is approximately 47 dBμV/m or less.

Segment S1-19

Similar to Segment S1-1, the addition of the new 345-kV AC line increases RN levels. Figure 27 shows that the post-project RN levels for AC-Only Segment S1-19 are calculated to increase

31 The distance at which the IEEE (IEEE 1971) recommends RN be evaluated is 50 feet from the outside conductor on both sides of the ROW
above the pre-project configuration. As shown in Table 12, in fair weather the RN level is 43 dBµV/m or less at a distance of ±50 feet from the outside conductor while in foul weather, the RN level at this distance is approximately 60 dBµV/m or less.

**Radio Noise Summary**

Figures and tables describing RN levels for all 27 segments are presented in Annex B, Figures B-166 through B-111192 and Annex A, Table A-7. The highest RN level in fair or foul weather along the Combined-DC/AC or AC-Only portion of the route (Segment N2-1 through S1-20) at a distance of ±50 feet from the outside conductor is calculated to be approximately 60 dBµV/m, which occurs in foul weather, on the south side of Segment S1-19. At a distance of 300 feet from the proposed NPT line, the highest RN level is calculated to be 40 dBµV/m or less in all segments and weather conditions. The proposed line has been designed in a manner consistent with the IEEE Radio Noise Design Guide for High-Voltage Transmission Lines (IEEE, 1971) that references 61 dBµV/m at a distance of 50 feet from an outside conductor as a design guide. Expected RN levels from the lines are below this level in fair or foul weather and should not pose a concern.

---

32 In Segment S1-19 the 345-kV AC line is proposed to be constructed on vertical lattice towers, 35 feet from the southern ROW edge.
Table 12. Calculated median radio noise levels in fair and foul weather for Segments C2-36, S1-1, and S1-19 (dBµV/m)*

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Condition</th>
<th>Distance from Centerline of NPT Circuit</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-300 ft</td>
<td>-50 ft from outside conductor†</td>
<td>Max</td>
<td>+50 ft from outside conductor†</td>
<td>300 ft</td>
</tr>
<tr>
<td>C2-36</td>
<td>Pre-project in fair weather</td>
<td>9</td>
<td>22</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>3</td>
<td>26</td>
<td>39</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>12</td>
<td>43</td>
<td>62</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>7</td>
<td>37</td>
<td>56</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>S1-1</td>
<td>Pre-project in fair weather</td>
<td>8</td>
<td>22</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>5</td>
<td>25</td>
<td>39</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>16</td>
<td>30</td>
<td>49</td>
<td>28</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>33</td>
<td>47</td>
<td>66</td>
<td>45</td>
<td>33</td>
</tr>
<tr>
<td>S1-19</td>
<td>Pre-project in fair weather</td>
<td>6</td>
<td>17</td>
<td>3</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project in foul weather</td>
<td>23</td>
<td>34</td>
<td>20</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project in fair weather</td>
<td>22</td>
<td>43</td>
<td>47</td>
<td>36</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Post-project in foul weather</td>
<td>39</td>
<td>60</td>
<td>64</td>
<td>53</td>
<td>40</td>
</tr>
</tbody>
</table>

* Calculated levels of RN that are 0 dBµV/m or less are represented in this table as “--,” indicating that the level of RN is below 1 µV/m.
† The distance of ±50 feet from the outside conductor will change from section to section and also from pre-project to post-project configurations. The RN values listed in this column therefore are not always positioned at the same location for pre-project and post-project conditions.
Figure 25. Calculated RN profile for Segment C2-36.
Figure 26. Calculated RN profile for Segment S1-1.
Phase optimization

Of the 27 separate cross sections analyzed, 13 cross sections had too few proposed and rebuilt AC transmission lines to benefit from phase optimization (i.e., one AC transmission line or less). The remaining 14 cross sections had at least two AC transmission lines (one of which is
proposed to be reconfigured as a result of this project) and so were analyzed to assess the potential magnetic-field reduction that could be achieved by phase optimization. NPT used the results of the phasing analysis and its assessment of the constructability of phase configurations to select the phasing of the new lines.

The difference between optimal phasing and constructible phasing is indicated in Table 13. In the northern and central portions of the route (Segment N2-9 through C2-38), the magnetic-field level at the selected phasing is within <3 mG of the optimal phasing in all cross sections. In the southern portion of the route, the magnetic-field level for the selected phasing is within <10% of the optimal phasing configuration in all sections except S1-4 and S1-5 where large reductions would be achieved.

Table 13. Optimization summary*

<table>
<thead>
<tr>
<th>Cross Section</th>
<th>Segment</th>
<th>Lines Optimized</th>
<th># of Scenarios Evaluated</th>
<th>Difference from Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>XS06</td>
<td>N2-9</td>
<td>115-kV(a)</td>
<td>6</td>
<td>&lt; 3 mG</td>
</tr>
<tr>
<td>XS07</td>
<td>N2-10</td>
<td>115-kV(a)</td>
<td>6</td>
<td>&lt; 1 mG</td>
</tr>
<tr>
<td>XS08</td>
<td>N2-11</td>
<td>115-kV(a), 115-kV(b)</td>
<td>36</td>
<td>&lt; 1 mG</td>
</tr>
<tr>
<td>XS17</td>
<td>C2-36</td>
<td>115-kV(c), 115-kV(d)</td>
<td>36</td>
<td>&lt; 1 mG</td>
</tr>
<tr>
<td>XS18</td>
<td>C2-38</td>
<td>115-kV(d)</td>
<td>6</td>
<td>&lt; 1 mG</td>
</tr>
<tr>
<td>XS19</td>
<td>S1-1</td>
<td>345-kV, 115-kV(d)</td>
<td>36</td>
<td>&lt; 1 mG†</td>
</tr>
<tr>
<td>XS20</td>
<td>S1-4</td>
<td>345-kV, 115-kV(e)</td>
<td>36</td>
<td>22%‡</td>
</tr>
<tr>
<td>XS21</td>
<td>S1-5</td>
<td>345-kV, 115-kV(e)</td>
<td>36</td>
<td>19%‡</td>
</tr>
<tr>
<td>XS22</td>
<td>S1-8</td>
<td>345-kV, 115-kV(e), 115-kV(f)</td>
<td>216</td>
<td>1%§</td>
</tr>
<tr>
<td>XS23</td>
<td>S1-12</td>
<td>345-kV, 115-kV(e), 115-kV(f)</td>
<td>216</td>
<td>2%</td>
</tr>
<tr>
<td>XS24</td>
<td>S1-13</td>
<td>345-kV, 115-kV(g)</td>
<td>36</td>
<td>8%</td>
</tr>
<tr>
<td>XS25</td>
<td>S1-16</td>
<td>345-kV</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>XS26</td>
<td>S1-19</td>
<td>345-kV</td>
<td>6</td>
<td>6%</td>
</tr>
<tr>
<td>XS27</td>
<td>S1-20</td>
<td>345-kV, 115-kV(g)</td>
<td>36</td>
<td>3%</td>
</tr>
</tbody>
</table>

