MANITOBA-MINNESOTA TRANSMISSION PROJECT

Socio-Economic Technical Data Reports

2.8 Electric Field, Magnetic Field, Audible Noise and Radio Noise Calculations

Electrical Engineering and
Computer Science Practice

Exponent®

Manitoba-Minnesota Transmission Project

Electric Field, Magnetic Field, Audible Noise, and Radio Noise Calculations

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Acronyms and Abbreviations

AC	Alternating current
AN	Audible noise
BPIII	Bipole III
BR	Basic restriction
dB	Decibel
dBA	Decibels on the A-weighted scale
dBμV/m	Decibels relative to 1 microvolt per metre
DC	Direct current
CSA	Canadian Standards Association
EMF	Electric and magnetic fields
G	Gauss
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
kHz	Kilohertz
km	Kilometre
kV	Kilovolt
kV/m	Kilovolt per metre
m	Metre
mA	Milliampere
mHz	Megahertz
MMTP	Manitoba Minnesota Transmission Project
MW	Megawatt
mG	Milligauss
NESC	National Electrical Safety Code
ROW	Right-of-way
RVTC	Riel to Vivian Transmission Corridor
SLTC	Southern Loop Transmission Corridor
V/m	Volt per metre

Limitations

At the request of Manitoba Hydro, Exponent modeled the electrical and acoustic environment of the proposed Manitoba Minnesota Transmission Project. This report summarizes and presents the findings resulting from that work. In the analysis, Exponent has relied upon transmission line design geometry, usage, specifications, and various other types of information provided by the client. Manitoba Hydro has confirmed that the data provided to Exponent and the summary contained herein are not subject to Critical Infrastructure Management Information restrictions. Exponent cannot verify the correctness of this input data, and relies on the client for the data's accuracy. 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 outside of the National Energy Board permitting and Environmental Assessment processes, 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

The proposed Manitoba Minnesota Transmission Project (MMTP) involves the construction of a new 500-kilovolt transmission line (designated D604I) from the Dorsey Converter Station located northwest of Winnipeg to the Manitoba-Minnesota border near Piney, Manitoba. At the Manitoba-Minnesota border, the proposed transmission line will connect to the Great Northern Transmission Line constructed by Minnesota Power, ultimately terminating at a new station called Iron Range located northwest of Duluth, Minnesota. MMTP also includes additions and modifications to equipment within the Dorsey and Riel Converter Stations and the Glenboro South Station in Manitoba to accommodate the new line. This report discusses the MMTP proposal for the Manitoba portion of the project only.

Existing and proposed transmission lines along the proposed route are sources of 60 Hertz electric and magnetic fields (EMF), audible noise (AN), and radio noise (RN). To characterize anticipated changes to EMF, AN, and RN levels from the MMTP project, Exponent modeled the operation of transmission lines on the MMTP route for nine sections of the line under existing and proposed configurations, and under average and peak loading. Comparisons of calculated values of the above parameters under existing and proposed configurations show that MMTP will increase EMF, AN, and RN on the transmission line right-of-way (ROW), but will result in only a small change in these parameters at the edge of the ROW and beyond. All transmission line EMF, AN, RN, and induced current levels are calculated to comply with standards and guidelines applied as health and environmental assessment criteria.

- **EMF** levels at the edge of the ROW were compared to standards and guidelines developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and International Committee for Electromagnetic Safety (ICES) and were calculated to be below the reference levels for public exposure (ICES, 2002; ICNIRP 2010).

- **Induced Currents.** Short-circuited currents induced on large tractor-trailer vehicles and farm equipment under the proposed transmission lines will not exceed the design guidelines recommended by the Canadian Standards Association (CSA, 2015), except for in Sections F and G for farmland. In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents. As construction of infrastructure in the RVTC continues, Manitoba Hydro will manage and monitor the use of the corridor. The proposed D604I line also meets all vertical clearance requirements specified by the CSA for overhead systems.

- **Audible Noise.** The fair-weather AN associated with the transmission lines will be below the Manitoba Provincial Guidelines specified for residential and commercial areas for both and daytime and nighttime conditions (EMD, 1992). These guidelines were identified as acceptable levels for which no community reaction is anticipated and which also have been identified by the US Environmental Protection Agency as preventing public annoyance and protecting public health and welfare with an adequate margin of safety (USEPA, 1974). The AN levels at the nearest residence associated with added equipment at the Dorsey Converter Station and Glenboro South Station, however, are calculated to exceed the maximum desirable level at nighttime based upon initial simplified modeling. These stations are located in areas zoned for agricultural use, and if a potential noise issue is identified, more accurate calculations or investigation of noise mitigation procedures may be necessary for these sites.

- **Radio Noise.** The fair-weather RN at 15 metres beyond the outer conductor throughout the proposed MMTP route will be below the guidelines recommended by Industry Canada (IC, 2013) and the Institute of Electrical and Electronics Engineers (IEEE, 1971) for RN from transmission lines.

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.

Introduction

The Manitoba-Minnesota Transmission Project (MMTP) has been proposed to transmit electricity to Minnesota Power in the United States. New hydroelectric generating facilities provide surplus electricity that can be sold in the United States to help subsidize the cost of electricity to users in Manitoba. The proposed MMTP transmission connection will facilitate the export of this electricity to the United States as well as improve system reliability in Manitoba by allowing for electricity import in contingency and drought situations. The MMTP line will connect at the Manitoba-Minnesota border to the Great Northern Transmission Line.

MMTP involves the construction of the 500-kilovolt (kV) alternating current (AC) transmission line, the Dorsey to Iron Range Transmission Line, with a line identification code of D604I. The proposed D604I line will run from the Dorsey Converter Station, located near Rosser, northwest of Winnipeg, and travel south around Winnipeg within the Southern Loop Transmission Corridor (SLTC). From southeast Winnipeg, the transmission line will continue southeast, crossing the Manitoba-Minnesota border near Piney, Manitoba. It will then connect to the Great Northern Transmission Line, which will be constructed by Minnesota Power, and ultimately terminate at the new Iron Range Substation adjacent to the existing Blackberry Substation located northwest of Duluth, Minnesota. MMTP also includes additions and modifications to associated substations at Dorsey and Riel Converter Stations and the Glenboro South Station in Manitoba to accommodate this line. This report discusses the MMTP proposal for the Manitoba portion only. The proposed route for this portion of the proposed D604I line in Manitoba is approximately 213 kilometres (km) long and is presented in Figure 1, along with annotations marking the representative sections of D604I where the electrical environment was modeled for this report.

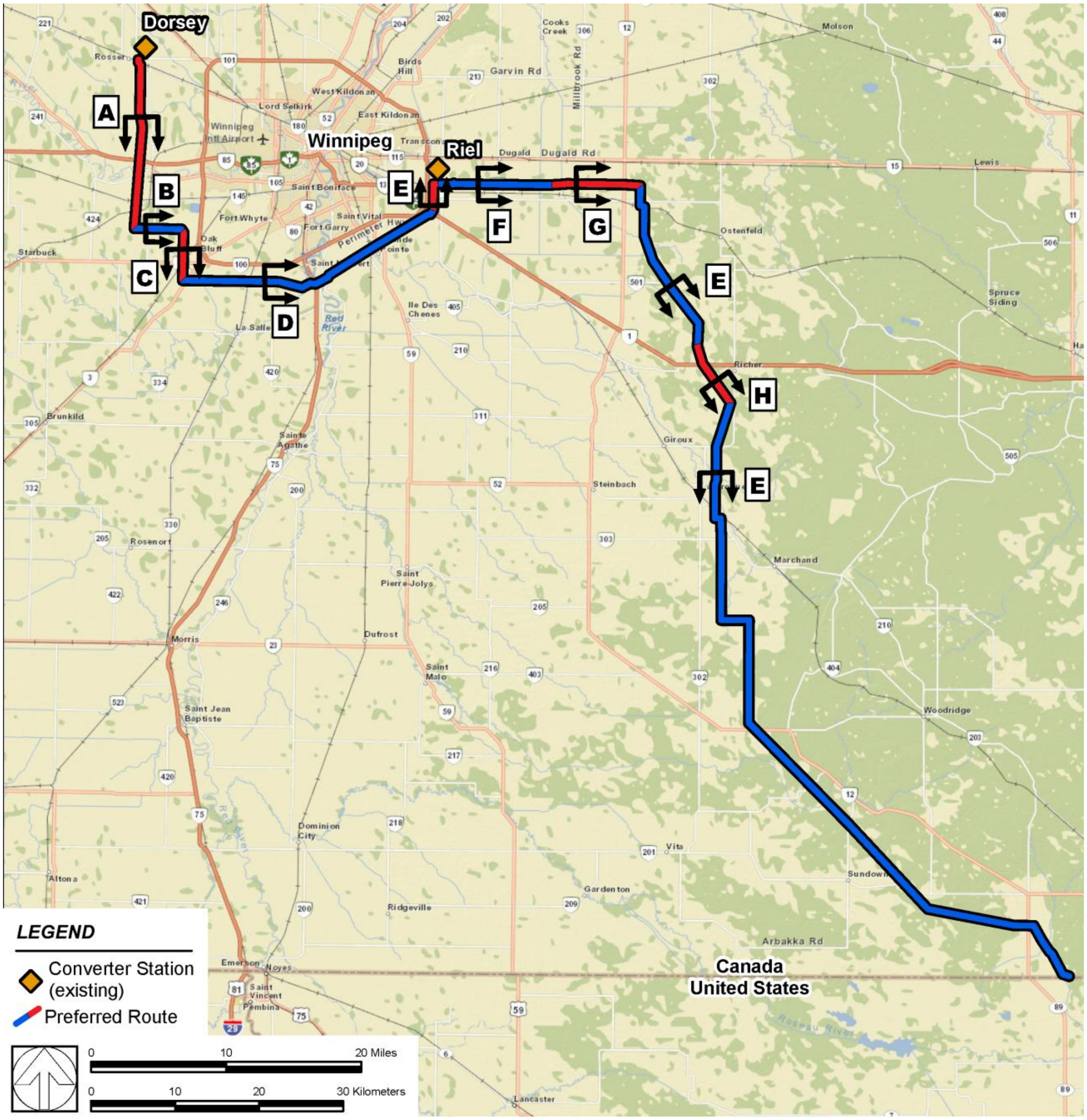

Figure 1. Proposed preferred route of the D604I line for MMTP in Manitoba showing the locations of Sections A-H.

Section E contains only the proposed D604I line and occurs at several locations along the route.

Arrows indicate the predominate direction of current flow.

Proposed D604I Line Route and Representative Sections

The proposed route for the D604I line runs from the Dorsey Converter Station, south and then east around Winnipeg, and then southeast to the Manitoba-Minnesota border. Along this route, the proposed D604I line will share sections of its right-of-way (ROW) with combinations of different existing lines producing nine unique ROW sections (Sections A-H). Section E was analyzed for portions where the line will be constructed in two configurations—self-supporting and guyed lattice steel structures, E1 and E2.[1] Existing and proposed transmission lines were modeled to generate calculations along transects perpendicular to these nine ROW sections at locations marked by brackets across the route in Figure 1 and described in more detail below. The arrow heads on the brackets show the predominate direction of power flow. The MMTP line in Sections A-D and the first portion of Section E, running from the Dorsey Converter Station to the southeast Winnipeg area up to the Riel Converter Station, will be within the existing SLTC dedicated transmission corridor. In Sections F-H of the route, and portions of Section E, the MMTP line will be constructed on a combination of new and existing ROWs owned by Manitoba Hydro.

The configuration of existing transmission lines will not be modified as part of MMTP, so the only change in the line configuration in each section is the addition of the proposed D604I line. A list of the existing transmission lines in each section is provided in Appendix C, Table C-1. A table summarizing the average and peak loading of each transmission line is provided in Appendix C, Table C-2.

In all Sections except for E, the proposed D604I line will be constructed on self-supporting lattice steel structures. In Section E, the proposed D604I line will be constructed on a combination of self-supporting and guyed lattice steel structures. Schematic diagrams showing these structures are presented in Appendix C, Figure C-1.

[1] The D604I line will be constructed on two different types of structures in different portions of the route. Section E1 represents portions of the route where the line is constructed using self-supporting lattice steel structures and section E2 represents portions of the route where the line is constructed using guyed lattice steel structures.

Section A (Dorsey – Laverendrye Corner) heads south from the Dorsey Converter Station along the SLTC for approximately 20 km to Laverendrye Corner. The existing ROW contains four 230-kV transmission lines (D55Y, D14S, D15Y, and D11Y) constructed on two separate double-circuit structures and located on a ROW with a minimum width of approximately 216 metres (m). In the proposed configuration, the proposed D604I line will be located a minimum of 46 m from the eastern ROW edge.

Section B (Laverendrye Corner – Laverendrye) heads east from Laverendrye Corner to the Laverendrye Station for approximately 6 km. The existing ROW contains three 230-kV transmission lines (D11Y, D15Y, and D55Y) constructed on two separate double-circuit structures on a 145 m ROW.[2] The proposed D604I line will be located approximately 46 m from the southern ROW edge.

Section C (Laverendrye – South Loop) heads south from Laverendrye Station along the SLTC for approximately 6 km. The existing ROW contains two 230-kV lines (Y51L and Y36V[3]) on single-circuit structures, and one 115-kV line (YM31) and one 66-kV line (L2) on double-circuit structures. The proposed D604I line will be located near the center of the ROW, approximately 38 m west of the Y36V line and 94 m from the eastern ROW edge. The total ROW width is approximately 223 m.

Section D (South Loop) travels east for ~15 km and then northeast for ~17 km near the southern border of the City of Winnipeg.[4] The existing ROW contains a single 230-kV line (Y36V[3]), which is located 55.5 m south of the north ROW edge. The proposed D604I line is located 38.1 m south of the existing Y36V line, and the south ROW edge is located 83.8 m south of the location for the proposed D604I line. The total ROW width is 177.4 m.

[2] The opposite side of the double-circuit structure supporting the D11Y circuit is vacant.

[3] The Y36V line is proposed for the separate St. Vital Transmission Complex project. It is included in both existing and proposed modeling configurations to most conservatively analyze the cumulative effects of all anticipated transmission lines within the ROW.

[4] All directions discussing the ROW for this section will assume the transmission line route is strictly traveling west to east.

Section E (Proposed D604I line only) describes several sections of the transmission line route where only the proposed D604I line is present. There are no existing lines in these sections, and the proposed D604I line will be located at the center of an 80 m wide ROW. In portions of Section E, the proposed D604I line will be constructed on self-supporting lattice steel structures and will be analyzed as Section E1. In other portions of Section E, the proposed D604I line will be constructed on guyed lattice steel structures and will be analyzed as Section E2. The first location of Section E extends north for approximately 3 km following Section D, passing along the west side of Deacon Reservoir and the City of Winnipeg's Water Treatment Plant as the route enters the Riel Converter Station. Additional locations of Section E occur following Sections F and G, where the proposed route turns south-southeast towards the Manitoba-Minnesota border. Most of this portion of the route following Sections F and G contains only the proposed D604I line and was analyzed as Section E. The only exception is Section H, where an 8 km stretch of the proposed D604I line will share the ROW with an existing 230-kV line (R49R).

Section F (East of the Riel Converter Station) exits the SLTC and extends east from the Riel Converter Station along the existing Riel to Vivian Transmission Corridor (RVTC) owned by Manitoba Hydro. The proposed D604I route travels east from Riel Converter Station for approximately 24 km. Section F encompasses the first 14 km of this 24 km path, while Section G encompasses the remaining 10 km. Both Section F and Section G share the ROW with the existing 500-kV D602F line, which the proposed D604I line would need to physically cross over if no further adjustments were made. To avoid this crossover of 500-kV lines, the load on the existing D602F line will be shifted to the proposed D604I line and the load on the D602F line shifted to the D6041 line within Sections F and G.

Section F also includes the future ±500-kV direct current (DC) Bipole III transmission line, which will be located 33 m from the north ROW edge. The structures supporting the D602F and D604I lines will be located over 100 m south of BPIII near the south ROW edge, and the total ROW width is 232 m. The proposed transmission line loading and structure locations in Section F are illustrated in Figure 2. In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents. As construction of infrastructure in the RVTC continues, Manitoba Hydro will manage and monitor the use of the corridor.

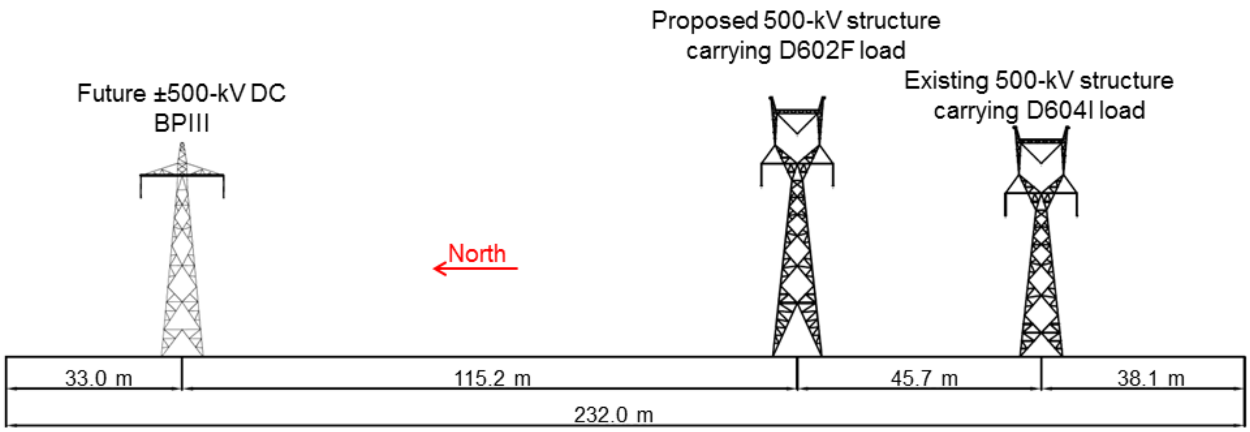

Figure 2. Illustration of the proposed locations of transmission structures and annotation of proposed loading condition in Section F.

The view faces east from the Riel Converter Station; north is to the left.

Section G (East of the Riel Converter Station, beyond BPIII) continues traveling east from Section F for approximately 10 km in the existing RVTC ROW owned by Manitoba Hydro. This section is identical to Section F except for the absence of the BPIII DC line, which exits this ROW approximately 14 km east of the Riel Converter Station. Section G contains only the existing D602F line and the proposed D604I line. As discussed above, line loading will be swapped between the existing D602F line and the proposed D604I line within Sections F and G.

Section H (Alongside the existing R49R line) is a specific portion of the remaining D604I route. The proposed D604I route turns south-southeast towards the Manitoba-Minnesota border. For much of this route, the proposed D604I is the only line on the ROW, which means its electrical environment calculations match those of Section E. For approximately 8 km near the Cottonwood and Oakwood Golf Courses, however, the proposed D604I line parallels the existing 230-kV R49R line. Section H thus pertains specifically to that portion where the proposed D604I line shares the ROW with the existing R49R line. The proposed D604I line will be located 50 m east of the west ROW edge, and the existing R49R line is approximately 68 m east of the proposed D604I location. The east ROW edge is located approximately 18 m east of the existing R49R line. The total ROW width is approximately 137 m.

MMTP Station Modifications

The proposed MMTP also includes additions and modifications to the Dorsey and Riel Converter Station and the Glenboro South Station in Manitoba. The locations of the Dorsey and Riel Converter Stations are marked in Figure 1. The Glenboro South Station is located further west, 1.5 km south of the junction of Provincial Trunk Highways 2 and 5.

- At the ***Dorsey Converter Station***, four 500-kV reactors, along with circuit breakers and capacitors, will be added to support integration of the proposed D604I line. The addition of reactors will act as a safety mechanism to reduce the D604I line voltage at Dorsey Converter Station in the event that a breaker is open at Dorsey Converter Station. To accommodate the new equipment, the station fence line will be expanded to the west 40 m by 273 m and 53 m by 94 m on property owned by Manitoba Hydro.

- At the ***Riel Converter Station***, three single-phase 400 MVA autophase transformers and associated equipment will be added. The additions will provide sufficient capacity for the increase in firm export capability in the US, especially in the event that one of the Dorsey or Riel 500-kV autotransformers is out of service. The Riel Converter Station is built on 112 hectares of land owned by Manitoba Hydro and is still under development for the previously approved and licensed Riel Reliability Improvement Initiative and BPIII. The proposed improvements to the station for MMTP will be contained within the existing fence line of the Riel Converter Station.

- At ***Glenboro South Station***, two 300 MVA phase shifting transformers will be installed to control the flow of electricity between the Manitoba and United States electrical systems. The station fence line will be expanded 130 m by 91 m east of the existing 230-kV switchyard on property owned by Manitoba Hydro, and a number of existing transmission lines and several pieces of equipment will need to be modified or relocated.

Electrical Environment and Assessment Criteria

Most electricity in North America is transmitted as AC at a frequency of 60 Hertz (Hz). This transmission of electricity produces electric and magnetic fields (EMF) when carried by either low or high voltage lines, but audible noise (AN) and radio noise (RN) are characteristics of interest primarily for transmission lines operating at voltages of 345 kV and above. The voltage and current on the transmission lines produce EMF, while corona discharges occurring near high-voltage conductors produce AN and RN.[5] This section briefly describes each of these phenomena and identifies the applicable guidelines and standards for each in assessing the potential health and environmental effects. A summary of the assessment criteria is provided at the end of the section.

Electric and Magnetic Fields

Electric fields from high voltage conductors of transmission lines terminate on nearby grounded objects such as the earth. Electric-field levels increase as conductor voltage increases, and field levels diminish rapidly with distance from the source. Since each transmission line is typically designed to operate at a specific voltage, electric-field levels are generally stable over time. Electric fields at ground level can still vary, however, due to conductor height variation and the presence of nearby conducting objects. Conducting materials such as trees, fences, and walls can block or alter nearby electric fields. Electric fields are measured in units of volts per metre (V/m) or kilovolts per metre (kV/m), where 1 kV/m = 1,000 V/m.

Magnetic fields around transmission lines are produced whenever current flows through the conductors. Like electric-field levels, magnetic-field levels diminish rapidly with distance from the source. Unlike electric fields, magnetic fields are not readily blocked by most objects like trees, fences, and walls. Magnetic-field levels increase and decrease as current flow increases and decreases, as demand for electric power fluctuates over each day, week, or season. This electric power demand is often expressed as annual average load (which represents the electrical load most likely to be present on any randomly selected day of the year) and annual peak load (which estimates the peak electrical load that might occur for a few hours or days during the year). The magnetic

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[5] The localized discharge of energy in the form of light, AN, and RN that occurs at points on conductors when the voltage stress at these points exceeds the insulating capacity of air.

fields produced at average and peak loading of the transmission lines were calculated for this report. The magnitude of magnetic fields is most often expressed in units of magnetic flux density as measured in units of Gauss (G) or milligauss (mG) where 1 mG = 0.001 G. In Europe and many scientific publications, magnetic flux density is often reported in units of tesla or microtesla, where 1 mG = 0.1 microtesla.

AC electricity produces AC electric and magnetic fields. Since the power line voltage and current oscillates at a frequency of 60 Hz, so too do the resultant EMF.[6] These 60-Hz electric and magnetic fields are often referred to as power-frequency EMF. Outdoors, the most common sources of power-frequency EMF are power distribution and transmission lines, while inside the home the most common sources are household appliances. The highest magnetic-field levels in a residential setting are typically found next to appliances (Zaffanella, 1993), and Figure 3 shows the range of common exposure levels in various environments. Common magnetic-field levels next to appliances in homes range from a few mG up to over 1,000 mG, but rarely exceed a few hundred mG near transmission lines. Common electric-field levels next to appliances range from tens of V/m up to ~100 V/m, but may approach several kV/m near high voltage transmission lines or in specialized occupational environments. Outside of the ROW for transmission lines, however, electric-field levels are typically below 1 kV/m.

[6] DC transmission lines also produce electric fields, magnetic fields, and corona-generated AN, and RN. The electric fields and magnetic fields produced by a DC line, however, are static (i.e., they do not change at a rate of 60 Hz as do AC EMF) and so the fields from adjacent AC and DC lines are considered separately with regard to health assessments. The calculations of the electrical environment of the proposed BPIII DC transmission line are detailed elsewhere and are not reproduced here. When constructed on the same structure or side-by-side, however, the AN and RN from adjacent AC and DC lines will add such that the total level of nearby lines may need to be evaluated together.

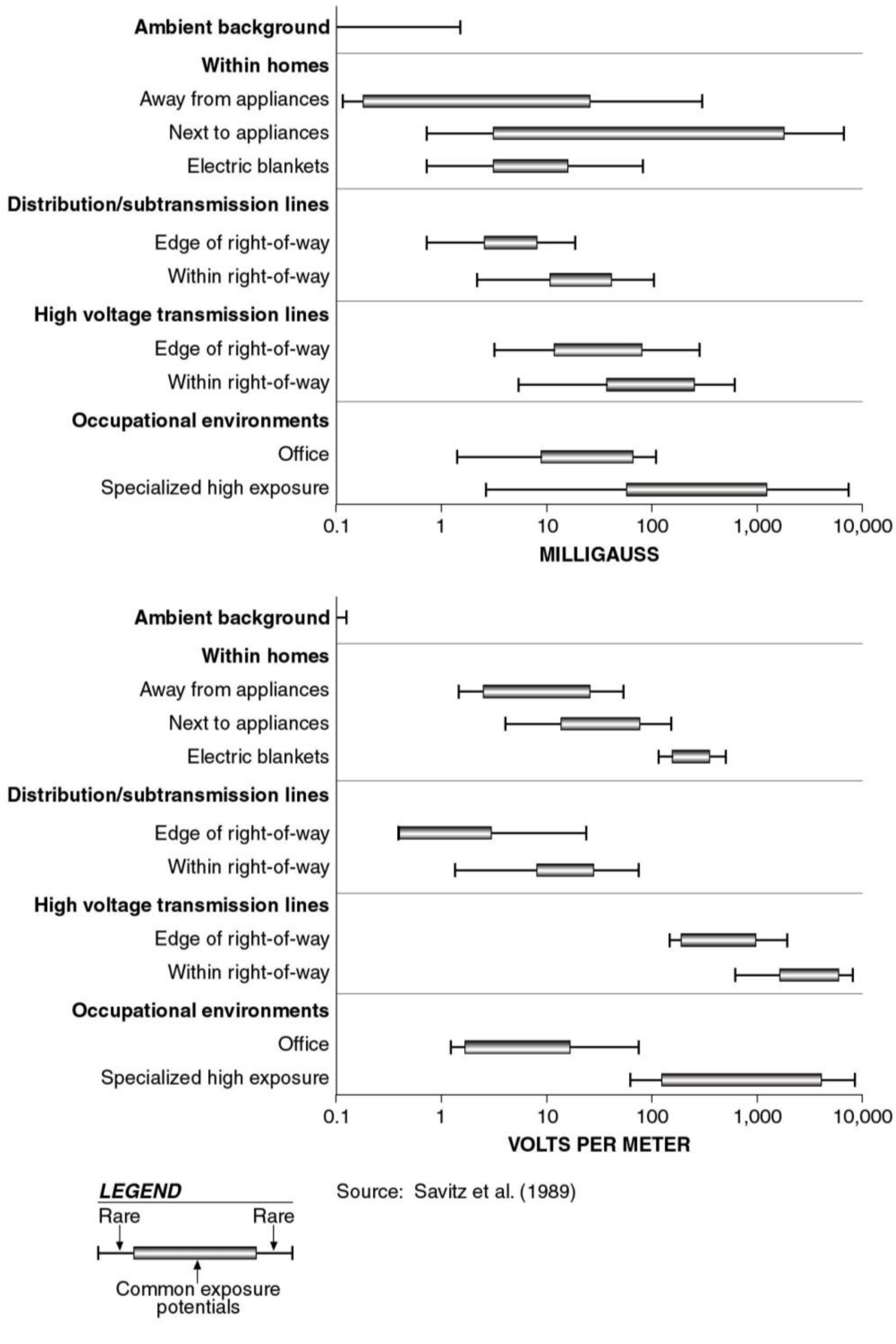

Figure 3. Typical electric and magnetic field levels in the environment.

Neither the federal Canadian government nor the province of Manitoba has regulations for EMF at power frequencies. Two international agencies, the International Commission on Non-ionizing Radiation Protection (ICNIRP) and the International Committee on Electromagnetic Safety (ICES) have developed standards and guidelines for limiting human exposure to power frequency EMF (ICES, 2002; ICNIRP, 2010). These guidelines were developed to protect public health and safety (higher limits are given for workers), and they base their exposure limits on extensive reviews and evaluations of relevant health research.

ICNIRP and ICES each specify both basic restrictions (BR) and reference levels for exposures of the general public and workers. The BRs limit the maximum recommended electric fields induced in body tissues. Since levels of electric fields induced in tissues are difficult to measure, the reference levels are provided as screening values to ensure that BRs 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 the BRs. Exposures expected to produce internal electric fields equal to the BRs can be derived by applying mathematical modeling described by Kavet et al. (2012). Reference levels for public exposure to EMF are summarized in Table 1.

Table 1. Reference levels and projected levels of electric fields meeting BRs for whole body exposure to 60 Hz EMF (General Public)

Agency	Magnetic Fields (mG)	Electric Fields (kV/m)
ICNIRP	2,000	4.2 36.4*
ICES	9,040	5.0 26.8*

* BRs computed according to Kavet et al. (2012).

Electric field-Induced Currents

The electric fields from transmission lines can couple to conductive objects so as to raise their electric potential with respect to ground. If the field and the object are both large enough, there is the potential for electrical discharge to a person touching the object. This only occurs if a large conductive object is insulated from ground, such as a large vehicle parked under a transmission line. In this situation, the electric field from the line causes electric charges within the conductive object to redistribute. If a person touches the conductive object, then an induced electric current may flow through the individual to ground when in contact or from a spark discharge.[7] The induced current will increase with larger vehicles, transmission lines with lower clearances to ground, and lines operating at higher voltages.

To limit induced currents and spark discharges to safe levels, both the 2015 Canadian Standards Association (CSA) standard for overhead systems and the 2012 American National Electrical Safety Code (NESC) provide design guidelines to limit the short-circuited induced current under overhead transmission lines to less than 5 Milliampere (mA).[8] This is also the minimum trip level for a ground fault circuit interrupter outlet for a 5 second contact. The CSA specifies minimum vertical design clearances above ground for overhead transmission lines as a function of both line voltage and location, which are intended to ensure compliance with the 5 mA limit (CSA, 2015). These clearances assume specific transmission line configurations and maximum vehicle sizes for the worst case scenarios. Near roadways, for example, CSA clearance requirements assume a large tractor-trailer that is 23.0 m long, 2.6 m wide, and 4.15 m high. Near farmland, clearance requirements assume a large farm vehicle that is 7.6 m long, 2.4 m wide, and 4.15 m high (CSA, 2015).[9]

To evaluate the induced currents that could be produced by the proposed MMTP project, the vertical clearance in each section was compared to clearances specified by CSA (2015). These vertical design clearances of wires and conductors above ground are summarized in Table 2 for a 500-kV AC line.

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7 A spark discharge may occur just prior to the moment of direct contact or just after breaking contact with the conducting object. These induced currents and spark discharges can occur, for example, when a person contacts a large vehicle that is parked below overhead transmission lines. Spark discharges are not specifically addressed in either the CSA or the NESC.

8 CSA (2015) refers to this as the “5 mA let go” limit because most individuals can still let go of a charged conductor at currents below this limit (Dalziel and Massoglia, 1956). Meeting this limit for short-circuited induced currents for the an assumed short circuit scenarios ensures that the current would not cause “grip tetanus” or muscle contractions that could cause an individual to be unable to let go. In practical cases, however, induced currents are typically below these short-circuited values because the average individual wearing shoes does not provide a short-circuited path to ground (e.g., IEC60479-1 – 2005).

9 For the induced current calculations for farmland performed in this report, a John Deere S680 combine whose main truck is 8.5 m long, 3.7 m wide, and 3.8 m high was used to represent the largest expected vehicle. These vehicle dimensions produce slightly larger induced current levels than the large farm vehicle dimensions specified by CSA (2015), thus providing a more conservative analysis.

Table 2. Vertical design clearance of wires and conductors above ground or rails for 500-kV AC transmission lines

Location	Minimum Clearance (m)
Roadways likely to be traveled by vehicles	15.4
Farmland likely to be traveled by vehicles	9.9
Alongside roadways in areas unlikely to be traveled by vehicles	7.2
Over ground normally accessible only to pedestrians, snowmobiles, and personal-use vehicles	6.3
Over the ROW of underground pipelines	9.9
Above the top of rails at railway crossings	10.7

Source: CSA, 2015

Since these clearances were calculated assuming specific conductor configurations and vehicle sizes that may not exactly match the transmission line configurations for MMTP, the safety of the proposed a transmission line was more precisely evaluated by directly computing induced currents. The short-circuit induced current produced beneath the existing and proposed overhead transmission lines was computed for vehicle placements resulting in maximum induced current and compared to the 5 mA limit.

Audible and Radio Noise

Both AN and RN can be produced by corona discharge at points along the transmission line conductors, especially in foul weather. If the localized electric field at the conductor surface exceeds the breakdown strength of air, corona discharge occurs, usually within a few centimeters of the conductor. The rapid expansion of air from the discharge produces AN, and the resulting small amount of current flow produces RN. Corona activity at transmission line conductors can also produce trace amounts of ozone and oxides of nitrogen. Measurements of gases downwind of transmission lines show that the production of ozone and oxides of nitrogen is insignificant and does not increase ambient concentrations at ground level even for transmission lines operating at much higher voltages (Roach et al., 1974, 1978; Sebo et al., 1976). Corona discharge occurs most readily near sharp points on high-voltage conductors where the concentration of charge in a small volume results in higher local electric fields. Transmission lines are designed to be smooth and thus avoid corona discharges in fair weather. During foul weather, however, droplets of precipitation on the conductor surface form conductive protrusions that result in increased electric fields and more readily generate corona.[10] Another factor that affects corona (and thus AN and RN) is altitude. At higher altitudes, the breakdown strength of air decreases and thus corona discharge is likely to increase. As a result, AN and RN are most pronounced during foul weather and increases with increasing altitude above sea level.

The AN produced by corona on AC transmission lines is typically heard as a soft hissing or crackling sound in foul-weather conditions that may be accompanied by a 120 Hz hum. AN, like all acoustic waves, decreases with distance from the source and can be absorbed or re-directed by walls, trees, or other solid objects. If there is sufficient corona activity and the ambient background noise level from other sources is low, the AN from transmission lines can be heard outside the ROW. AN also can be produced by substation equipment, such as transformers and transformer fans. Transformer noise is caused by vibration of the steel in the transformer core that generates AN at 120 Hz and higher frequency multiples.

AN is typically reported in units of decibels on the A-weighted scale (dBA) relative to the pressure threshold of human hearing at 1 kilohertz (kHz) (20 micropascals). A-weighting accounts for the relative loudness perceived by the human ear across different frequencies, and reporting values relative to the threshold of human hearing provides a convenient reference point. Some commonly encountered acoustic sources and their associated AN levels are presented in Table 3. Included in this table are Manitoba's Provincial Guidelines for maximum desirable 1-hour equivalent noise levels for residential and commercial areas. Manitoba's Provincial Guidelines specify a nighttime limit of 45 dBA and a daytime limit of 55 dBA (EMD, 1992). The nighttime limit of 45 dBA was used as the criterion for assessing the AN produced by MMTP.

[10] Additional protrusions such as dust, pollen, and insects can also result in increased corona activity.

Table 3. Commonly encountered acoustic sources and audible noise levels

Source	A-weighted sound level (dBA)
Auto horn	110
Inside subway	95
Traffic	75
Conversation	65
Office	55
Manitoba Provincial Guideline (Night–Day)*	**45–55**
Living Room	45
Library	35
Quiet rural area	30-40
Bedroom	24
Hearing Threshold	0

*Maximum desirable 1-hour equivalent noise levels for residential and commercial areas (EMD, 1992).

The RN represents electromagnetic interference that can affect reception of radio signals. While RN from a transmission line can exist over a wide range of frequencies, its magnitude decreases rapidly with increasing frequency above 1 megahertz (MHz). As a result, radio receivers that operate at lower frequencies (such as amplitude-modulated radio at 0.52 to 1.72 MHz) are more susceptible to interference than devices that operate at higher frequencies (such as frequency-modulated radio at 88 to 108 MHz). Transmission lines in Canada are evaluated for compliance with design guidelines that vary with the voltage of the line. Industry Canada (IC, 2013) recommends an acceptable RN level of 60 decibels relative to 1 microvolt per metre (dBµV/m)[11] for 500-kV transmission lines and transmission substations. The Institute of Electrical and Electronics Engineers (IEEE) has recommended an acceptable level of 61 dBµV/m, as measured at a frequency of 500 kHz and at a distance of 15 m from the outside conductor under fair-weather conditions (IEEE 1971, 1986).

[11] These units of dBµV/m are decibels relative to 1 µV/m, where 10^6 µV/m = 1 V/m.

Summary of Assessment Criteria

The primary environmental assessment criteria for EMF, AN, and RN, as detailed throughout this section, are summarized in Table 4.