* The seven different 115-kV transmission lines involved in the phase optimization are labeled 115-kV(a) through 115-kV(g).
† Segment S1-1 was constrained by the 115-kV (d) line shared with Segments C2-36 and C2-38 as well as by the 345-kV AC line, shared with Segments S1-4 through S1-20.
‡ Segments S1-4 and S1-12 were constrained to have the same phasing of the 345-kV AC line and 115-kV (e) line. The optimal phasing in Segments S1-4 and S1-5 would result in a significant increase in magnetic-field level of Segment S1-8 (which already has a highest edge-of-ROW magnetic field approximately 8 mG higher than S1-4 or S1-5).
§ If the optimal phasing for Segments S1-4 and S1-5 were selected, the highest edge-of-ROW magnetic field level in Segment S1-8 would be nearly 80% higher than either Segment S1-4 or S1-5.
Effect of the Alternating Current Line on Electronic Devices

Implanted Medical Devices

Implanted medical devices such as pacemakers, implanted cardiac defibrillators (ICD), and other devices have been reported to be susceptible to interference from a variety of sources including permanent magnets, security screening systems, and automobile ignitions. Older models of pacemakers or ICDs in particular may be more susceptible to interference; however, the immunity of these devices to AC electric and magnetic fields is continually improving. The manufacturer of any particular medical device can give precise information regarding the limits of interference to that device, and it is always recommended to confer with the device manufacturer and one’s physician for specific guidance on medical questions. In theory, the EMF under AC transmission lines also might be a potential source of interference and therefore was evaluated below.

In the absence of specific information from the manufacturer of the pacemaker, however, standards such as the European Committee for Electrotechnical Standardization (CENELEC) may be consulted. CENELEC states that implanted medical devices are expected to function without interference below the reference levels of 5 kV/m and 1,000 mG for ELF electric fields and magnetic fields, respectively. These limits are based on European Council Recommendation 1999/519/EC. The European Standards document further states that “[f]or higher fields the voltage can cause electromagnetic interference effects but often this is not clinically significant … and transient exposure [to higher fields] can be permitted” (EN 50527-1, 2010).

The highest AC magnetic field on the proposed route is far lower than this 1,000 mG reference level and the highest AC electric-field level of 5.2 kV/m would exceed this limit only under very specific conservative circumstances, and even then, only for a very small area directly beneath the transmission lines at midspan. At highway crossings, however, where one is more likely to be on the ROW, electric-field levels will be lower due to increased conductor height. Furthermore, conducting objects such as trees, brush, walls, fences, or automobiles will shield the electric field. This information, combined with CENELEC’s statement that transient
exposure to higher fields can be permitted without becoming clinically significant, suggests that AC transmission lines associated with this project are not likely to pose a risk.

**Environmental Criteria for Alternating Current Lines**

**Alternating Current Electric and Magnetic Fields**

Neither the federal government nor the state of New Hampshire has enacted standards for magnetic fields or electric fields from transmission lines or other sources at power frequencies. The exposure limits recommended by scientific organizations that were developed to protect health and safety and are based on reviews and evaluations of relevant health research are listed in Table 8 and used as assessment criteria.

The highest 60-Hz magnetic-field level on the ROW along any portion of the route is 366 mG, more than 5-fold lower than the ICNIRP or ICES magnetic field reference levels. The highest electric-field level on the ROW along any portion of the route is 5.2 kV/m, approximately half the ICES reference level for the general public on a transmission line ROW but slightly higher than the ICNIRP reference level; however this is a factor of 7-fold below the exposure level calculated by Kavet et al. (2012) that would cause the ICNIRP Basic Restriction to be exceeded. At the edge of the ROW and beyond, where people are more likely to be present, the highest EMF levels are 127 mG and 2.7 kV/m, below reference levels for both ICNIRP and ICES and 10-fold or more lower than exposures (as calculated by Kavet et al., 2012) that would cause the Basic Restrictions published by ICNIRP and ICES to be exceeded.

**Audible Noise**

The acceptable level of AN from transmission lines in the United States follows the EPA’s guideline value of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas (USEPA, 1974). 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. The highest edge of ROW AN level on any of the Combined-DC/AC or AC-Only segments is less than 43 dBA and occurs in Segment S1-
Therefore, the calculated AN levels will be below the EPA’s guideline even when 10 dB is added to each, accounting for the nighttime 10 dB penalty. This maximum level can be evaluated directly against the EPA guideline by estimating how often foul weather occurs and comparing these data to previous research, summarized in Table 14, which shows the difference between the L_{50} values and L_{dn} values, based upon different foul weather occurrence rates.

Hourly precipitation data from the National Climatic Data Center between January 1, 2010, and January 1, 2014, was used to assess the foul weather occurrence rate along the Project route.34 Nine stations along the route with hourly precipitation data were used to estimate the foul weather occurrence rate.35 These stations indicated precipitation of at least 1/10th of an inch occurred approximately 3% of the time. Based on the 3% foul weather occurrence rate reported by these stations and an ambient noise environment of 40 dBA, the L_{dn} level would be approximately 39 dBA.

More detailed weather information that includes the occurrence of even trace amounts of precipitation is available from the Concord Municipal Airport weather station.36 This data indicate that considering trace amounts of precipitation recorded at this weather station, the foul weather rate would be 15%. Using this higher occurrence rate, which considers even trace amounts of precipitation, the resulting highest L_{dn} for the project is 44 dBA, which is still below the EPA L_{dn} guideline limit of 55 dBA.