Table 4. Environmental assessment criteria for 60-Hz EMF, AN, and RN relevant to transmission lines

Electrical Parameter	Limit	Agency providing guideline (year)	Comment
Electric field	4.2kV/m*	ICNIRP (2010)	General public exposure
	5.0kV/m*	ICES (2002)	
	10kV/m	ICES (2002)	General public limit on transmission ROW
Induced currents	5 mA	CSA (2015)	Short-circuit induced current
Magnetic field	2,000 mG	ICNIRP (2010)	General public exposure
	9,040 mG	ICES (2002)	
Audible noise	45–55 dBA†	EMD (1992)	Outdoors in residential and commercial areas for nighttime–daytime
Radio noise	60 (dBµV/m)‡	IC (2013)	Measured at 15 m horizontal distance from the conductor in fair weather
	61 (dBµV/m)§	IEEE (1971)	

* Reference level. BRs computed from Kavet et al. (2012) at 60 Hz provide higher limits. See Table 1.
† Maximum desirable 1-hour equivalent noise levels for residential and commercial areas as specified by the Manitoba Provincial Guidelines. The lower limit is for nighttime conditions and the upper limit is for daytime (EMD, 1992).
‡ For transmission lines and transmission substations with nominal phase-to-phase voltage of 401-600 kV.
§ 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).

Methods

Transmission Line Calculations

EMF, AN, and RN levels were calculated using computer algorithms developed by the Bonneville Power Administration, an agency of the U.S. Department of Energy (BPA, 1991). These algorithms have been shown to accurately predict field and noise levels near transmission lines (IEEE, 1982; Chartier and Dickson, 1990; Perrin et al., 1991; Olsen et al., 1992). The inputs to the algorithm include voltage, current, phasing, and conductor configurations for each transmission line on the ROW. These input data were provided by Manitoba Hydro. Each of the nine transmission line sections was evaluated for existing and proposed configurations, and for average and peak loading.

For each section of the ROW, Exponent calculated EMF, AN, and RN levels at mid-span between structures along a transect perpendicular to the centerline of the transmission line midway between the supporting structures for the existing and the proposed configurations. Midway between structures is where conductors are closest to the ground, and therefore calculations at this location typically yield the highest levels of EMF, AN, and RN.

EMF levels were calculated at 1 m above ground as the root mean square value of the field in accordance with IEEE Std. C95.3.1-2010 and IEEE Std. 644-1994 (Rev. 2008). The voltages of all transmission lines were assumed to be in phase, and both electric and magnetic fields were calculated as the resultant of the x, y, and z field vectors. Each conductor was modeled as infinite in length at a fixed height above a flat, infinite earth, and was assumed to be parallel to all other conductors.

Electric field, AN, and RN levels were computed assuming a 5% overvoltage condition for circuits of line voltage less than or equal to 345 kV and a 10% overvoltage condition for circuits of voltage greater than 345 kV. This ensures that all calculated values represent the maximum expected values.

Induced currents were calculated using formulae outlined by the Electric Power Research Institute (EPRI, 1982, Section 8.8) for the largest anticipated vehicle or equipment under the line. The electric field at 1 m above ground was computed as discussed above. Different vehicle shapes and conductor heights were applied depending on the location. For lines passing over or alongside roadways likely to be traveled by vehicles, conductors are higher above ground and the largest anticipated vehicle is a tractor-trailer that is 23.0 m long, 2.6 m wide, and 4.15 m high, as recommended by CSA (2015, A.5.3.1). For lines passing over or alongside farmland likely to be traveled by vehicles, conductor heights may be lower and the largest anticipated farm vehicle indicated by CSA is 7.6 m long, 2.4 m wide, and 4.15 m high, similar to a John Deere S680 combine whose main truck is 8.5 m long, 3.7 m wide, and 3.8 m high. Since the John Deere S680, which is approximately the largest farm vehicle expected to be used in Manitoba, produces larger induced current values than the large farm vehicle indicated by CSA, the John Deere S680 was used in calculations for farmland to facilitate a conservative evaluation. If the vehicle is oriented parallel to the transmission lines, then the maximum electric-field value on the ROW is directly applied as the uniform electric-field value for induced current calculations. This provides the most conservative induced current estimate. If the vehicle is oriented perpendicular to the transmission lines, then the equivalent uniform electric field is calculated by averaging the electric-field components over the effective length of the vehicle. This equivalent uniform electric field was calculated for each possible vehicle position along the ROW, and the maximum value was used in induced current calculations.

AN and RN levels associated with the transmission lines were calculated for fair-weather conditions as specified in the guidelines, and for an altitude of 340 m above mean sea level, which is the maximum altitude along the MMTP route. These fair-weather values were obtained by calculating the AN and RN levels for foul weather, and then subtracting 25 dBA and 17 dBμV/m, respectively, as recommended by the Bonneville Power Administration. AN levels were calculated at a sound-receiver height of 5 feet above ground, corresponding roughly to ear level, and the L_{50} values are presented (i.e., the median levels; levels exceeded 50 percent of the time). RN levels were calculated assuming a receiving antenna height of 1 m above ground and a frequency of 500 kHz in accordance with IEEE Std. 430-1986.

Section F of the MMTP route is unique in that it shares the ROW with a DC transmission line. As was shown in Figure 2, this section includes a future ±500-kV BPIII DC transmission line located 33 m from the north ROW edge and approximately 115 m from the proposed 500-kV structure that will carry the D602F load. This DC line is not included in the present AC analysis, and evaluation of Section F focuses instead on the southern half of the ROW, which contains the D604I and D602F lines. In general, both ICNIRP (2010) and ICES (2002) recommend that upon simultaneous exposure to multiple frequency AC EMF, the exposures are additive in their effects and the sum of all frequency components should be considered. In this case, however, the AC and DC fields do not have significant additive effects on the internal electric field in tissue or induction, which are the limiting factors for exposure, and therefore the AC and DC fields were calculated and considered separately. For AN and RN, the contributions from the BPIII line were not included in calculations, but estimates of its contributions were derived from previous calculations.[12] The BPIII transmission line is more than 100 m from the nearest AC line on this ROW, far enough away to be considered separately in this context, and the analysis herein therefore focuses on the southern half of the ROW for Section F. Without consideration of the BPIII transmission line, there is no difference between Sections F and G regarding AN and RN sources.

Station Calculations

A brief discussion of EMF, AN, and RN levels for the proposed station modifications is also included. As will be discussed in the comparison to environmental assessment criteria, EMF levels at station boundaries are typically dominated by transmission or distribution lines entering and exiting the station and can be analyzed based on the transmission line calculations discussed above. RN can also be generated by station equipment, but levels typically decrease rapidly with distance. In the unlikely event that interference is encountered, simple mitigation techniques such as change of location or receiving antenna type can be effective. Other industry practices such as filtering or other mitigation techniques can also be applied to equipment directly.

AN levels can be locally dominated by station equipment and may require separate evaluation. In this report, several approximations were employed to estimate the maximum AN levels at the residences nearest to each station due to proposed MMTP modifications. Each primary noise-producing piece of equipment added to a station was modeled as a spherically-radiating noise source, and any reflections and attenuation of the generated AN were ignored. AN levels near each

[12] Bipole III Transmission Project Electromagnetic Fields (EMF) Technical Report, November, 2011

piece of equipment and equipment dimensions were estimated based on equipment specifications, as specified in Table 5. The distance to the nearest residence has been estimated for each piece of equipment, and the AN contributions from each piece of equipment computed assuming the AN power from the source decreases with the square of the distance from the center of each noise source. AN contributions from multiple noise sources were summed to conservatively estimate the total AN level.

Table 5. AN specifications of equipment to be added to the Dorsey and Riel Converter Stations and the Glenboro South Station for MMTP.

Station	Equipment	Dimensions of Each (length x width x height)	AN Levels for Each
Dorsey	4 x 500-kV Reactors	5.8 x 10 x 8 m	84 dBA at 1 m distance
Riel	3 x Autophase Transformers	8.3 x 8.3 x 7.6 m	76 dBA at 2 m distance
Glenboro South	2 x Phase Shifting Transformers	16 x 9 x 10 m	87 dBA at 2 m distance

Modeling Results

This section summarizes the EMF, AN, and RN levels calculated for the nine representative sections of the MMTP route, as well as AN levels calculated for each of the three modified stations. The results are discussed for both existing and proposed configurations, and for average and peak loading. Changes to transmission line load directly affect only the magnetic-field levels, so differences between average and peak loading are discussed only for magnetic fields. Complete modeling results can be found in Appendices A and B. Calculated EMF, AN, RN, and induced current levels for all sections are summarized in Table A-1 through Table A-7 in Appendix A. Calculated profiles of EMF, AN, and RN along transects perpendicular to the ROW are shown in Figures B-1 through B-36 in Appendix B. Modeling results are discussed in this section; comparisons to the environmental assessment criteria can be found in the following section.

The maximum levels of EMF, AN, RN, and current induced in a very large vehicle along the MMTP route all occur in Sections F and G. These maximum values are dominated *not* by the transmission line supported on the proposed 500-kV structures, but by the existing 500-kV structure which currently supports the D602F line, located 38.1 m from the south ROW edge in Sections F and G. The transmission line supported on the existing 500-kV structures operates at the same voltage as the transmission line supported on the proposed 500-kV structures, but has lower conductor height (10.0 m vs 14.4 m).[13] The lower conductor height produces higher EMF, AN, RN, and induced current levels under the line and for some distance away from the line. The addition of the proposed 500-kV D604I line will have only a small effect in sections where the existing 500-kV D602F line is already present, so Sections F and G will often be discussed separately from other sections along the MMTP route, particularly with respect to EMF levels and induced currents.

[13] The transmission line supported on the proposed 500-kV structure will carry a larger load than the transmission line supported on the existing 500-kV structures in Sections F and G (1,000 megawatts [MW] vs 881 MW average loading; 1,770 MW vs 1,000 MW peak loading), due to the proposed swapping of loads in these sections, but the transmission line supported on the existing 500-kV structures still dominates the maximum calculated EMF, AN, RN, and induced current levels due to its lower conductor height.

Magnetic Fields

The maximum magnetic-field level under average loading anywhere along the edge of the MMTP ROW is calculated to increase by approximately 3 mG—from approximately 22 mG for existing configurations to 25 mG for proposed configurations. These maximum values occur in Sections F and G and are dominated by the transmission line supported on existing 500-kV structures in that section. The largest increase in magnetic-field level at a ROW edge (for sections where there are existing transmission lines on the ROW) at average loading occurs in Section A, where the proposed D604I line will be the only line on the eastern half of the ROW and the calculated value at the eastern ROW edge increases from 1.6 mG under existing configurations to 15 mG under proposed configurations.

At peak loading, the maximum magnetic-field level anywhere along the edge of the MMTP ROW is calculated to decrease from approximately 40 mG for existing configurations to 32 mG for proposed configurations (in Sections F and G). The decrease in magnetic-field level is due to the proposed swapping of loads between the D604I and D602F structures in Sections F and G, moving the larger load of the existing D602F line to the taller proposed 500-kV structure.[14] In sections where the proposed D604I line will be the only line above 300 kV (all Sections except F and G), the proposed MMTP will more noticeably increase magnetic-field levels on the ROW, but will still have only a small effect at the ROW edge and beyond.[15]

Calculated magnetic-field levels for all sections of the proposed MMTP route are summarized in Appendix A, Table A-1 and Table A-2 (for average and peak loading, respectively), and calculated profiles perpendicular to the ROW are shown in Appendix B, Figures B-1 through B-9. Values will be compared to the applicable environmental assessment criteria in the following section of the report.

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[14] The overall maximum magnetic-field level at average loading anywhere along the MMTP route decreases from 217 mG for existing configurations to 181 mG for proposed configurations (Sections F and G). At peak loading, values are higher: 384 mG for existing configurations and 225 mG for proposed configurations.

[15] In sections without the existing D602F transmission line, the maximum magnetic-field level at average loading increases from 61 mG for existing configurations to 125 mG for proposed configurations (both in Section B). At peak loading values are higher: 91 mG for existing configurations and 144 mG for proposed configurations.

Electric Fields

The maximum electric-field level at the ROW edge anywhere along MMTP route under existing configuration of lines is 0.7 kV/m (Section H) and 0.8 kV/m under proposed configurations (Section E2). The largest increase in electric-field level at a ROW edge (for sections where there are existing transmission lines on the ROW) occurs in Section B, where the proposed D604I line will be the only line on the southern half of the ROW and the calculated value at the southern ROW edge increases from 0.1 kV/m under existing configurations to 0.5 kV/m under proposed configurations.

Where the existing 500-kV D602F line is present in Sections F and G, the addition of the proposed 500-kV D604I line will have only a small effect on the existing levels of electric field on the ROW and beyond.[16] In sections where the proposed D604I line will be the only line above 300 kV, the proposed MMTP will more noticeably increase electric-field levels on ROW, but will still have only a small effect at the ROW edge and beyond.[17]

Calculated electric fields for all sections of the proposed MMTP route are summarized in Appendix A, Table A-3, and calculated profiles perpendicular to the ROW are shown in Appendix B, Figures B-10 through B-18. Values will be compared to the applicable environmental assessment criteria in the following section of the report.

Electric field-Induced Currents

The maximum induced current value at roadway crossings (for a tractor-trailer oriented perpendicular to the transmission lines) increases by 0.2 mA from 3.1 mA (Sections F and G) under existing configurations to 3.3 mA (Sections E2, F, G, and H) under proposed configurations. The maximum induced current value for a John Deere S680 combine oriented parallel to the transmission lines is 5.6 mA (Sections F and G) for both existing and proposed configurations. This maximum value is dominated by the transmission line supported on existing 500-kV structures in these sections and will not noticeably increase following the addition of the proposed transmission line.

[16] The overall maximum electric-field level across the ROW, anywhere along the MMTP route, increases from 9.9 kV/m for existing configurations to 10.0 kV/m for proposed configurations (Sections F and G)

[17] In sections without the existing D602F transmission line, the maximum electric-field level increases from 3.0 kV/m for existing configurations (Section A) to 5.9 kV/m for proposed configurations (Section E2)

In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents.

Excluding Sections F and G, the maximum induced current value for farmland increases from 1.7 mA (Sections A and B) under existing configurations to 3.3 mA (Sections B, C, D, and E2) under proposed configurations.

Maximum calculated induced currents for all conductor height and vehicle orientation scenarios for each section are presented in Appendix A, Table A-6 for the tractor trailer and Table A-7 for the John Deere S680. For each section and scenario, only the maximum calculated induced current level is presented for a vehicle at the location producing the highest induced current. As discussed above, the most informative scenarios for assessing induced currents are: a tractor-trailer oriented perpendicular to the transmission lines for roadway crossings, and a John Deere S680 oriented parallel to the transmission lines for farmland. For both roadway crossings and farmland outside the RVTC, the calculated values for these scenarios are 3.3 mA. Results for additional exposure scenarios are provided in Appendix A for reference. For example, if a tractor trailer was oriented parallel to the overhead transmission lines at a roadway crossing, the maximum induced current level would be ≤4.9 mA under both existing and proposed configurations.

Audible Noise

The largest AN level anywhere along the edge of the MMTP ROW increases by approximately 1 decibel (dB); from 22 dBA for existing configurations to 23 dBA for proposed configurations in fair weather. These largest values occur in Sections F and G and are dominated by the transmission line supported by the existing 500-kV structures. If the contribution of the BPIII DC line were included in Section F, the calculated AN at the southern edge of the ROW would rise by about 4 dB.[18,19] The

[18] In foul weather, the added contribution from BPIII at the southern ROW edge would be less than 0.1 dB.

largest increase in AN level at a ROW edge (for sections where there are existing transmission lines on the ROW) occurs at the southern edge of the ROW in Section D, where the calculated value increases from approximately 5 dBA for existing configurations to 17 dBA for proposed configurations.

Calculated fair-weather AN levels for all sections of the proposed MMTP route are summarized in Appendix A, Table A-4, and calculated profiles perpendicular to the ROW are shown in Appendix B, Figures B-19 through B-27. In foul weather, the AN levels would be 25 dB higher at all locations. Values will be compared to the applicable environmental assessment criteria in the following section of the report

Radio Noise

The maximum fair weather RN value calculated at a 15 m distance from the conductors closest to the edge of ROW is approximately 48 dBµV/m for both existing and proposed configurations. This value of 48 dBµV/m occurs in nearly every section where a 500-kV line is closest to an edge of the ROW.[20] For sections where there are existing transmission lines on the ROW, the largest increase due to the proposed MMTP occurs in Section D, where the calculated RN value at 15 m south of the southern-most conductor increases from 36 dBµV/m to 48 dBµV/m.

Calculated fair-weather RN levels for all sections of the proposed MMTP route are summarized in Appendix A, Table A-5, and calculated profiles perpendicular to the ROW are depicted in Appendix B, Figures B-28 through B-36. In foul weather, the RN levels would be 17 dB higher at all locations. Values will be compared to the applicable environmental assessment criteria in the following section of the report

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19 AN levels from the BPIII line were taken from the Bipole III Transmission Project Electromagnetic Fields (EMF) Technical Report, November, 2011.

20 If the contribution of the BPIII DC line were included in Section F, these maximum calculated RN values (located at 15 m south of the southern-most conductor in Section F) would increase by less than 0.1 dBµV/m.

Station Audible Noise

In addition to a new 500-kV transmission line, equipment needs to be installed at several stations to accommodate the new line. Very conservative estimates likely to yield high AN values were made of the estimated AN levels at the residences nearest each of these stations and are summarized in Table 6. The contribution of this equipment to background AN levels is expected to be greatest at the Glenboro South Station, where the equipment to be added is a pair of phase shifting transformers.

Table 6. Conservative AN calculations at residences nearest the stations with proposed MMTP modifications

Station	AN Level at Nearest Residence
Dorsey	52 dBA
Riel	44 dBA
Glenboro South	55 dBA

Comparison to Environmental Criteria and Discussion

Electrical parameters associated with transmission lines were evaluated in comparison to the environmental assessment criteria for EMF, AN, RN, and induced currents identified previously in this report. These comparisons are summarized in Table 7 and Table 8.

Electric and Magnetic Fields

The highest calculated electric-field at the edge of the ROW for any section of the route is 0.8 kV/m. This value is well below the recommended reference levels for public exposure, which are 4.2 kV/m (ICNIRP, 2010) and 5.0 kV/m (ICES 2002). The highest calculated electric-field level on the ROW, where the general public can be expected to spend a limited amount of time, is 10 kV/m. ICES (2002) provides separate guidelines for electric-field levels on a ROW, recommending that they do not exceed 10 kV/m. CSA (2015) also refers to this 10 kV/m recommendation and further notes that it is based on comfort, stating that electric-field levels may exceed 10 kV/m for voltage classes 200 kV and greater. ICNIRP does not discuss separate guidelines for within a ROW, but notes that in cases where reference levels are exceeded, further analyses and computations are needed to demonstrate compliance with the BRs. Exposures expected to produce internal electric fields equal to the BRs can be derived by applying mathematical modeling such as those described by Kavet et al. (2012). The maximum electric field on ROW is well below the electric-field level of 36.4 kV/m, calculated by Kavet et al. (2012), based on ICNIRP guidelines (2010). So neither the calculated electric-field levels on the ROW nor the calculated electric-field levels at the edge of the ROW exceed the applicable guidelines recommended by ICNIRP, ICES, and CSA.

The highest calculated magnetic-field levels are 25 mG at the ROW edge and 181 mG on the ROW for average loading, and 32 mG at ROW edge and 225 mG on the ROW for peak loading. These values are all well below the reference levels for public exposure, which are 2,000 mG (ICNIRP, 2010) and 9,040 mG (ICES, 2002).

Electric Field-Induced Currents

The minimum vertical clearance of the proposed D604I line is 16.6 m at roadway crossings and 14.4 m in rural areas and near farmland. The clearances required to meet the CSA (2015) requirements to minimize currents induced in large vehicles by electric fields at these locations are 15.4 m and 9.9 m, respectively. The highest calculated induced current value for the most typical scenarios of roadway crossings (tractor trailer oriented perpendicular to the transmission lines) is 3.3 mA, and for farmland (John Deere S680 combine oriented parallel to the transmission lines) is also 3.3 mA when excluding Sections F and G. These values are below the 5.0 mA guideline cited by both CSA (2015) and NESC (2012).[21]

The highest calculated induced current value for farmland, considering all sections of the route, is 5.6 mA in Sections F and G, which is just above the CSA guideline of 5.0 mA. In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents. As construction of infrastructure in the RVTC continues, Manitoba Hydro will manage and monitor the use of the corridor.

Audible Noise

Sensitivity to AN is affected by ambient noise conditions, so the same level of AN from a transmission line is perceived differently in quiet conditions compared to noisy conditions. The highest median fair-weather edge-of-ROW AN level anywhere along the proposed route is approximately 23 dBA, which would result in an inaudible increase (less than 1 dB) above the

[21] While EPRI (1982) recommends that induced currents at roadway crossings be evaluated for perpendicular vehicle orientation, producing the results discussed above, roadway crossings can also be evaluated assuming a theoretical parallel vehicle orientation. If the tractor trailer were oriented parallel to the overhead transmission lines at roadway crossings and positioned at the location of the highest electric-field level on the ROW, the maximum induced current would be 2.3 mA, which is still below the 5.0 mA guideline.

ambient noise level of 30-40 dBA, typical of a quiet rural location (USEPA, 1974).[22] Thus, AN from the MMTP project is expected to have a negligible effect on ambient noise levels, and total sound levels would remain well below the Manitoba Provincial Guidelines of 45 dBA for nighttime outdoor conditions in residential and commercial areas, and 55 dBA for daytime conditions. During foul weather, the calculated levels of AN are higher, but the wind and rain that typically occur are themselves likely to generate ~41-63 dBA of AN and would likely mask the noise from the transmission lines during these conditions (Miller, 1978).

Radio Noise

RN levels were compared to the fair-weather IEEE (1971) and Industry Canada (2013) recommended limits for 15 m beyond the outermost conductor of 61 dBμV/m and 60 dBμV/m, respectively. The maximum RN level at such a location along the proposed MMTP route is approximately 48 dBμV/m, which is more than 12 dB below the recommended limits.[23] Historically, transmission-line operators have not had difficulty avoiding the production of harmful radio interference. Under fair-weather conditions, most sources of RN from power lines are due to gap-type discharges that can be identified and repaired (USDOE, 1980).

Station EMF, AN, and RN

Maximum EMF levels near converter stations and substations are typically dominated by the EMF generated by the transmission lines entering and exiting the station. IEEE Standard 1127 (1990) notes that "electric and magnetic fields attenuate sharply with distance [from the substation] and will often be reduced to a general ambient level at the substation property lines. The exception is where transmission or distribution lines enter the substation." Thus, EMF levels near the Dorsey and Riel Converter Stations and the Glenboro South Station are not expected to exceed those discussed above for each of the transmission line sections. RN levels may increase near stations if issues such as gap discharges occur in the station equipment, but such issues can be identified and repaired if they occur. In general, RN levels are not expected to significantly exceed those produced by each of the

[22] The just-noticeable-difference necessary for the human ear to be able to detect a change in the AN level is 3 dB (Hansen, 2001)

[23] In the majority of sections (all ROW edges except the west side of Section C) RN levels at the ROW edge are lower than at a distance of 15 m from the conductor nearest the ROW edge.

transmission line sections as discussed above. Furthermore, the land surrounding each station is zoned for agricultural use,[24] and Manitoba Hydro owns a significant amount of land surrounding each station such that the distance from each station to the nearest residence is significantly larger than the widths of any of the transmission line ROWs. The shortest distances from site boundaries of the Dorsey and Riel Converter Stations and the Glenboro South Station to the residences nearest each are approximately 462, 538, and 582 m, respectively. The widest ROW for any of the nine sections of the MMTP transmission line route is 232 m. So a significant distance exists between each of the stations and the nearest residences, and EMF and RN levels due to the station equipment would not increase the typical range of background levels.

AN levels due to equipment added at each station are conservatively calculated to be as high as 52 dBA at the residence nearest to Dorsey Converter Station, 44 dBA at the residence nearest to Riel Converter Station, and 55 dBA at the residence nearest to Glenboro South Station. These do not exceed the 55 dBA daytime guideline for maximum desirable 1-hour equivalent noise levels for residential and commercial areas as specified by the Manitoba Provincial Guidelines, but several do exceed the 45 dBA nighttime guideline (EMD, 1992). These calculated values, however, were based on several modeling simplifications to ensure the most conservative levels are presented, and several established mitigation procedures exist for lowering these noise levels if they should prove to be a nuisance. The AN levels at the nearest residence will likely be lower if each piece of equipment does not behave as an ideal spherical source, or if any plants or structures absorb or reflect the radiated AN before it reaches the nearest residence. Furthermore, over 10 dB of noise reduction is readily achievable via passive techniques such as the construction of sound-attenuating barriers. AN levels associated with the equipment to be added at the Glenboro South Station and the Dorsey Converter Station may warrant further investigation with more precise calculations and measurements, but the highest AN level estimates are already below the recommended daytime guidelines, and it is expected that appropriate mitigation procedures would be able to lower the AN levels below the recommended nighttime guidelines in the event that AN is found to be a nuisance.

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[24] Dorsey Converter Station in RM of Rosser is zoned a combination of “AL – Limited Agriculture” and “A80 – Agricultural Zone.” Riel Converter Station in RM of Springfield is zoned “AG – Agricultural General Zoning District.” Glenboro South Station in RM of South Cypress is zoned “AML – Agricultural (Moderately Limited) District”.

Summary

A summary of the calculated values of magnetic field, AN, and RN for the transmission line sections of the proposed MMTP project is provided in Table 7. A summary of the calculated values for electric field and induced currents is provided in Table 8. Applicable environmental assessment criteria are provided in each table for comparison to these calculated values (repeated from Table 4).

Table 7. Comparison of calculated AC magnetic field, audible noise, and radio noise for the proposed MMTP project to environmental assessment criteria

	Magnetic Field at Average Load (mG)		Magnetic Field at Peak Load (mG)		Fair Weather Audible Noise (dBA)	Fair Weather Radio Noise (dBμV/m)	
Agency	ICNIRP (2010)	ICES (2002)	ICNIRP (2010)	ICES (2002)	EMD (1992)	IEEE (1971)	IC (2013)
Limit	2,000	9,040	2,000	9,040	45–55*	61†	60‡
Section	ROW Edge		ROW Edge		ROW Edge	15 m from conductor	
A	15		17		20	48	
B	14		15		21	48	
C	5.1		5.8		18	36	
D	5.0		5.8		17	48	
E1	20		22		20	48	
E2	21		24		20	47	
F	25		32		23	48	
G	25		32		23	48	
H	13		14		22	48	

* Maximum desirable 1-hour equivalent noise levels for residential and commercial areas as specified by the Manitoba Provincial Guidelines. The lower limit is for nighttime conditions and the upper limit is for daytime (EMD, 1992).

† 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).

‡ For transmission lines and transmission substations with nominal phase-to-phase voltage of 401-600 kV.

Table 8. Comparison of calculated electric field and induced currents for the proposed MMTP project to environmental assessment criteria

Agency	Electric Field (kV/m) ICNIRP (2010)	Electric Field (kV/m) ICES (2002)	Induced Currents Roadways* (mA) CSA (2015)	Induced Currents Farmland† (mA) CSA (2015)
Limit	4.2	5.0	5.0	5.0
Section	ROW Edge		Max on ROW	Max on ROW
A	0.5		3.2	3.2
B	0.5		3.2	3.3
C	0.2		3.2	3.3
D	0.1		3.2	3.3
E1	0.7		3.2	3.2
E2	0.8		3.3	3.3
F	0.7		3.3	5.6‡
G	0.7		3.3	5.6‡
H	0.7		3.3	3.2

* Induced currents at roadway crossings are computed for roadway conductor height specifications and a tractor-trailer (23.0 m long, 2.6 m wide, 4.15 m tall) oriented perpendicular to the transmission lines.

† Induced currents for farmland are computed for farmland conductor height specifications and a John Deere S680 (8.5 m long, 3.7 m wide, 3.8 m tall) oriented parallel to the transmission lines.

‡ In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents. As construction of infrastructure in the RVTC continues, Manitoba Hydro will manage and monitor the use of the corridor.

Conclusion

This report evaluated the levels of EMF, AN, RN, and induced current associated with the operation of the lines and substation equipment included in the proposed MMTP project. These levels were compared to applicable environmental and health assessment criteria. The modeling shows that the proposed MMTP project will have only a very small effect on the sections of the route with existing 500-kV transmission lines. An increase in calculated values will occur on sections of the route without existing 500-kV transmission lines, but the resulting values will be lower than for the sections of the route with existing 500-kV transmission lines.

The highest magnetic-field levels on the ROW will decrease due to the proposed swap of the existing D602F load to the taller proposed 500-kV structures in Sections F and G. Values at some ROW edges are calculated to increase slightly following the proposed MMTP project, but throughout the route magnetic-field levels are calculated to remain well below recommended limits used to assess potential effects on humans. At the edges of the ROW the magnetic field will continue to be more than 50 time lower than the reference levels recommended by ICES and ICNIRP.

The electric field at ROW edges also will be far below the electric-field reference levels recommended by the ICES and ICNIRP standards. On the ROW the induced current values are calculated to be below the 5.0 mA CSA guideline, except for farmland in Sections F and G. In the RVTC the induction level associated with the transmission lines is just above the CSA recommended limit of 5 milliamperes for the largest farm combine in the Province. While the RVTC is owned 100% by Manitoba, the land is, in some instances, being used for farming activities. In order to mitigate any potential issues associated with induction to such a large vehicle, Manitoba Hydro will reinforce standard electrical safety messages and educate farmers in the RVTC about appropriate safety measures associated with induced currents. As construction of infrastructure in the RVTC continues, Manitoba Hydro will manage and monitor the use of the corridor. The proposed D604I line also meets all vertical clearance requirements specified by the CSA for overhead systems.

The AN and RN levels from the transmission lines both remain well below the associated fair-weather assessment criteria. AN levels at ROW edge are below typical ambient noise levels for even a quiet rural location, so the total AN levels at the ROW edge near the MMTP route will typically be dominated by ambient noise (e.g., 30-40 dBA) and not by the transmission lines. Total ambient AN levels at ROW edge are estimated to be 5 to 15 dBA below the Manitoba Provincial Guidelines for residential and commercial areas, and should increase by less than 1 dB due to MMTP. AN levels associated with substation equipment additions for Glenboro South Station and Dorsey Converter Station are calculated to be at or below the 55 dBA daytime guideline, but exceed the 45 dBA nighttime guideline. It is likely, however, that more accurate calculations or the implementation noise mitigation procedures would lower these AN levels below nighttime guidelines as well. RN levels at 15 m beyond the outer conductor are dB or more below the limits recommended by the IEEE and Industry Canada.

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Appendix A

Summary Tables of Calculated EMF, AN and RN

Table A-1. Magnetic-field levels (mG) at average loading for existing and proposed configurations

Section	Existing/Proposed	Location				
		30 m beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	30 m beyond +ROW edge
A	Existing	3.4	7.0	55	1.6	1.1
	Proposed	3.3	6.8	117	15	5.9
B	Existing	3.3	9.2	61	2.6	1.5
	Proposed	3.4	11	125	14	5.1
C	Existing	1.7	3.1	30	1.2	0.6
	Proposed	2.8	5.1	117	4.9	2.7
D	Existing	0.5	1.0	9.8	0.2	0.2
	Proposed	2.6	4.5	117	5.0	2.8
E1	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	6.9	20	118	20	6.9
E2	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	7.4	21	122	21	7.4
F	Existing	0.7	0.9	217	22	7.4
	Proposed	1.9	2.6	181	25	9.6
G	Existing	0.7	0.9	217	22	7.4
	Proposed	1.9	2.6	181	25	9.6
H	Existing	0.3	0.4	24	11	2.3
	Proposed	5.2	13	119	9.4	1.7

Table A-2. Magnetic-field levels (mG) at peak loading for existing and proposed configurations

Section	Existing/Proposed	Location				
		30 m beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	30 m beyond +ROW edge
A	Existing	4.9	10	83	2.4	1.6
	Proposed	4.8	9.9	133	17	6.7
B	Existing	5.0	14	91	3.9	2.2
	Proposed	4.8	15	144	15	5.5
C	Existing	2.0	2.8	34	1.8	0.9
	Proposed	3.1	4.5	132	5.8	3.2
D	Existing	0.7	1.6	15	0.4	0.2
	Proposed	3.0	5.4	132	5.8	3.2
E1	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	7.9	22	134	22	7.9
E2	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	8.4	24	139	24	8.4
F	Existing	1.2	1.6	384	40	13
	Proposed	2.9	4.1	225	32	13
G	Existing	1.2	1.6	384	40	13
	Proposed	2.9	4.1	225	32	13
H	Existing	0.3	0.5	29	13	2.9
	Proposed	5.9	14	135	12	2.0

Table A-3. Electric-field levels (kV/m) for existing and proposed configurations

Section	Existing/Proposed	Location				
		30 m beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	30 m beyond +ROW edge
A	Existing	0.1	0.1	3.0	0.0	0.0
	Proposed	0.1	0.2	5.8	0.5	0.1
B	Existing	0.1	0.1	2.9	0.1	0.0
	Proposed	0.1	0.2	5.8	0.5	0.2
C	Existing	0.0	0.2	1.1	0.1	0.0
	Proposed	0.1	0.2	5.8	0.1	0.1
D	Existing	0.0	0.1	0.8	0.0	0.0
	Proposed	0.1	0.1	5.8	0.1	0.1
E1	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	0.2	0.7	5.7	0.7	0.2
E2	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	0.2	0.8	5.9	0.8	0.2
F	Existing	0.0	0.0	9.9	0.6	0.2
	Proposed	0.0	0.0	10.0	0.7	0.2
G	Existing	0.0	0.0	9.9	0.6	0.2
	Proposed	0.0	0.1	10.0	0.7	0.2
H	Existing	0.0	0.0	1.0	0.7	0.1
	Proposed	0.1	0.4	5.8	0.7	0.1

Table A-4. Fair weather AN levels (dBA) for existing and proposed configurations*

Section	Existing/Proposed	Location				
		30 m beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	30 m beyond +ROW edge
A	Existing	13	15	21	11	10
	Proposed	16	17	25	20	18
B	Existing	14	17	21	13	12
	Proposed	18	20	26	21	19
C	Existing	13	15	21	12	10
	Proposed	17	18	26	18	17
D	Existing	7	9	15	5	4
	Proposed	16	17	25	17	16
E1	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	18	20	25	20	18
E2	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	17	20	24	20	17
F	Existing	13	14	28	22	19
	Proposed	16	17	29	23	21
G	Existing	13	14	28	22	19
	Proposed	16	17	29	23	21
H	Existing	11	12	22	20	16
	Proposed	18	20	25	22	19

* In foul weather, the AN values are calculated to be 25 dB higher in all locations.

Table A-5. Fair weather RN levels (dBμV/m) for existing and proposed configurations*

Section	Existing/Proposed	Location				
		15 m beyond −outside conductor	−ROW edge	Max on ROW	+ROW edge	15 m beyond +outside conductor
A	Existing	41	28	47	16	41
	Proposed	41	28	55	37	48
B	Existing	41	37	48	22	40
	Proposed	41	37	55	37	48
C	Existing	30	32	51	25	36
	Proposed	30	32	55	28	36
D	Existing	36	25	44	15	36
	Proposed	36	28	55	29	48
E1	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	48	39	55	39	48
E2	Existing	n/a	n/a	n/a	n/a	n/a
	Proposed	47	39	54	39	47
F	Existing	48	17	60	38	48
	Proposed	48	22	60	38	48
G	Existing	48	17	60	38	48
	Proposed	48	22	60	38	48
H	Existing	44	21	53	46	44
	Proposed	48	36	55	45	44

* In foul weather, the RN values are calculated to be 17 dB higher in all locations.

Table A-6. Maximum on ROW short-circuit induced current values (mA) for tractor-trailer (23.0 m long, 2.6 m wide, 4.15 m tall)

	Parallel Vehicle Orientation				Perpendicular Vehicle Orientation			
	Roadway Conductor Heights*		Farmland Conductor Heights*		Roadway Conductor Heights*		Farmland Conductor Heights*	
Section	Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
A	3.2	4.8	3.2	6.1	2.4	3.2	2.4	3.8
B	3.1	4.8	3.1	6.1	1.9	3.2	1.9	3.8
C	1.1	4.8	1.1	6.1	0.7	3.2	0.7	3.8
D	0.9	4.8	0.9	6.1	0.6	3.2	0.6	3.8
E1	n/a	4.7	n/a	6.0	n/a	3.2	n/a	3.8
E2	n/a	4.9	n/a	6.2	n/a	3.3	n/a	3.9
F	4.9	4.9	10.4	10.5	3.1	3.3	5.1	5.2
G	4.9	4.9	10.4	10.5	3.1	3.3	5.1	5.2
H	1.0	4.8	1.0	6.1	0.6	3.3	0.6	3.8

* Specific roadway/farmland conductor heights have only been specified for circuits D604I and D602F. For all other circuits, a single set of conductor heights are applied for both the roadway and farmland scenarios.