In addition, the wind and rain that typically occurs during foul weather are themselves likely to generate levels of AN (41-63 dBA) that are similar to or exceed the levels of AN from the transmission line, therefore would likely mask transmission line AN during these conditions (Miller, 1978).

33 Segment S1-13 is a very short segment (~2,000 feet total) with no adjacent residences in a commercial area.
34 http://www.ncdc.noaa.gov/edw-web/datasets. The most recent data available was January 1, 2014, and approximately 4 years of data were evaluated to determine this foul weather occurrence rate.
35 The nine stations included in this evaluation were: COOP:273182 in Franklin Falls Dam, COOP:276818 in Pinkham Notch, COOP:272842 in Errol, COOP:276234 in North Stratford, COOP:276856 at Pittsburg Reservoir, COOP:274218 at Hopkinton Lake, COOP:274806 in Littleton, COOP:275780 in New Durham, COOP:270998 in Bristol.
36 National Climatic Data Center weather station COOP:271683 at the Concord Municipal Airport in Concord, New Hampshire, recorded at least 1/100th inch of precipitation in approximately 9% of the hours and trace precipitation in approximately an additional 6% of the hours.
### Table 14. Correction factors to obtain equivalent sound levels ($L_{eq}$) and day-night sound level ($L_{dn}$) from median ($L_{50}$) foul weather transmission line sound level

<table>
<thead>
<tr>
<th>% Foul weather</th>
<th>40 dBA ambient</th>
<th>No ambient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-7.6</td>
<td>-17.6</td>
</tr>
<tr>
<td>1</td>
<td>-6.6</td>
<td>-12.0</td>
</tr>
<tr>
<td>3*</td>
<td>-4.8</td>
<td>-7.9</td>
</tr>
<tr>
<td>5</td>
<td>-4.0</td>
<td>-6.0</td>
</tr>
<tr>
<td>10</td>
<td>-2.0</td>
<td>-2.9</td>
</tr>
<tr>
<td>15*</td>
<td>-0.5</td>
<td>-1.2</td>
</tr>
<tr>
<td>100</td>
<td>+6.7</td>
<td>+6.7</td>
</tr>
</tbody>
</table>

Source: Dietrich (1982).
* Interpolated from data in Dietrich (1982)

### Radio Noise

The state of New Hampshire has not enacted a limit for RN. Likewise, the Federal Communication Commission (FCC) Rules and Regulations (2008) contain no guideline regarding RN levels near high-voltage transmission lines. Power transmission lines fall into the FCC category of “incidental radiator,” which is defined as “a device that generates radio frequency energy during the course of its operation although the device is not intentionally designed to generate or emit radio frequency energy.” Operation of an incidental radiator “is subject to the conditions that no harmful interference is caused and that interference must be accepted that may be caused by the operation of an authorized radio station, by another intentional or unintentional radiator, by industrial, scientific and medical (ISM) equipment, or by an incidental radiator.” Section 15.1(m) of the FCC regulations defines “harmful interference” as “any emission, radiation or induction that endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunications service operating in accordance with this Chapter.”

Historically, transmission-line operators have not had difficulty in operating under the present FCC rules, since most sources of harmful interference from transmission lines in fair weather are due to gap-type discharges that can be identified and repaired (USDOE, 1980). Residences very near transmission lines, however, may be affected by corona-type RN in foul weather. For
this reason, the IEEE Radio Noise Design Guide (IEEE, 1971) identifies an acceptable level of
average fair-weather RN of 61 dBμV/m at 50 feet from the outside conductor.37 As discussed
above and shown in full detail in Annex A, Table A-7, the highest fair-weather RN values at 50
feet from the outer conductor in the proposed configuration is 55 dBμV/m (Segment N2-1). In
the southern (AC-Only) portion of the route the highest fair-weather RN value 43 dBμV/m
(Segment S1-19). Therefore all calculated RN levels are far below the IEEE-recommended
level in all proposed cross sections.

Comparisons of Calculated Values to Environmental Criteria for
Alternating Current Lines

A summary of the calculated values of EMF, AN, and RN are provided in Table 15 for the
highest level within the ROW and for the level at whichever ROW edge is highest. The
environmental levels used as criteria (repeated from Table 8) are shown at the head of each
column.

37 The 1 MHz measurement frequency in IEEE (1971) was changed to 500 kHz by IEEE Radio Noise
Measurement Standard 430-1986. The guideline has therefore been adjusted for frequency (calculations
performed at 500 kHz) and receiver (-2 dB for 9 kHz bandwidth receiver) to update guideline to present
methods of measurement and calculation (500 kHz with CISPR receiver).
Table 15. Comparison of calculations to environmental assessment criteria for AC electric field magnetic field, audible noise, and radio noise

<table>
<thead>
<tr>
<th>Agency</th>
<th>AC Magnetic Field (mG)</th>
<th>AC Electric Field (kV/m)</th>
<th>Fair Weather Audible Noise (dBA)</th>
<th>Fair Weather Radio Noise (dBµV/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit</td>
<td>2,000</td>
<td>4.2</td>
<td>27</td>
<td>L_{dn} of 55†</td>
</tr>
<tr>
<td></td>
<td>(12,420)*</td>
<td>(36.4)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(9,150)*</td>
<td>(26.8)*</td>
<td></td>
<td>L_{eq} of 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment Number</td>
<td>ROW Edge**</td>
<td>Max on ROW**</td>
<td></td>
<td>50 feet from conductor</td>
</tr>
<tr>
<td>N1-1</td>
<td>NA</td>
<td>NA</td>
<td>27</td>
<td>51</td>
</tr>
<tr>
<td>N1-UG-T</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>N1-UG-S</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>N2-1</td>
<td>10</td>
<td>0.1</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>N2-2</td>
<td>13</td>
<td>0.1</td>
<td>25</td>
<td>48</td>
</tr>
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<td>N2-3</td>
<td>7.2</td>
<td>0.2</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>C1-1</td>
<td>7.8</td>
<td>0.0</td>
<td>25</td>
<td>44</td>
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<td>43</td>
</tr>
<tr>
<td>C2-19</td>
<td>17</td>
<td>0.1</td>
<td>26</td>
<td>50</td>
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<td>46</td>
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<tr>
<td>C2-28</td>
<td>10</td>
<td>0.2</td>
<td>26</td>
<td>47</td>
</tr>
<tr>
<td>C2-33</td>
<td>10</td>
<td>0.2</td>
<td>24</td>
<td>40</td>
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</tr>
<tr>
<td>C2-38</td>
<td>4.8</td>
<td>0.4</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td>S1-1</td>
<td>44</td>
<td>0.4</td>
<td>14</td>
<td>30</td>
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<td>37</td>
</tr>
<tr>
<td>S1-13</td>
<td>127</td>
<td>2.7</td>
<td>18</td>
<td>38</td>
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<tr>
<td>S1-16</td>
<td>88</td>
<td>1.7</td>
<td>15</td>
<td>36</td>
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<td>S1-19</td>
<td>83</td>
<td>0.5</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>S1-20</td>
<td>78</td>
<td>0.5</td>
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<td>DS-1</td>
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</tr>
<tr>
<td>DS-2</td>
<td>69</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>DS-3</td>
<td>71</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