Table A-7. Maximum on ROW short-circuit induced current values (mA) for main truck of John Deere S680 (8.5 m long, 3.7 m wide, 3.8 m tall)

	Parallel Vehicle Orientation				Perpendicular Vehicle Orientation			
	Roadway Conductor Heights*		Farmland Conductor Heights*		Roadway Conductor Heights*		Farmland Conductor Heights*	
Section	Existing	Proposed	Existing	Proposed	Existing	Proposed	Existing	Proposed
A	1.7	2.6	1.7	3.2	1.5	2.2	1.5	2.8
B	1.7	2.6	1.7	3.3	1.4	2.3	1.4	2.8
C	0.6	2.6	0.6	3.3	0.5	2.2	0.5	2.8
D	0.5	2.6	0.5	3.3	0.4	2.3	0.4	2.8
E1	n/a	2.5	n/a	3.2	n/a	2.2	n/a	2.7
E2	n/a	2.6	n/a	3.3	n/a	2.3	n/a	2.8
F	2.6	2.6	5.6	5.6	2.2	2.3	4.2	4.2
G	2.6	2.6	5.6	5.6	2.2	2.3	4.2	4.2
H	0.5	2.6	0.5	3.2	0.5	2.2	0.5	2.8

* Specific roadway/farmland conductor heights have only been specified for circuits D604I and D602F. For all other circuits, a single set of conductor heights are applied for both the roadway and farmland scenarios.

Appendix B

Graphical Profiles of Calculated EMF, AN and RN

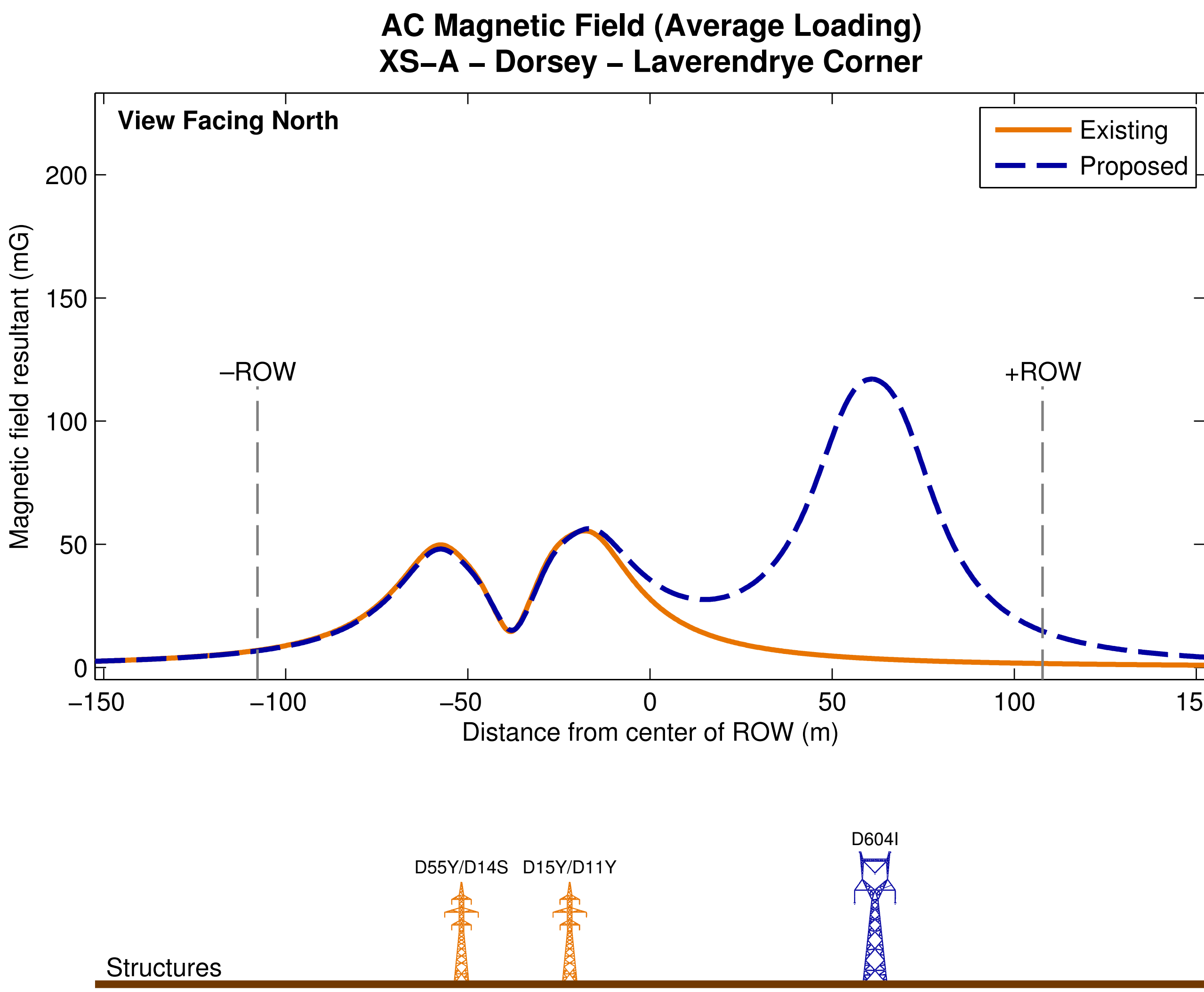

Figure B-1. AC magnetic-field profile along XS-A - Dorsey - Laverendrye Corner.

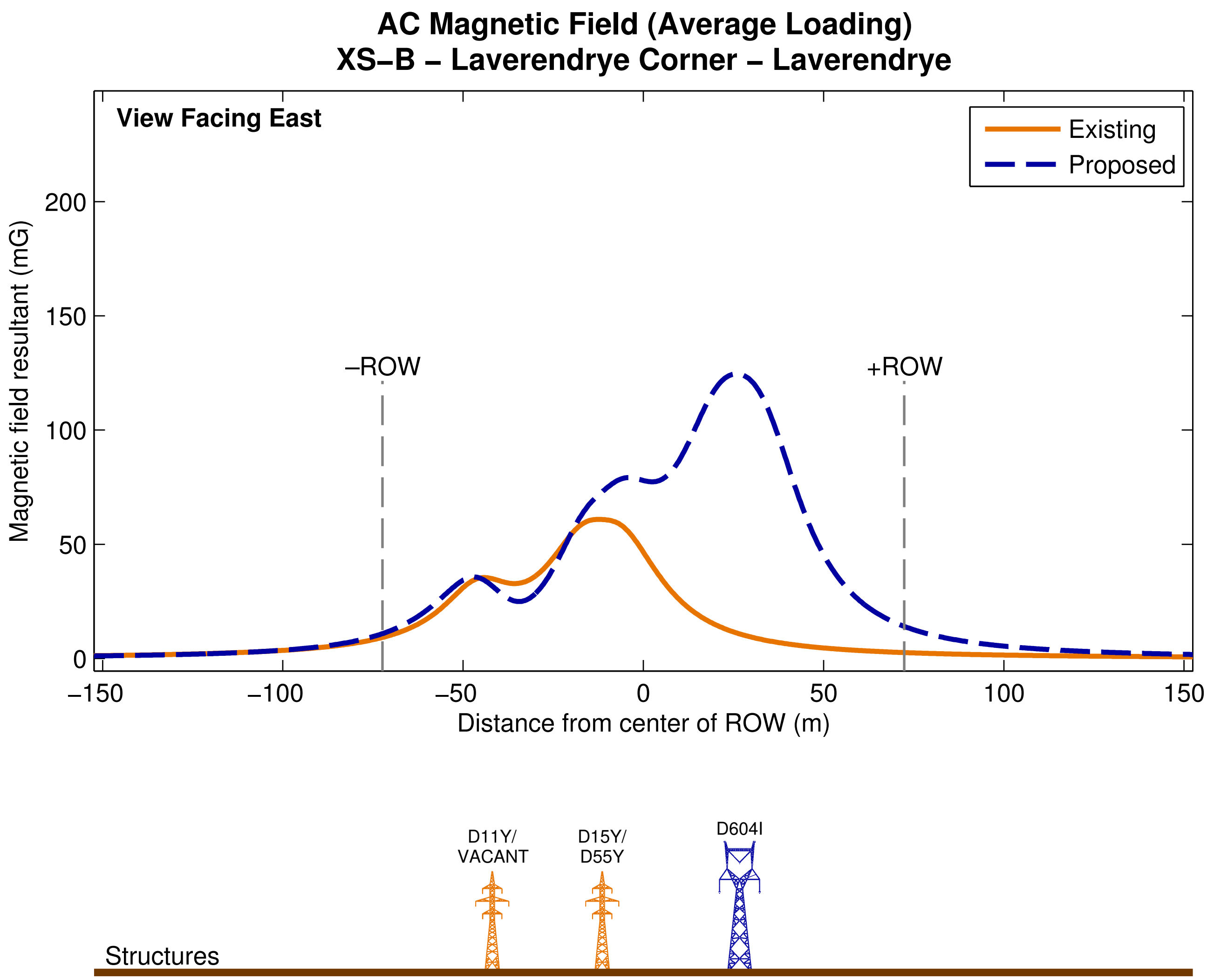

Figure B-2. AC magnetic-field profile along XS-B - Laverendrye Corner - Laverendrye.

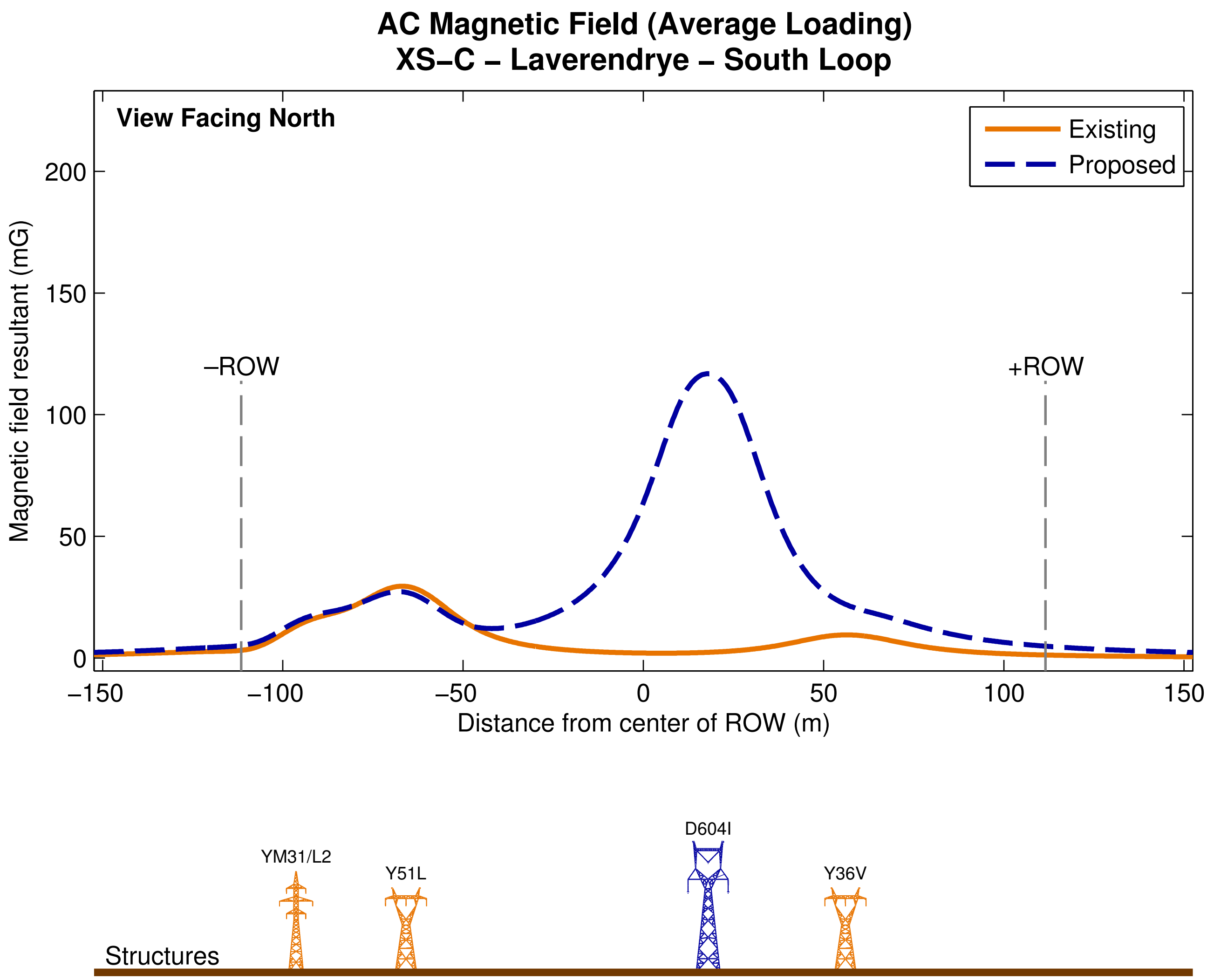

Figure B-3. AC magnetic-field profile along XS-C - Laverendrye - South Loop.

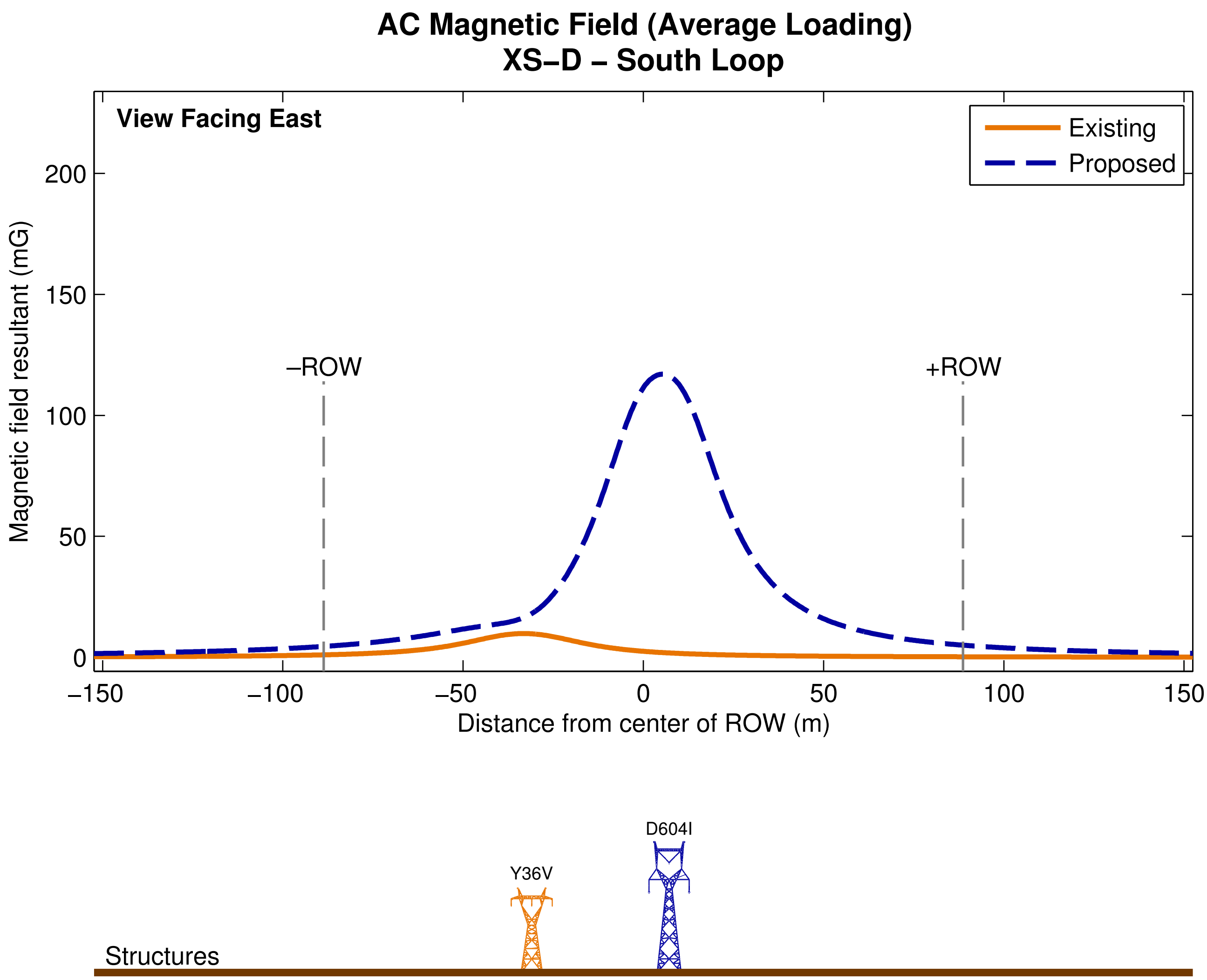

Figure B-4. AC magnetic-field profile along XS-D - South Loop.

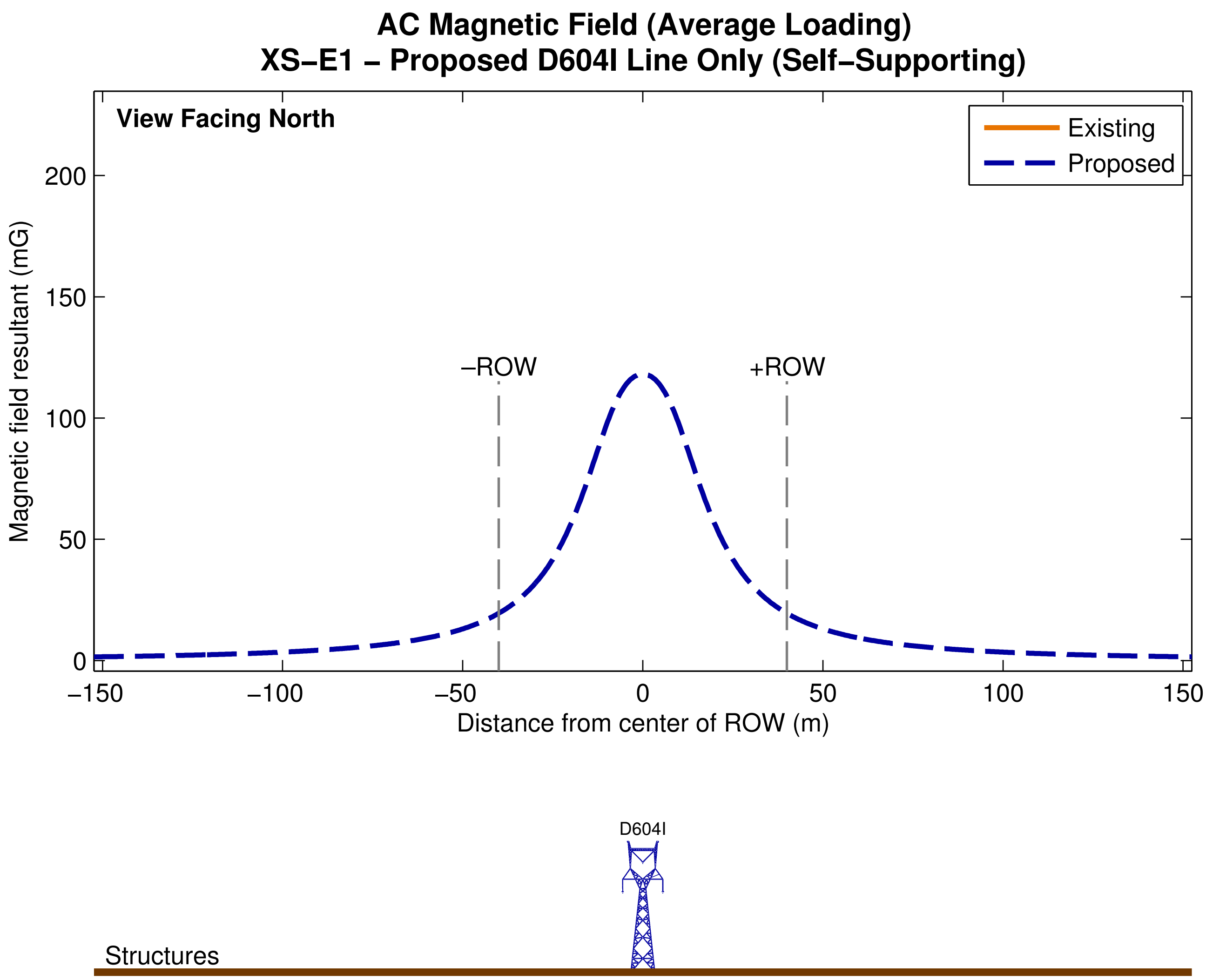

Figure B-5. AC magnetic-field profile along XS-E - Proposed D604I Line Only (Self-Supporting).

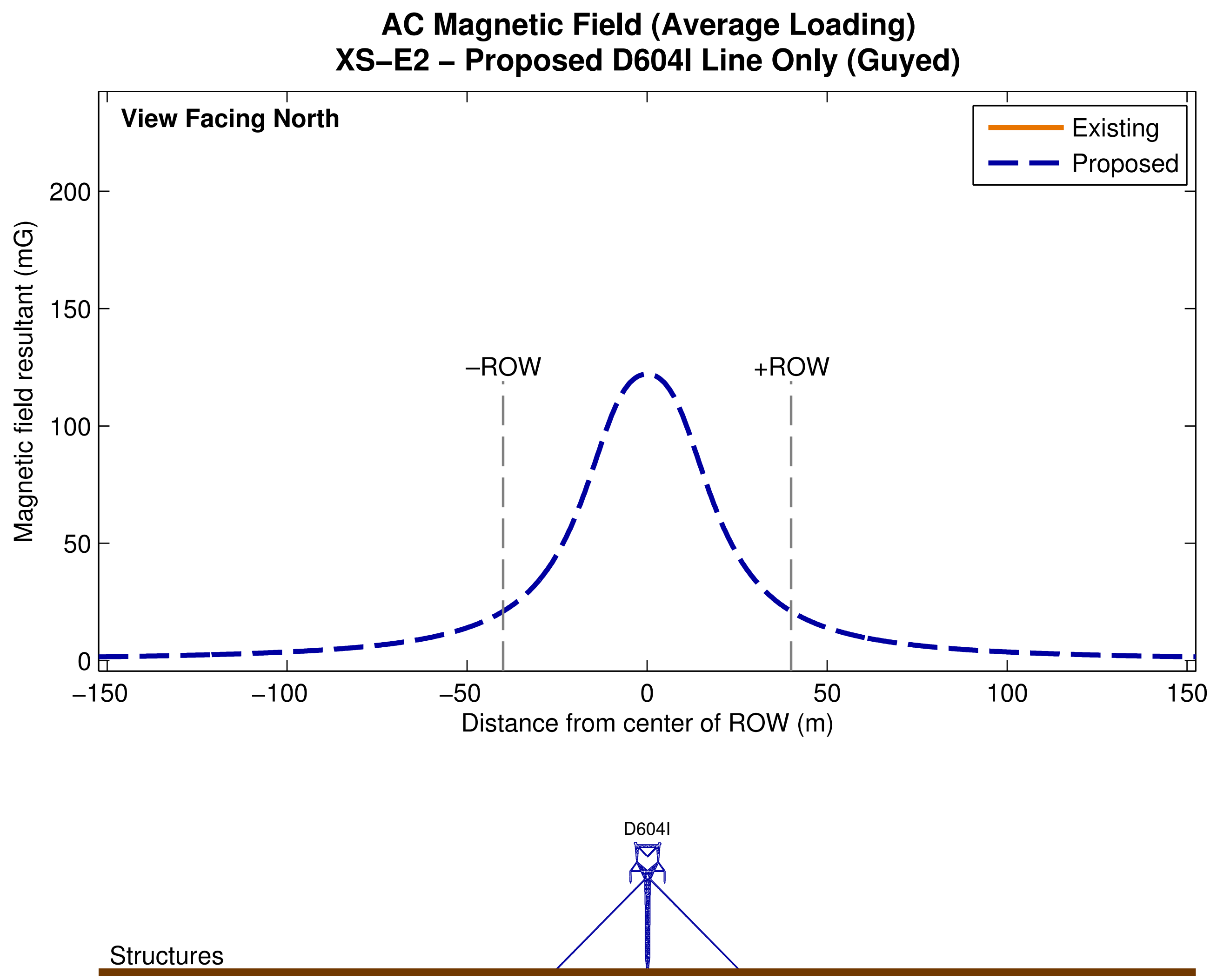

Figure B-6. AC magnetic-field profile along XS-E - Proposed D604I Line Only (Guyed).

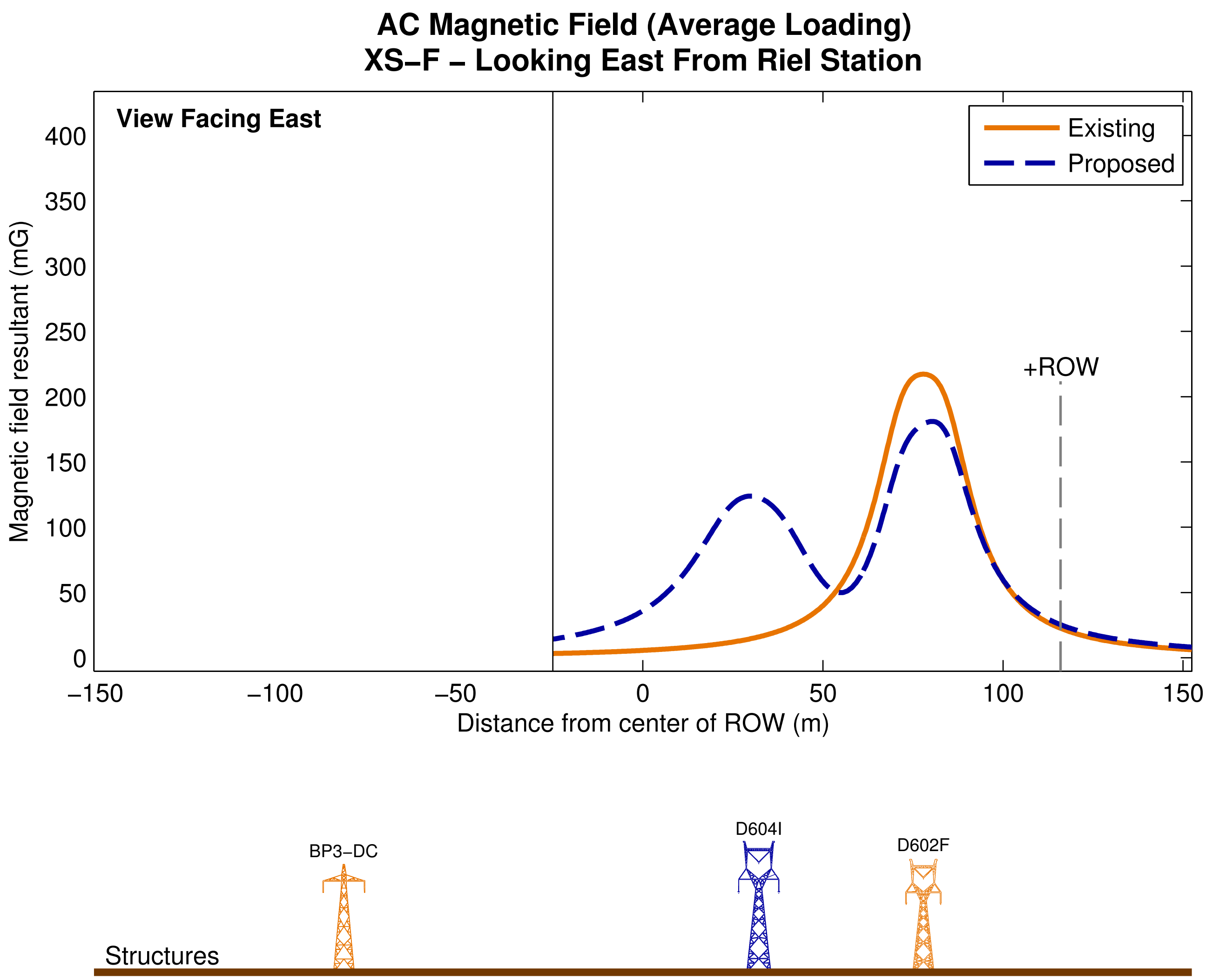

Figure B-7. AC magnetic-field profile along XS-F - Looking East From Riel Station. The magnetic field from the Bipole III DC line is not shown here as it will not affect the AC magnetic field calculations presented above.

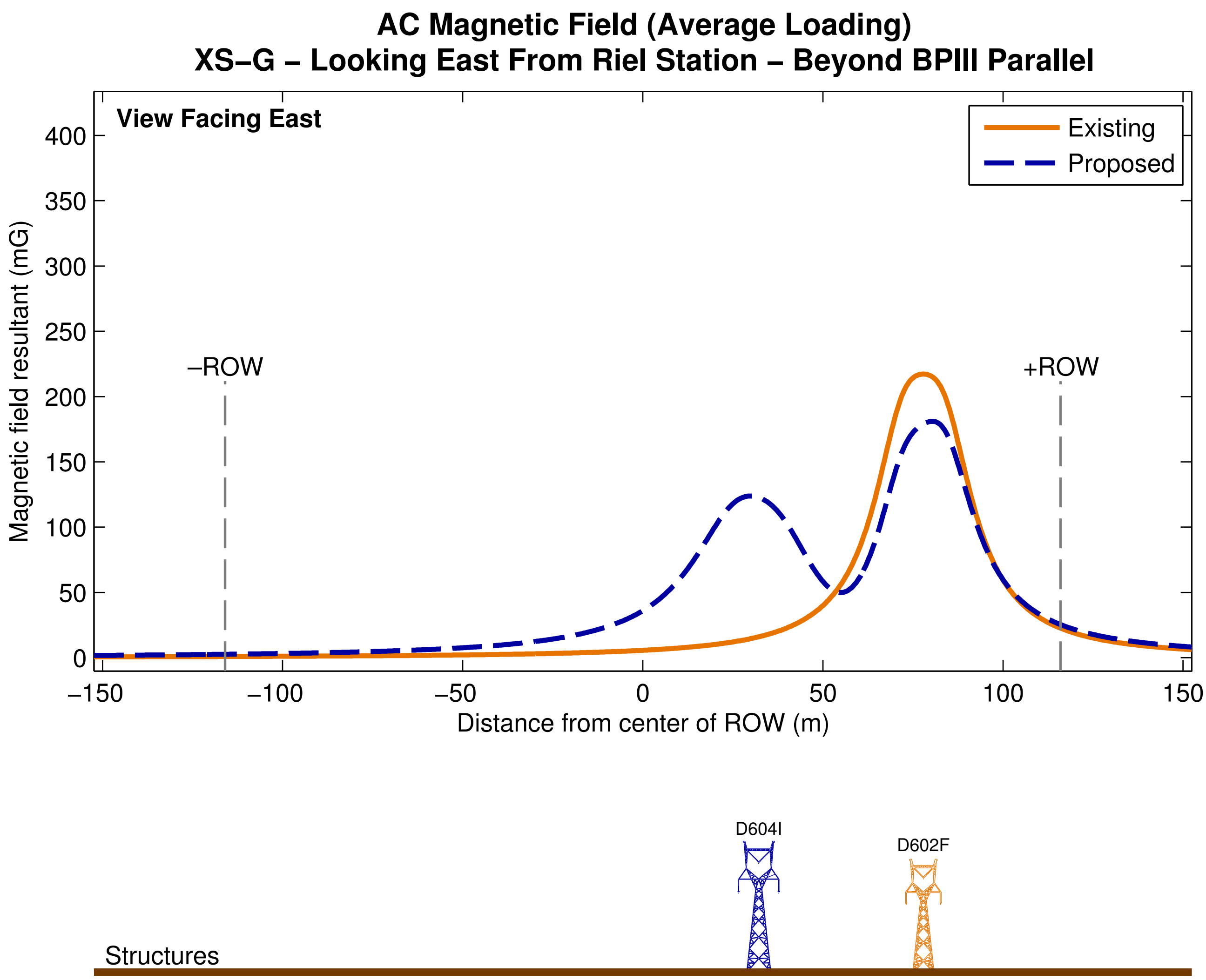

Figure B-8. AC magnetic-field profile along XS-G - Looking East From Riel Station - Beyond Bipole III Parallel.

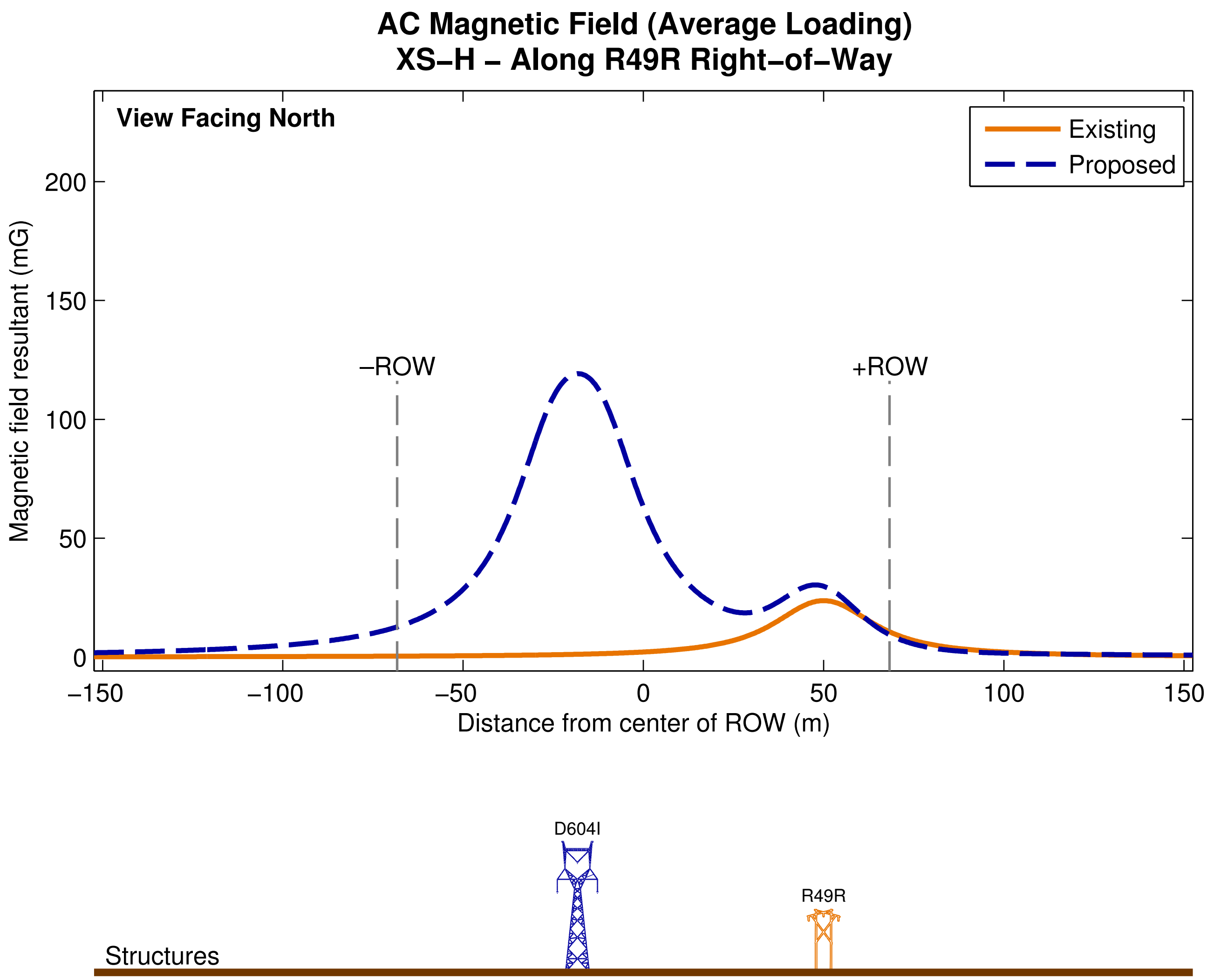

Figure B-9. AC magnetic-field profile along XS-H - Along R49R Right-of-Way.