* The ICNIRP or ICES Reference Level is provided on the first line. The ICNIRP or ICES Basic Restriction computed from Kavet et al. (2012) at 60 Hz, shown in parenthesis on the second line.
† There is an exception within transmission line ROWs, where the limit is 10 kV/m, because people do not spend a substantial amount of time in ROWs.
‡ When calculating the L_{dn}, a 10 dB penalty is imposed during nighttime hours. For a continuous noise source over a full 24 hour day, an L_{dn} of 55 dBA, after appropriate application of the 10 dB penalty imposed during the nighttime hours, translates to a continuous equivalent L_{eq} of approximately 48 dBA. L_{eq} dBA levels are reported above for the segments.
§ The 1 MHz measurement frequency in IEEE (1971) was changed to 500 kHz by IEEE Radio Noise Measurement Standard 430 -1986. The guideline has therefore been adjusted for frequency (calculations performed at 500 kHz) and receiver (-2 dB for 9 kHz bandwidth receiver) to update guideline to present methods of measurement and calculation (500 kHz with CISPR receiver).
** The calculated magnetic-field level is shown for the NPT full rating; AC lines at AAL.
Summary

This report has summarized calculations of the DC electric- and magnetic-fields; AC electric- and magnetic-field; and space charge, AN, and RN associated with both the existing AC transmission lines and the proposed NPT DC and 345-kV AC lines on the proposed route between the border with Québec, Canada, and Deerfield, New Hampshire. The calculations have been made using methods that have been found to match well with measurements and are accepted within the scientific and engineering community and have been compared to applicable standards or guidelines. These calculated field levels were found to be below recommended limits for assessing impacts to environmental and public health.

Along the route of the proposed NPT line, there are four distinct types of configurations:

1) **DC-Only**: an overhead ±320-kV DC transmission line on a new ROW.
2) **DC-Underground**: an underground ±320-kV DC transmission line.
3) **Combined-DC/AC**: an overhead ±320-kV DC transmission line on a ROW shared with existing AC lines.
4) **AC-Only**: an overhead 345-kV AC transmission line on a ROW shared with existing AC lines.

This report details modeling results for sections of the propose route containing 1 DC-Only configuration, 2 DC-Underground configurations, 15 Combined DC/AC configurations, and 9 AC-Only configurations.

The DC-Only electrical environment includes an assessment of DC electric fields, DC magnetic fields, space charge (i.e., mostly air ions), AN, and RN. The AC-Only electrical environment includes AC electric fields, AC magnetic fields, AN, and RN. When both AC and DC lines are present as in the Combined- DC/AC corridor, the DC and AC electric and magnetic fields were calculated independently, but the AN and RN were calculated together to account for their additive effects.

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38 When constructed below, ground the DC transmission line will be a source of DC magnetic fields above ground, but not a source of DC electric fields, air ions, AN, or RN above ground.
Static Electric Fields, Magnetic Fields

The median electric-field levels at the ROW edge (8.9 kV/m) and on the ROW (23.3 kV/m) for all configurations and operating conditions are below the NRPB’s identification of 25 kV/m as a level above which field perception may be annoying (NRPB, 2004b) while the DC magnetic-field levels due to the transmission line at the ROW edge (79 mG) and on the ROW (526 mG) are well below the lowest guideline, 4,000 G (i.e., 4 million mG), 1,080 G (i.e., 1.08 million mG), and 400 G (i.e., 400,000 mG) for static magnetic-field exposure when considering just the field from the NPT line or when combined with earth’s geomagnetic field.

Alternating Current Electric and Magnetic Fields

The highest AC electric and magnetic-fields calculated at the ROW edge (2.7 kV/m; 127 mG) are below ICNIRP and ICES Reference Levels and the highest AC electric and magnetic-fields on the ROW (5.2 kV/m; 366 mG) along any portion of the route are below the lowest exposures calculated to equal the ICNIRP or ICES Basic Restrictions on exposure, which are 26.8 kV/m and 9,150 mG (Kavet et al., 2012).

Corona-Related Phenomena

Space Charge

Neither the federal government, nor the state of New Hampshire has standards or guidelines for space charge associated with DC transmission lines. The space charge associated the proposed NPT DC line would be within the range of levels encountered in the environment and similar or less than the space charge from the existing ±450kV DC line in New Hampshire.

Audible Noise

The AN from the DC-only or Combined DC/AC lines is 31 dBA or less on the ROW and decreases to 27 dBA or less at the edge of the ROW in fair or foul weather for all the computed cross sections (N1-1 through C2-38). This is below the 45 dBA EPA night time level or the 40 dBA night time level recommended by the WHO, both of which are based on protection of
sleep (USEPA, 1978; WHO 1999, 2009). These levels are also at or below ambient noise levels such that the noise contribution from the DC line would not be expected to produce a noticeable increase in the existing AN level.

On the AC-Only portion of the route (cross sections S1-1 through S1-20) the highest fair weather AN level on the ROW is 21 dBA or less and decreases to 18 dBA or less at the ROW edge. In foul weather, the highest level would be approximately 25 dB higher, however the wind and rain that typically occurs during foul weather are themselves likely to generate levels of AN (41-63 dBA) that are similar to or exceed the levels of AN from the transmission line and would likely mask the noise from the transmission lines during these conditions (Miller, 1978).