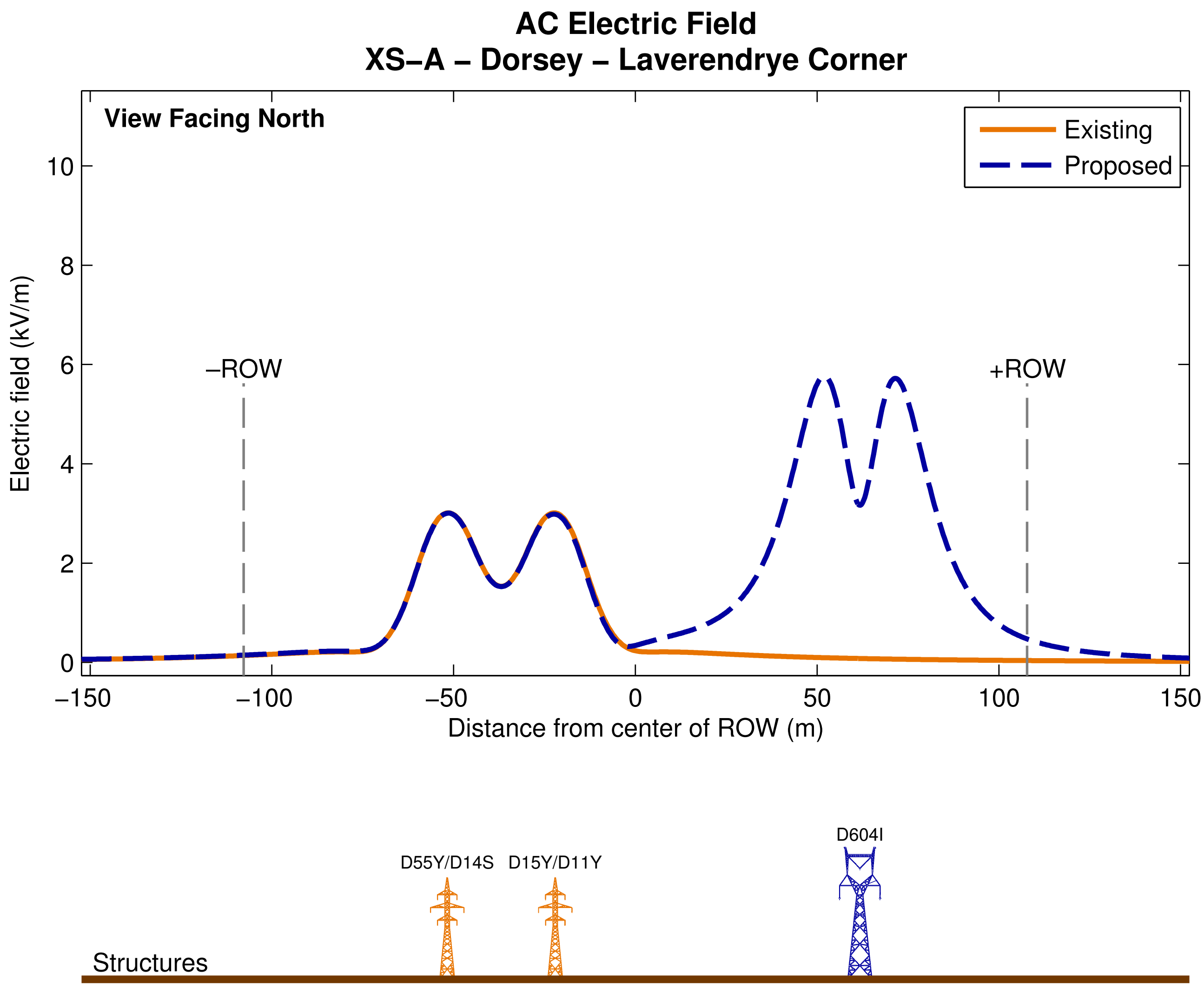

Figure B-10. AC electric-field profile along XS-A - Dorsey - Laverendrye Corner.

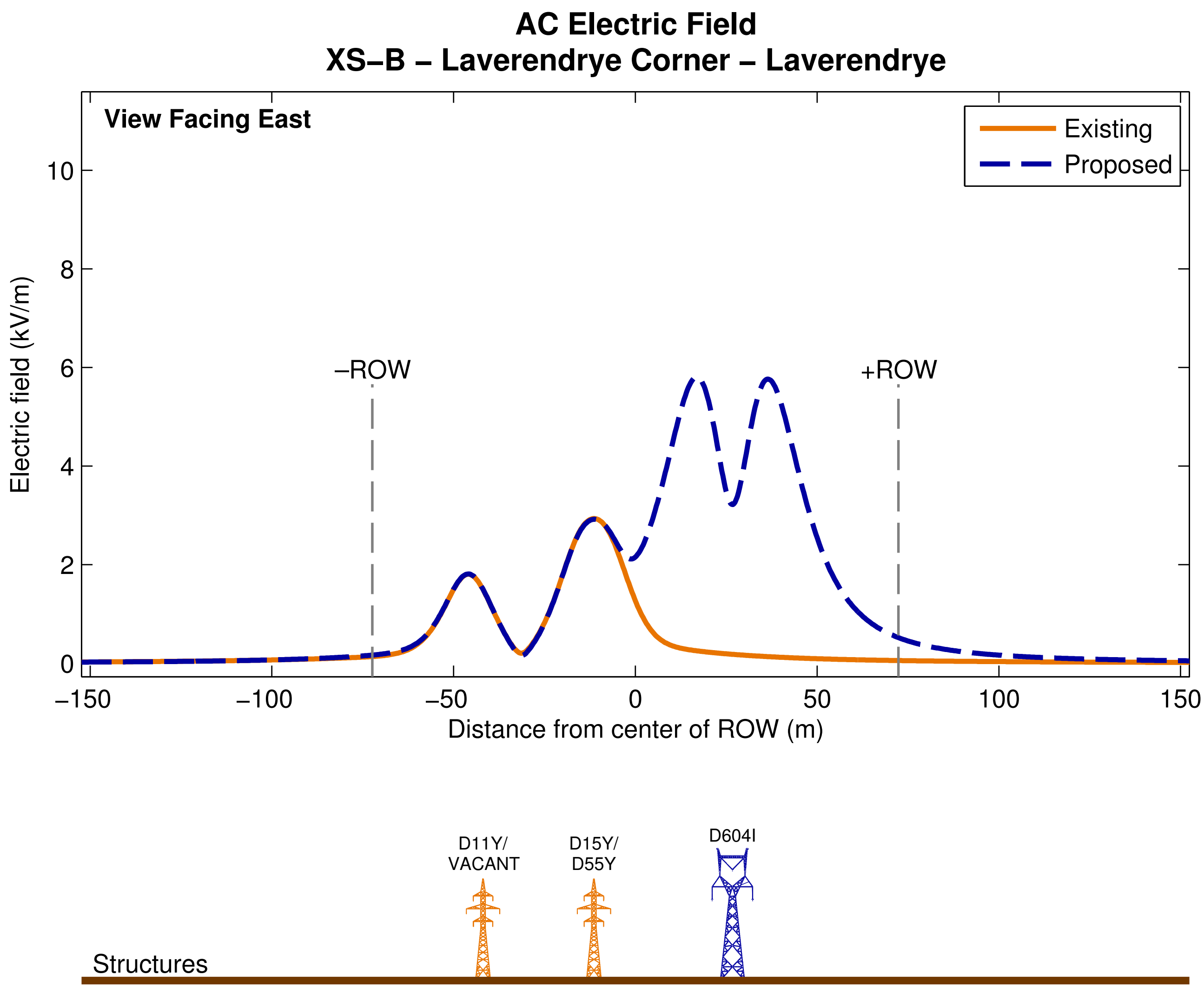

Figure B-11. AC electric-field profile along XS-B - Laverendrye Corner - Laverendrye.

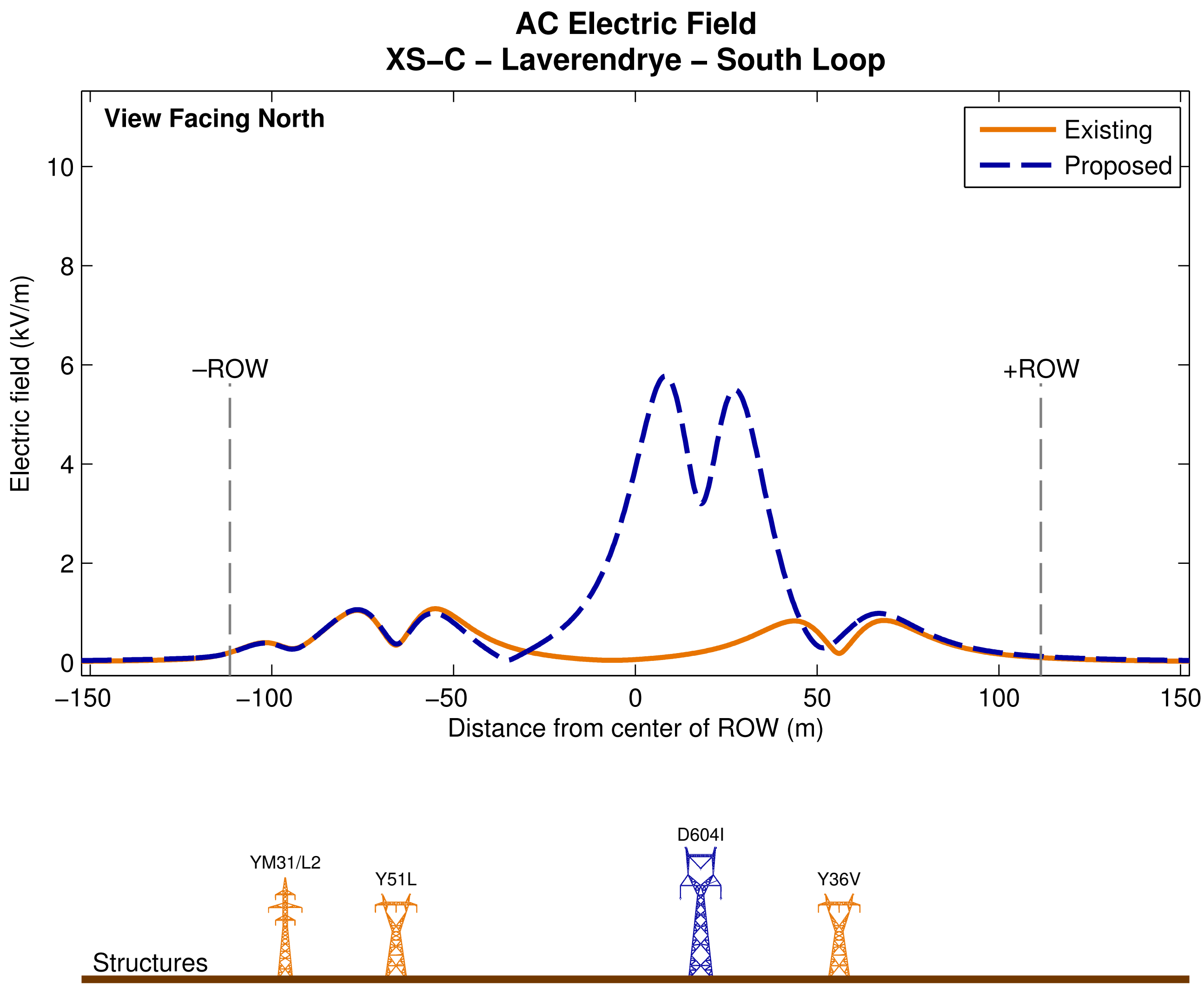

Figure B-12. AC electric-field profile along XS-C - Laverendrye - South Loop.

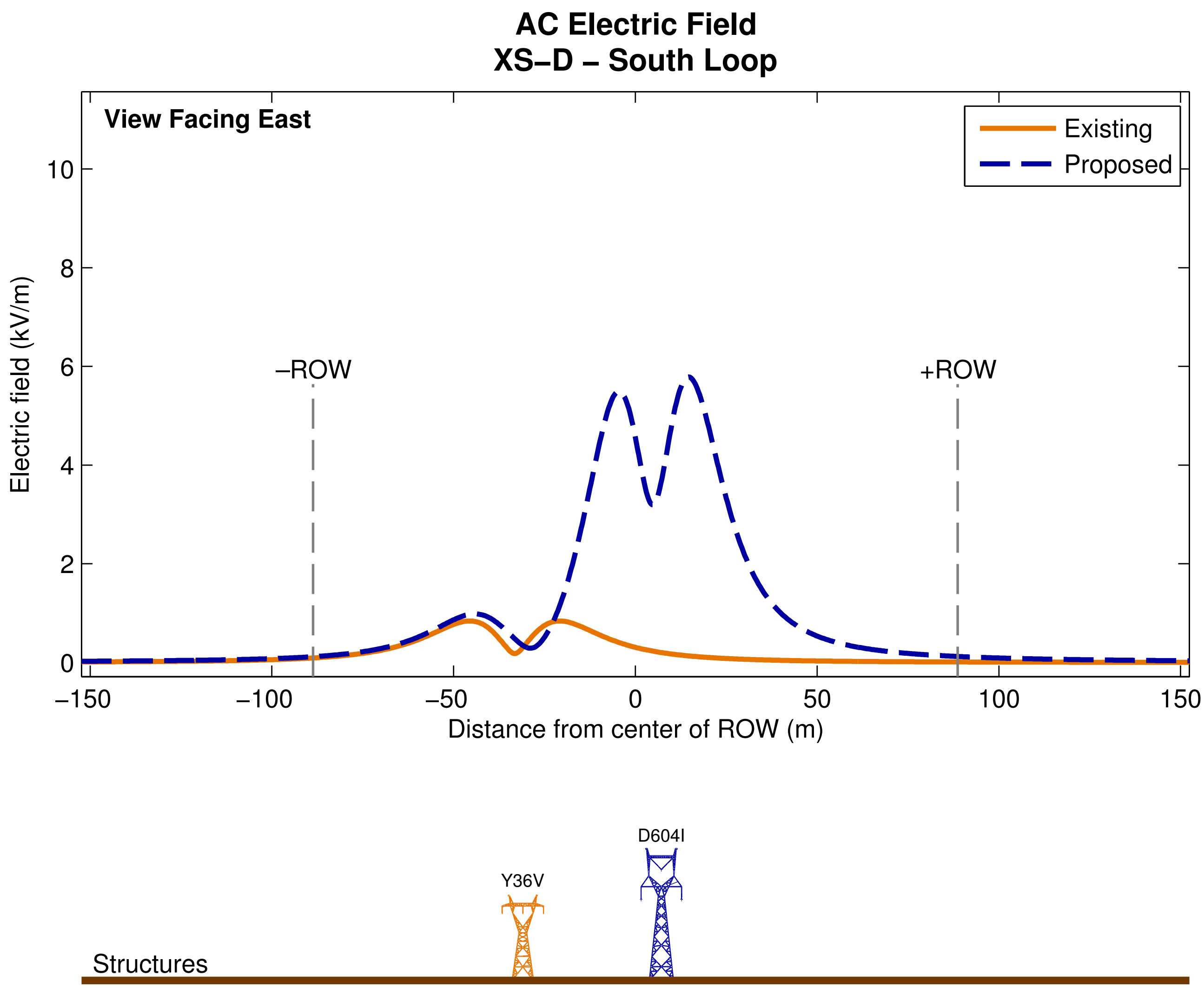

Figure B-13. AC electric-field profile along XS-D - South Loop.

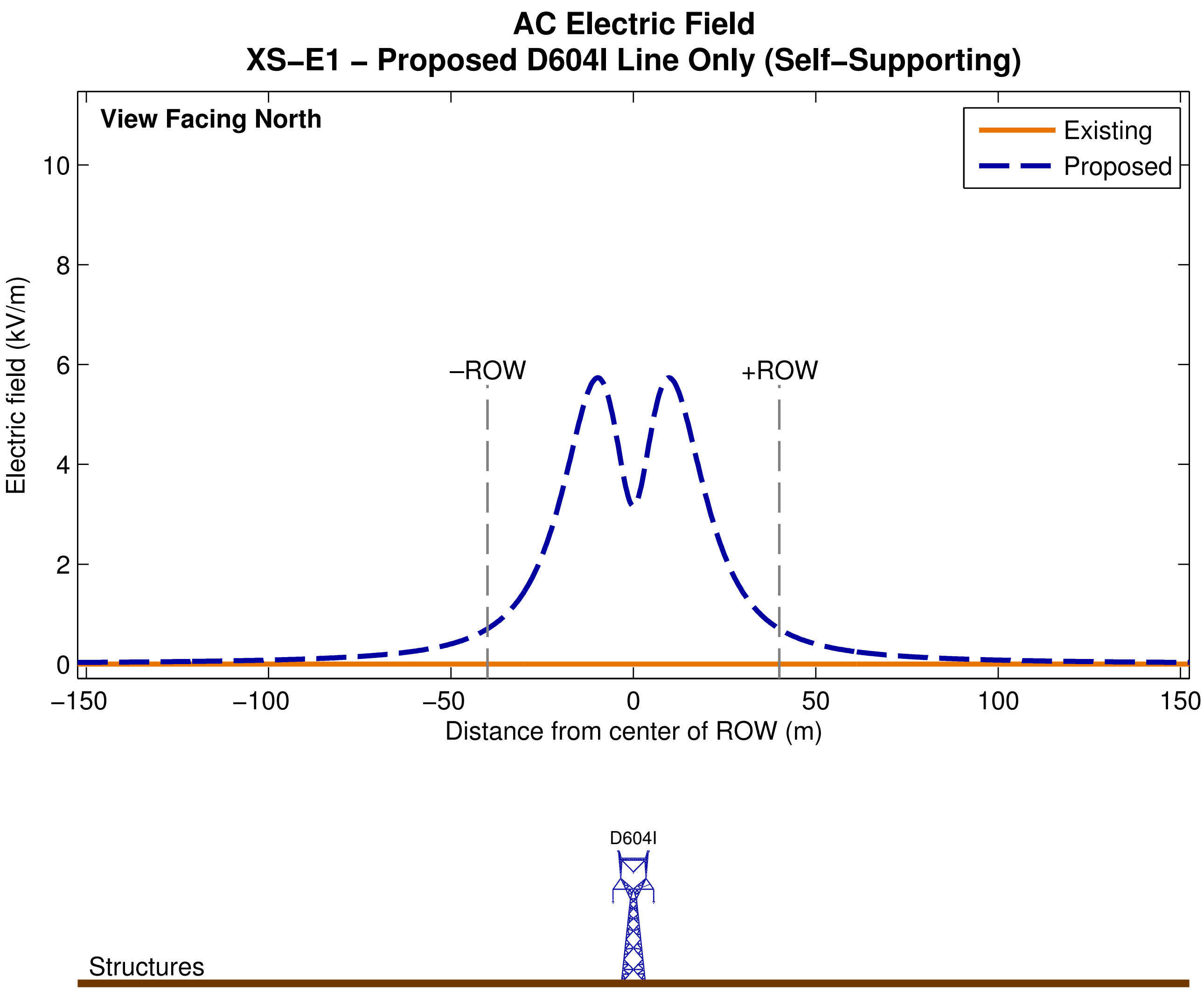

Figure B-14. AC electric-field profile along XS-E - Proposed D604I Line Only (Self-Supporting).