**Radio Noise**

The highest fair-weather RN values at 50 feet from the outer conductor in the DC-Only, Combined DC/AC (55 dBµV/m) or AC-Only (43 dBµV/m) portions of the route is well below the IEEE guideline level of 61 dBµV/. If interference to radio reception at a residence is a problem, it can be mitigated by use of a directional antenna, relocation of an existing antenna, or other solutions (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).
References


Fern WJ and Brabets RI. Field investigation of ozone adjacent to high voltage transmission lines. IEEE PES Winter Meeting, at New York, 1974.


Annex A

Summary Tables:

DC Magnetic Field
DC Electric Field,
Air Ion Density

AC Magnetic Field
AC Electric Field

Audible Noise
Radio Noise
Summary of Annex A Contents

Calculations of the environment around existing and proposed transmission lines were performed for 27 representative segments of the proposed project route from the Canadian border to the Deerfield Substation. In addition, calculations of the AC magnetic field were performed for three segments that will carry a portion of the Project power from Deerfield Substation to Scobie Pond Substation and require thermal-related upgrades to accommodate heavier loading due to the NPT Project. This annex summarizes the calculated levels of AC and static magnetic fields, AC and static electric fields, air ions, AN, and RN at locations on the ROW in each segment and at the edge of the ROW and at 300 feet from the NPT line on both sides of each segment. The tables in Annex A that summarize these calculations are:

<table>
<thead>
<tr>
<th>Table</th>
<th>Annex Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table A-1 DC magnetic field</td>
<td>A-1</td>
</tr>
<tr>
<td>Table A-2 DC electric field</td>
<td>A-6</td>
</tr>
<tr>
<td>Table A-3 Air ion density</td>
<td>A-9</td>
</tr>
<tr>
<td>Table A-4 AC magnetic field</td>
<td>A-13</td>
</tr>
<tr>
<td>Table A-5 AC electric field</td>
<td>A-22</td>
</tr>
<tr>
<td>Table A-6 Audible noise</td>
<td>A-25</td>
</tr>
<tr>
<td>Table A-7 Radio noise</td>
<td>A-33</td>
</tr>
</tbody>
</table>

Annex B contains graphic profiles of the calculated levels associated with pre- and post-construction conditions for each of the representative segments of the project route.

AC and DC magnetic fields were calculated for five scenarios:

- Pre-project AC lines at annual average load (designated AAL in tables);
- Pre-project AC lines at peak load (designated PL in tables);
- Post-project NPT DC transmission line at half rating with AC lines at AAL;
- Post-project NPT DC transmission line at full rating with AC lines at AAL; and
- Post-project NPT DC transmission line at full rating with AC lines at PL.

---

1 See the main body of this report for a description of these loading conditions. Full rating and half rating are descriptive terms; 1133 MW and 566 MW on the NPT DC transmission line, respectively, and were used in calculations of magnetic field from the DC and AC lines.
AC electric fields were calculated for two scenarios:
- Pre-project conditions; and
- Post-project conditions.

DC electric fields were calculated for two scenarios:
- Post-project fair weather; and
- Post-project foul weather.

Air ion density was calculated for two scenarios:
- Post-project fair weather, and
- Post-project foul weather.

Audible noise and radio noise were calculated for four scenarios:
- Pre-project fair weather
- Pre-project foul weather
- Post-project fair weather, and
- Post-project foul weather
Table A-1. DC magnetic-field levels due to the DC line (mG)

<table>
<thead>
<tr>
<th>Section Identifier</th>
<th>Condition*</th>
<th>Distance from Centerline of NPT Circuit</th>
<th>-300 ft</th>
<th>-ROW Edge</th>
<th>Max</th>
<th>+ROW Edge</th>
<th>+300 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N1-1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N1-1 has cleared area of 120 ft but NPT owns property and land rights (similar to the ROW) at distances greater than 120 ft. The nearest adjacent property occurs at -84 ft and 81 ft from the centerline of the NPT DC circuit. These distances have been used as the effective ROW edge for Section N1-1.</td>
<td>Pre-project: AC lines AAL</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-project: AC lines PL</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>1.8</td>
<td>22</td>
<td>177</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>3.6</td>
<td>43</td>
<td>355</td>
<td>46</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
<td>3.6</td>
<td>43</td>
<td>355</td>
<td>46</td>
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<td><strong>N1-Underground-Trench (N1-UG-T)</strong></td>
<td>Pre-project: AC lines AAL</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>±25 ft used as ROW edge</td>
<td>Pre-project: AC lines PL</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
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<td>397</td>
<td>26</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
<td>0.2</td>
<td>26</td>
<td>397</td>
<td>26</td>
<td>0.2</td>
<td></td>
</tr>
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<td><strong>N1-Underground-Splice (N1-UG-S)</strong></td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td></td>
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<tr>
<td>±25 ft used as ROW edge</td>
<td>Pre-project: AC lines PL</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td>263</td>
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<td>526</td>
<td>58</td>
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<tr>
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<td>Post-project: NPT full rating; AC lines PL</td>
<td>0.5</td>
<td>58</td>
<td>526</td>
<td>58</td>
<td>0.2</td>
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</tr>
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<td></td>
<td>Pre-project: AC lines AAL</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td>Pre-project: AC lines PL</td>
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<td>NA</td>
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<td>Distance from Centerline of NPT Circuit</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>-ROW Edge</td>
<td>Max</td>
<td>+ROW Edge</td>
<td>+300 ft</td>
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</tr>
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<td>NA</td>
<td>NA</td>
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<td></td>
</tr>
<tr>
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<td>Pre-project: AC lines PL</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
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<td>39</td>
<td>177</td>
<td>19</td>
<td>1.8</td>
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</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>3.6</td>
<td>79</td>
<td>355</td>
<td>38</td>
<td>3.6</td>
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</tr>
<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-project: AC lines PL</td>
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<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-project: NPT half rating; AC lines AAL</td>
<td>1.8</td>
<td>39</td>
<td>177</td>
<td>9</td>
<td>1.8</td>
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<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines AAL</td>
<td>3.6</td>
<td>79</td>
<td>355</td>
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<td>3.6</td>
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<tr>
<td></td>
<td>Post-project: NPT full rating; AC lines PL</td>
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<td>79</td>
<td>355</td>
<td>19</td>
<td>3.6</td>
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<td>N2-10</td>
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<sup>‡</sup> An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the ROW edge are lower than at 300 feet from the centerline of the NPT line.

<sup>†</sup> There is no NPT ('new') line in sections DS-1, DS-2 or DS-3, so no results are presented at 300 feet from the center of the NPT circuit in these sections.
Table A-5. AC electric-field levels (kV/m)

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An oddity in Segment C2-36 is that the 300 feet from the centerline of the NPT circuit is still inside the ROW edge. Therefore, while in most segments the field levels at a distance of 300 feet from the NPT line are lower than at the ROW edge, in this segment, field levels at the ROW edge are the same as at 300 feet from the centerline of the NPT line.

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‡ There is no NPT line or other ‘new’ line in sections DS-1, DS-2, or DS; therefore electric field levels are not expected to change and are not considered for these sections.
Table A-6. Median audible noise levels from lines in fair and foul weather (dBA)*

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</table>

* Calculated levels of AN that are 0 dBA or less are represented in this table as a <0, indicating that the level of AN is below 20 μPa, the threshold of human hearing.

‡ There is no NPT line or other new line in sections DS-1, DS-2, or DS; therefore AN levels are not expected to change and are not considered for these sections.
Table A-7. Median radio noise levels in fair and foul weather (dBµV/m)*

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<th>Max</th>
<th>-50 ft from outside conductor‡</th>
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‡ Additional notes or conditions related to the outside conductor.
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* Calculated levels of RN that are 0 dBμV/m or less are represented in this table as a <0, indicating that the level of RN is below 1μV/m.

† The physical location of the ±50 foot distance from the outside conductor will change from section to section and also from pre-project to post-project configurations. The RN values listed in this column therefore are not always positioned at the same location for pre-project and post-project conditions.

‡ There is no NPT line or other ‘new’ line in sections DS-1, DS-2, or DS; therefore RN levels are not expected to change and are not considered for these sections.
Annex B

Profiles of Pre- and Post-Project Electrical Parameters:

DC Magnetic Field
DC Electric Field,
Air Ion Density

AC Magnetic Field
AC Electric Field

Audible Noise
Radio Noise
Summary of Annex B Contents

Profiles of the pre- and post-project electrical parameters were plotted for 27 representative segments of the proposed project route from the Canadian border to the Deerfield Substation. In addition, profiles of the AC magnetic field were performed for three segments that will carry a portion of the project power from Deerfield Substation to Scobie Pond Substation and require thermal-related upgrades to accommodate heavier loading due to the NPT Project.

Annex B contains profiles of the calculated levels of AC and static magnetic fields, AC and static electric fields, air ions, AN, and RN for each of the representative segments. Some profiles on the same graph may be identical or so similar that they appear as one profile.

The profiles in Annex B are:

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<td>Figures B-166 thru B-192:</td>
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Figure B-1. Static magnetic field profile along XS-1, Segment N1-1.
Figure B-2. Static magnetic field profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-3. Static magnetic field profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-4. Static magnetic field profile along XS-4, Segment N2-1.
Figure B-5. Static magnetic field profile along XS-5, Segment N2-8.
Figure B-6. Static magnetic field profile along XS-6, Segment N2-9.
Figure B-7. Static magnetic field profile along XS-7, Segment N2-10.
Figure B-8. Static magnetic field profile along XS-8, Segment N2-11.
Figure B-9. Static magnetic field profile along XS-9, Segment C1-2.
Figure B-10. Static magnetic field profile along XS-10, Segment C1-3.
Figure B-11. Static magnetic field profile along XS-11, Segment C2-18.
Figure B-12. Static magnetic field profile along XS-12, Segment C2-19.
Figure B-13. Static magnetic field profile along XS-13, Segment C2-26.
Figure B-14. Static magnetic field profile along XS-14, Segment C2-28.
Figure B-15. Static magnetic field profile along XS-15, Segment C2-33.
Figure B-16. Static magnetic field profile along XS-16, Segment C2-35.
Figure B-17. Static magnetic field profile along XS-17, Segment C2-36.
Figure B-18. Static magnetic field profile along XS-18, Segment C2-38.
Figure B-19. Static magnetic field profile along XS-19, Segment S1-1.
Figure B-20. Static magnetic field profile along XS-20, Segment S1-4.
Figure B-21. Static magnetic field profile along XS-21, Segment S1-5.
No DC Transmission Line in this Segment

Figure B-22. Static magnetic field profile along XS-22, Segment S1-8.
Figure B-23. Static magnetic field profile along XS-23, Segment S1-12.
Figure B-24. Static magnetic field profile along XS-24, Segment S1-13.
Figure B-25. Static magnetic field profile along XS-25, Segment S1-16.
Figure B-26. Static magnetic field profile along XS-26, Segment S1-19.
Figure B-27. Static magnetic field profile along XS-27, Segment S1-20.
Figure B-28. Static electric field profile along XS-1, Segment N1-1.
Figure B-29. Static electric field profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-30. Static electric field profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-31. Static electric field profile along XS-4, Segment N2-1.
Figure B-32. Static electric field profile along XS-5, Segment N2-8.
Figure B-33. Static electric field profile along XS-6, Segment N2-9.
Figure B-34. Static electric field profile along XS-7, Segment N2-10.
Figure B-35. Static electric field profile along XS-8, Segment N2-11.
Figure B-36. Static electric field profile along XS-9, Segment C1-2.
Figure B-37. Static electric field profile along XS-10, Segment C1-3.
Figure B-38. Static electric field profile along XS-11, Segment C2-18.
Figure B-39. Static electric field profile along XS-12, Segment C2-19.
Figure B-40. Static electric field profile along XS-13, Segment C2-26.
Figure B-41. Static electric field profile along XS-14, Segment C2-28.
Figure B-42. Static electric field profile along XS-15, Segment C2-33.
Figure B-43. Static electric field profile along XS-16, Segment C2-35.
Figure B-44. Static electric field profile along XS-17, Segment C2-36.
Figure B-45. Static electric field profile along XS-18, Segment C2-38.
Figure B-46. Static electric field profile along XS-19, Segment S1-1.
Figure B-47. Static electric field profile along XS-20, Segment S1-4.
Figure B-48. Static electric field profile along XS-21, Segment S1-5.
Figure B-49. Static electric field profile along XS-22, Segment S1-8.
Figure B-50. Static electric field profile along XS-23, Segment S1-12.
Figure B-51. Static electric field profile along XS-24, Segment S1-13.
Figure B-52. Static electric field profile along XS-25, Segment S1-16.
Figure B-53. Static electric field profile along XS-26, Segment S1-19.
Figure B-54. Static electric field profile along XS-27, Segment S1-20.
Figure B-55. Air ion density profile along XS-1, Segment N1-1. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-56. Air ion density profile along XS-2, Segment N1-UG-T (Typical Trench). Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-57. Air ion density profile along XS-3, Segment N1-UG-S (Typical Splice). Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-58. Air ion density profile along XS-4, Segment N2-1. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-59. Air ion density profile along XS-5, Segment N2-8. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-60. Air ion density profile along XS-6, Segment N2-9. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-61. Air ion density profile along XS-7, Segment N2-10. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-62. Air ion density profile along XS-8, Segment N2-11. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-63. Air ion density profile along XS-9, Segment C1-2. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-64. Air ion density profile along XS-10, Segment C1-3. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-65. Air ion density profile along XS-11, Segment C2-18. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-66. Air ion density profile along XS-12, Segment C2-19. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-67. Air ion density profile along XS-13, Segment C2-26. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-68. Air ion density profile along XS-14, Segment C2-28. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-69. Air ion density profile along XS-15, Segment C2-33. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-70. Air ion density profile along XS-16, Segment C2-35. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-71. Air ion density profile along XS-17, Segment C2-36. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-72. Air ion density profile along XS-18, Segment C2-38. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-73. Air ion density profile along XS-19, Segment S1-1. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-74. Air ion density profile along XS-20, Segment S1-4. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-75. Air ion density profile along XS-21, Segment S1-5. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-76. Air ion density profile along XS-22, Segment S1-8. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-77. Air ion density profile along XS-23, Segment S1-12. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-78. Air ion density profile along XS-24, Segment S1-13. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-79. Air ion density profile along XS-25, Segment S1-16. Densities of positive and negative ions are indicated by ion densities $>0$ and $<0$, respectively.
Figure B-80. Air ion density profile along XS-26, Segment S1-19. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-81. Air ion density profile along XS-27, Segment S1-20. Densities of positive and negative ions are indicated by ion densities >0 and <0, respectively.
Figure B-82. AC magnetic field profile along XS-1, Segment N1-1.
Figure B-83. AC magnetic field profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-84. AC magnetic field profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-85. AC magnetic field profile along XS-4, Segment N2-1.
Figure B-86. AC magnetic field profile along XS-5, Segment N2-8.
Figure B-87. AC magnetic field profile along XS-6, Segment N2-9.
Figure B-88. AC magnetic field profile along XS-7, Segment N2-10.
Figure B-89. AC magnetic field profile along XS-8, Segment N2-11.
AC Magnetic Field
XS-9 (Segment C1-2)

View Facing East

-ROW
+ROW

Magnetic field resultant (mG)

Distance from structure centerline (ft)

Existing Structures

Proposed Structures

Figure B-90. AC magnetic field profile along XS-9, Segment C1-2.
Figure B-91. AC magnetic field profile along XS-10, Segment C1-3.
Figure B-92. AC magnetic field profile along XS-11, Segment C2-18.
Figure B-93. AC magnetic field profile along XS-12, Segment C2-19.
Figure B-94. AC magnetic field profile along XS-13, Segment C2-26.
Figure B-95. AC magnetic field profile along XS-14, Segment C2-28.
Figure B-96. AC magnetic field profile along XS-15, Segment C2-33.
AC Magnetic Field
XS-16 (Segment C2-35)

View Facing North

Magnetic field resultant (mG)

Distance from structure centerline (ft)

-ROW

+ROW

Existing Structures

Abandoned
A11
12WB12

Proposed Structures

NPT
A11
12WB12

Figure B-97. AC magnetic field profile along XS-16, Segment C2-35.
Figure B-98. AC magnetic field profile along XS-17, Segment C2-36.
Figure B-99. AC magnetic field profile along XS-18, Segment C2-38.
Figure B-100. AC magnetic field profile along XS-19, Segment S1-1.
Figure B-101. AC magnetic field profile along XS-20, Segment S1-4.
AC Magnetic Field
XS–21 (Segment S1–5)

View Facing North

Figure B-102. AC magnetic field profile along XS-21, Segment S1-5.
Figure B-103. AC magnetic field profile along XS-22, Segment S1-8.
Figure B-104. AC magnetic field profile along XS-23, Segment S1-12.
Figure B-105. AC magnetic field profile along XS-24, Segment S1-13.
Figure B-106. AC magnetic field profile along XS-25, Segment S1-16.
Figure B-107. AC magnetic field profile along XS-26, Segment S1-19.
Figure B-108. AC magnetic field profile along XS-27, Segment S1-20.
Figure B-109. AC magnetic field profile along XS-28, Segment DS-1 (Deerfield to Scobie Pond).
Figure B-110. AC magnetic field profile along XS-29, Segment DS-2 (Deerfield to Scobie Pond).
Figure B-111. AC magnetic field profile along XS-30, Segment DS-3 (Deerfield to Scobie Pond).
Figure B-112. AC electric field profile along XS-1, Segment N1-1.
Figure B-113. AC electric field profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-114. AC electric field profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-115. AC electric field profile along XS-4, Segment N2-1.
Figure B-116. AC electric field profile along XS-5, Segment N2-8.
Figure B-117. AC electric field profile along XS-6, Segment N2-9.
Figure B-118. AC electric field profile along XS-7, Segment N2-10.
AC Electric Field
XS–8 (Segment N2–11)

Figure B-119. AC electric field profile along XS-8, Segment N2-11.
Figure B-120. AC electric field profile along XS-9, Segment C1-2.
AC Electric Field
XS-10 (Segment C1-3)

View Facing North

Electric field (kV/m)

Distance from structure centerline (ft)

-ROW

+ROW

Existing Structures

Proposed Structures

Figure B-121. AC electric field profile along XS-10, Segment C1-3.
Figure B-122. AC electric field profile along XS-11, Segment C2-18.
Figure B-123. AC electric field profile along XS-12, Segment C2-19.
Figure B-124. AC electric field profile along XS-13, Segment C2-26.
Figure B-125. AC electric field profile along XS-14, Segment C2-28.
Figure B-126. AC electric field profile along XS-15, Segment C2-33.
AC Electric Field
XS-16 (Segment C2-35)

View Facing North

Electric field (kV/m)

Distance from structure centerline (ft)

-ROW +ROW

Existing Structures

Abandoned
A111
12WB12

Proposed Structures

NPT
A111
12WB12

Figure B-127. AC electric field profile along XS-16, Segment C2-35.
Figure B-128. AC electric field profile along XS-17, Segment C2-36.
Figure B-129. AC electric field profile along XS-18, Segment C2-38.
Figure B-130. AC electric field profile along XS-19, Segment S1-1.
Figure B-131. AC electric field profile along XS-20, Segment S1-4.
Figure B-132. AC electric field profile along XS-21, Segment S1-5.
Figure B-133. AC electric field profile along XS-22, Segment S1-8.
Figure B-134. AC electric field profile along XS-23, Segment S1-12.
Figure B-135. AC electric field profile along XS-24, Segment S1-13.
Figure B-136. AC electric field profile along XS-25, Segment S1-16.
Figure B-137. AC electric field profile along XS-26, Segment S1-19.
Figure B-138. AC electric field profile along XS-27, Segment S1-20.
Figure B-139. Audible noise profile along XS-1, Segment N1-1.
Figure B-140. Audible noise profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-141. Audible noise profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-142. Audible noise profile along XS-4, Segment N2-1.
Figure B-143. Audible noise profile along XS-5, Segment N2-8.
Figure B-144. Audible noise profile along XS-6, Segment N2-9.
Figure B-145. Audible noise profile along XS-7, Segment N2-10.
Figure B-146. Audible noise profile along XS-8, Segment N2-11.
Figure B-147. Audible noise profile along XS-9, Segment C1-2.
Figure B-148. Audible noise profile along XS-10, Segment C1-3.
Figure B-149. Audible noise profile along XS-11, Segment C2-18.
Figure B-150. Audible noise profile along XS-12, Segment C2-19.
Figure B-151. Audible noise profile along XS-13, Segment C2-26.
Figure B-152. Audible noise profile along XS-14, Segment C2-28.
Figure B-153. Audible noise profile along XS-15, Segment C2-33.
Figure B-154. Audible noise profile along XS-16, Segment C2-35.
Figure B-155. Audible noise profile along XS-17, Segment C2-36.
Figure B-156. Audible noise profile along XS-18, Segment C2-38.
Figure B-157. Audible noise profile along XS-19, Segment S1-1.
Figure B-158. Audible noise profile along XS-20, Segment S1-4.
Figure B-159. Audible noise profile along XS-21, Segment S1-5.
Figure B-160. Audible noise profile along XS-22, Segment S1-8.
Figure B-161. Audible noise profile along XS-23, Segment S1-12.
Figure B-162. Audible noise profile along XS-24, Segment S1-13.
Figure B-163. Audible noise profile along XS-25, Segment S1-16.
Figure B-164. Audible noise profile along XS-26, Segment S1-19.
Figure B-165. Audible noise profile along XS-27, Segment S1-20.
Figure B-166. Radio noise profile along XS-1, Segment N1-1.
Radio Noise
XS-2 (Segment N1-UG-T (Typical Trench))

View Facing North

No Transmission Line Above Ground

Distance from structure centerline (ft)

Radio Noise (dBuV/m)

Figure B-167. Radio noise profile along XS-2, Segment N1-UG-T (Typical Trench).
Figure B-168. Radio noise profile along XS-3, Segment N1-UG-S (Typical Splice).
Figure B-169. Radio noise profile along XS-4, Segment N2-1.
Figure B-170. Radio noise profile along XS-5, Segment N2-8.
Figure B-171. Radio noise profile along XS-6, Segment N2-9.
Figure B-172. Radio noise profile along XS-7, Segment N2-10.
Figure B-173. Radio noise profile along XS-8, Segment N2-11.
Figure B-174. Radio noise profile along XS-9, Segment C1-2.
Figure B-175. Radio noise profile along XS-10, Segment C1-3.
Figure B-176. Radio noise profile along XS-11, Segment C2-18.
Figure B-177. Radio noise profile along XS-12, Segment C2-19.
Radio Noise
XS-13 (Segment C2-26)

View Facing North

Distance from structure centerline (ft)

Radio Noise (dBuV/m)

-300 -200 -100 0 100 200 300

Pre-project in fair weather
Pre-project in foul weather
Post-project in fair weather
Post-project in foul weather

existing
removed

Existing Structures

Proposed Structures

Figure B-178. Radio noise profile along XS-13, Segment C2-26.
Figure B-179. Radio noise profile along XS-14, Segment C2-28.
Figure B-180. Radio noise profile along XS-15, Segment C2-33.
Figure B-181. Radio noise profile along XS-16, Segment C2-35.
Figure B-182. Radio noise profile along XS-17, Segment C2-36.
Figure B-183. Radio noise profile along XS-18, Segment C2-38.
Figure B-184. Radio noise profile along XS-19, Segment S1-1.
Radio Noise
XS–20 (Segment S1–4)

View Facing North

-ROW

+ROW

Distance from structure centerline (ft)

Radio Noise (dBuV/m)

-300 -200 -100 0 100 200 300

Pre–project in fair weather
Pre–project in foul weather
Post–project in fair weather
Post–project in foul weather

existing
removed

Existing Structures

Proposed Structures

Figure B-185. Radio noise profile along XS-20, Segment S1-4.
Figure B-186. Radio noise profile along XS-21, Segment S1-5.
Figure B-187. Radio noise profile along XS-22, Segment S1-8.
Figure B-188. Radio noise profile along XS-23, Segment S1-12.
Figure B-189. Radio noise profile along XS-24, Segment S1-13.
Figure B-190. Radio noise profile along XS-25, Segment S1-16.
Figure B-191. Radio noise profile along XS-26, Segment S1-19.
Figure B-192. Radio noise profile along XS-27, Segment S1-20.