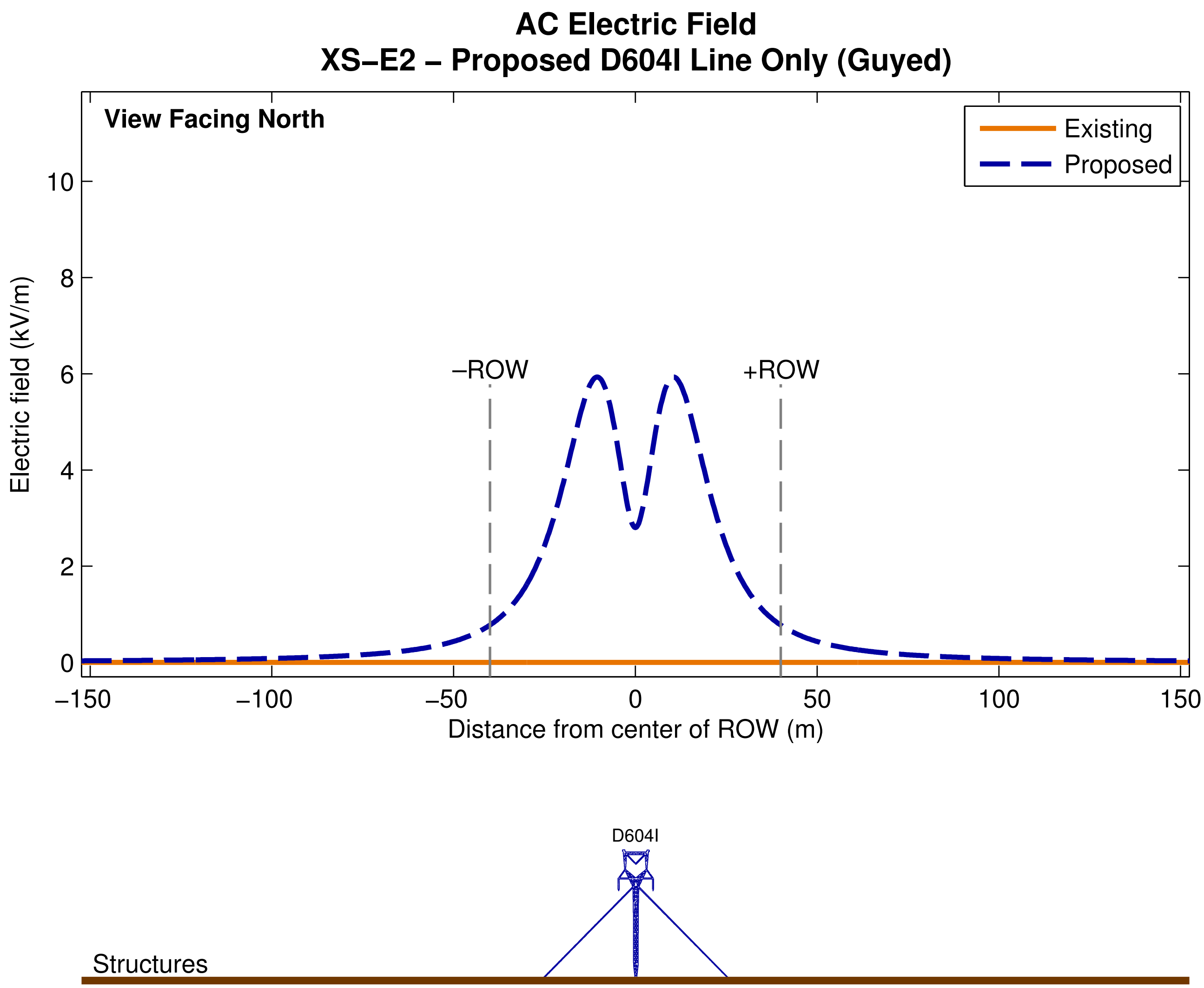

Figure B-15. AC electric-field profile along XS-E - Proposed D604I Line Only (Guyed).

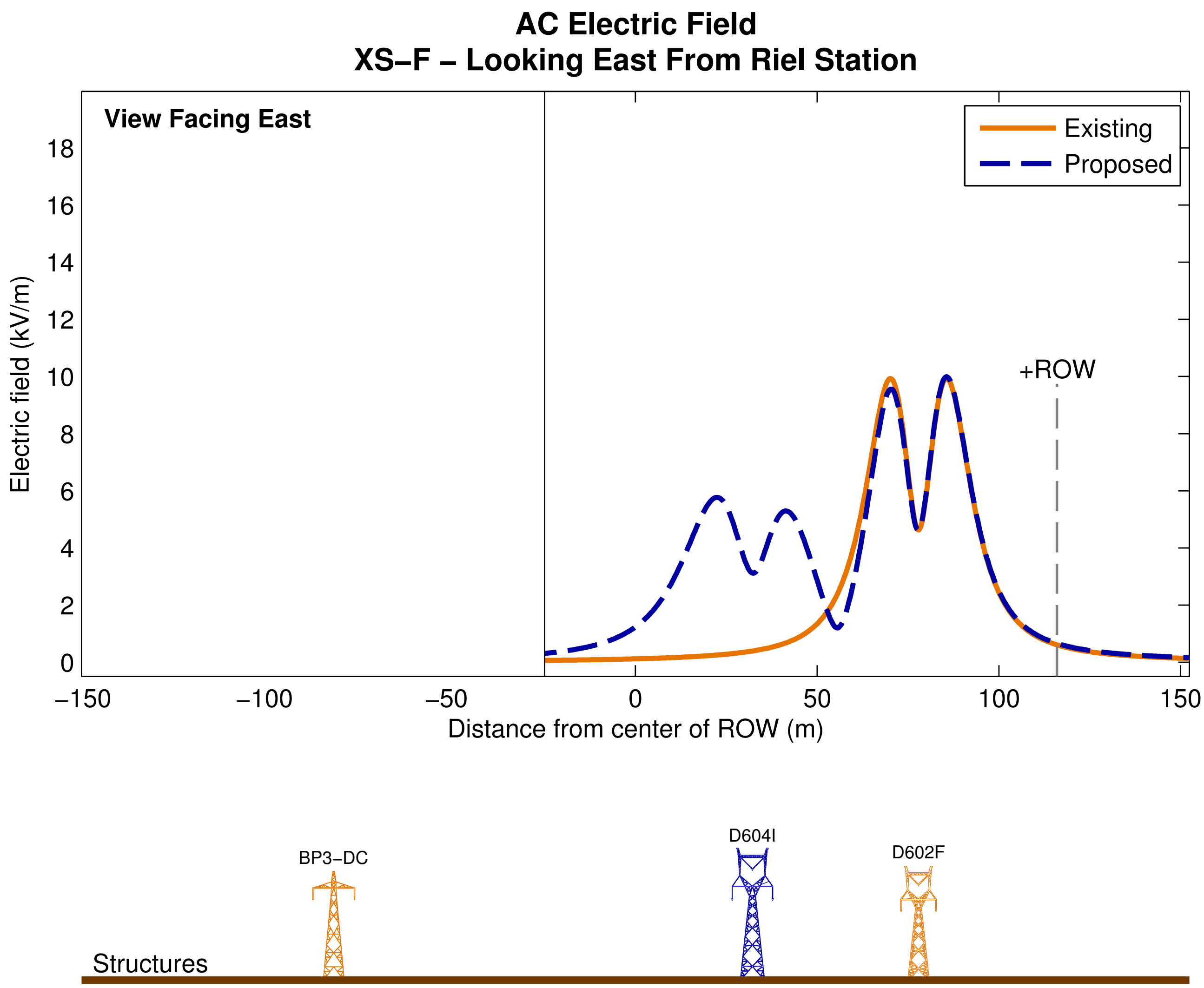

Figure B-16. AC electric-field profile along XS-F - Looking East From Riel Station. The electric field from the Bipole III DC line is not shown here as it will not affect the AC electric field calculations presented above.

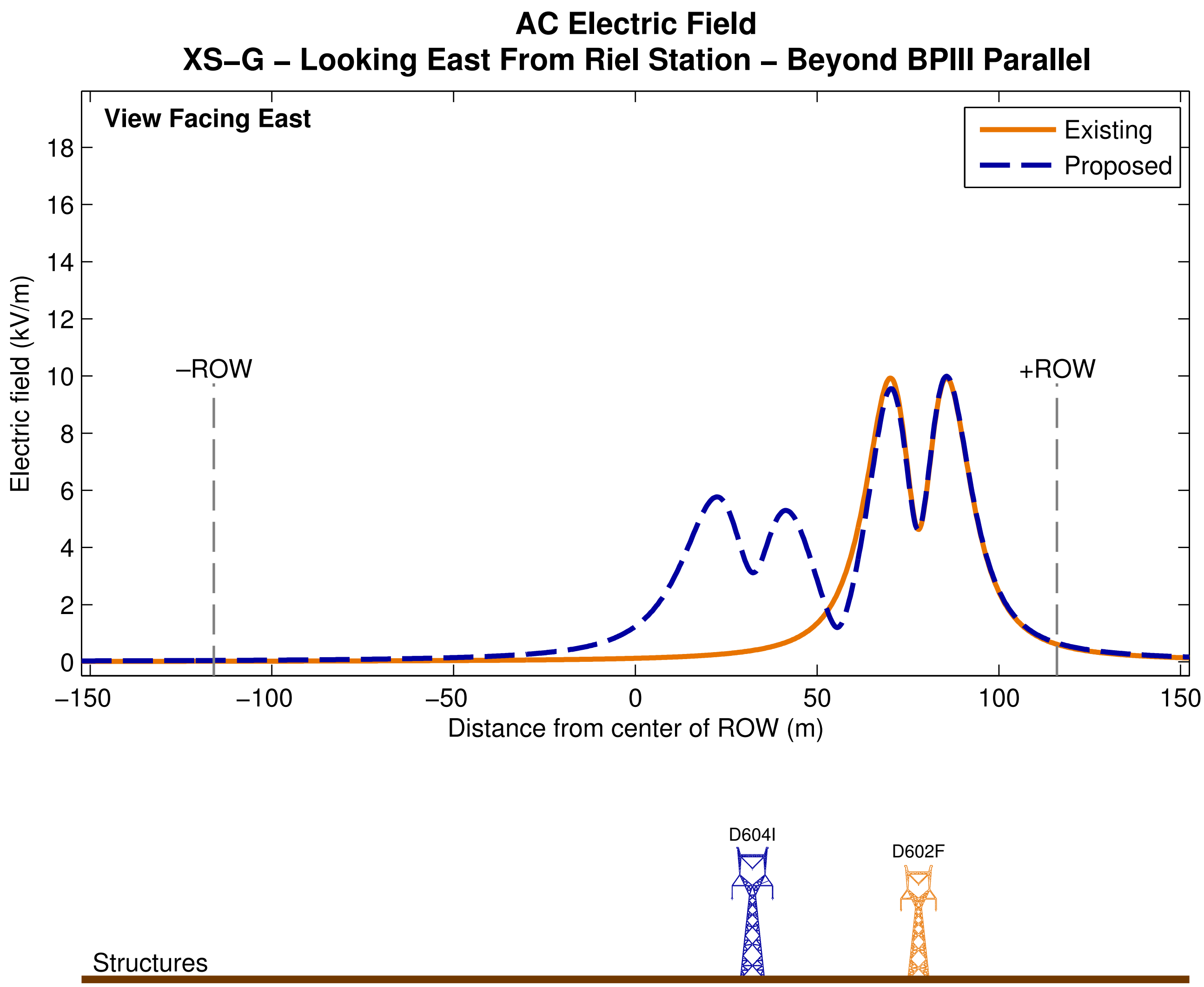

Figure B-17. AC electric-field profile along XS-G - Looking East From Riel Station - Beyond Bipole III Parallel.

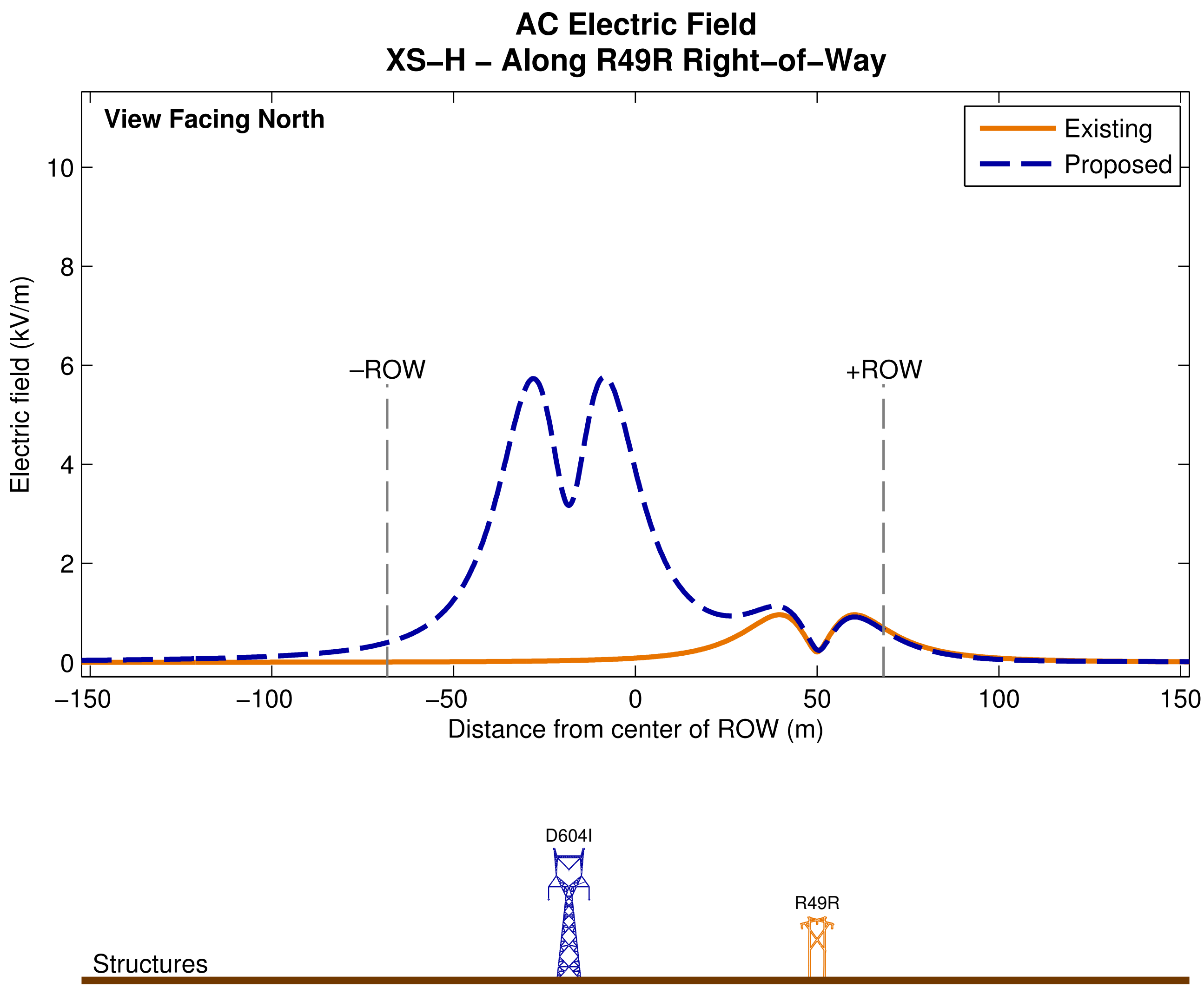

Figure B-18. AC electric-field profile along XS-H - Along R49R Right-of-Way.

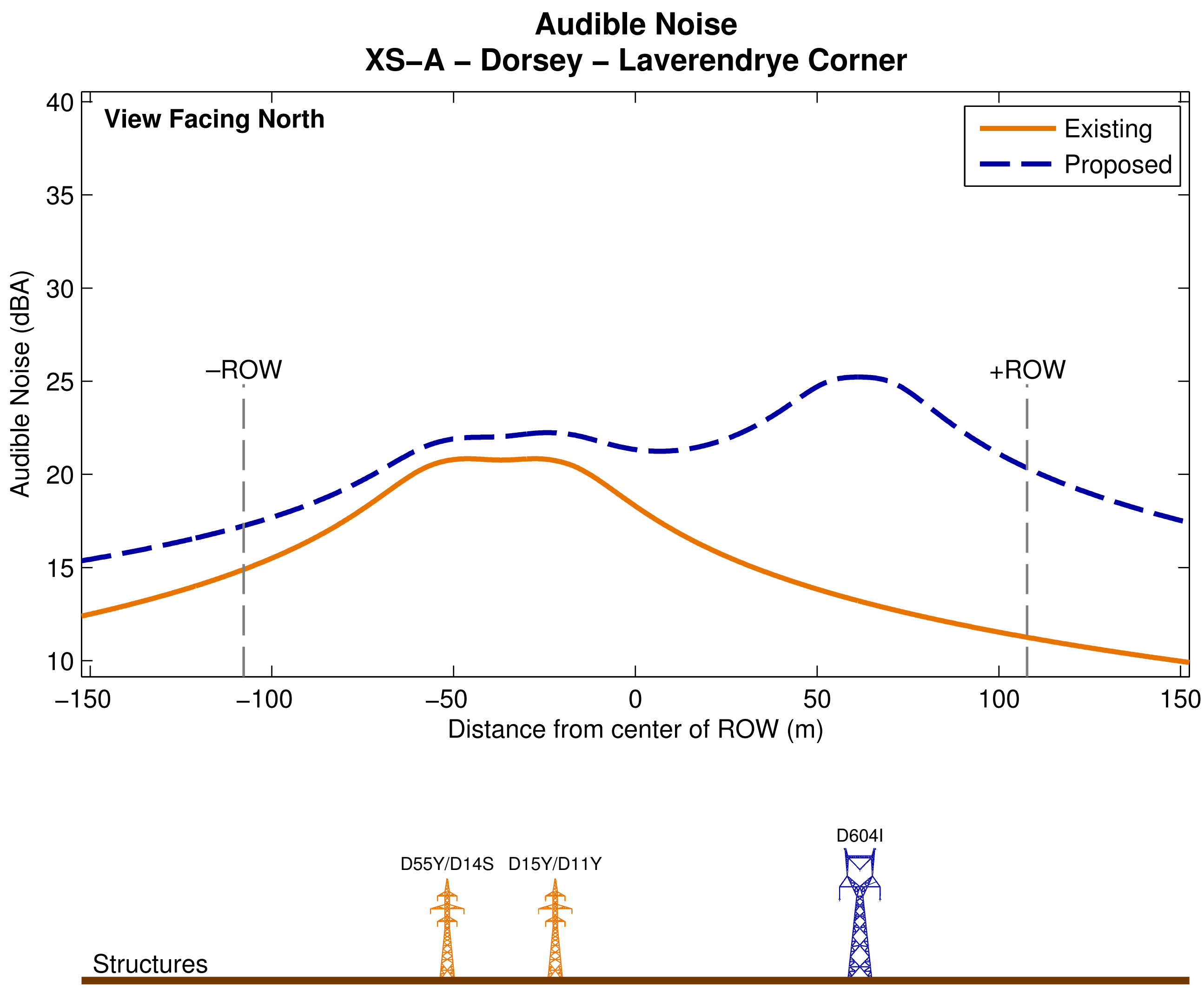

Figure B-19. Audible noise profile in fair weather along XS-A - Dorsey - Laverendrye Corner.

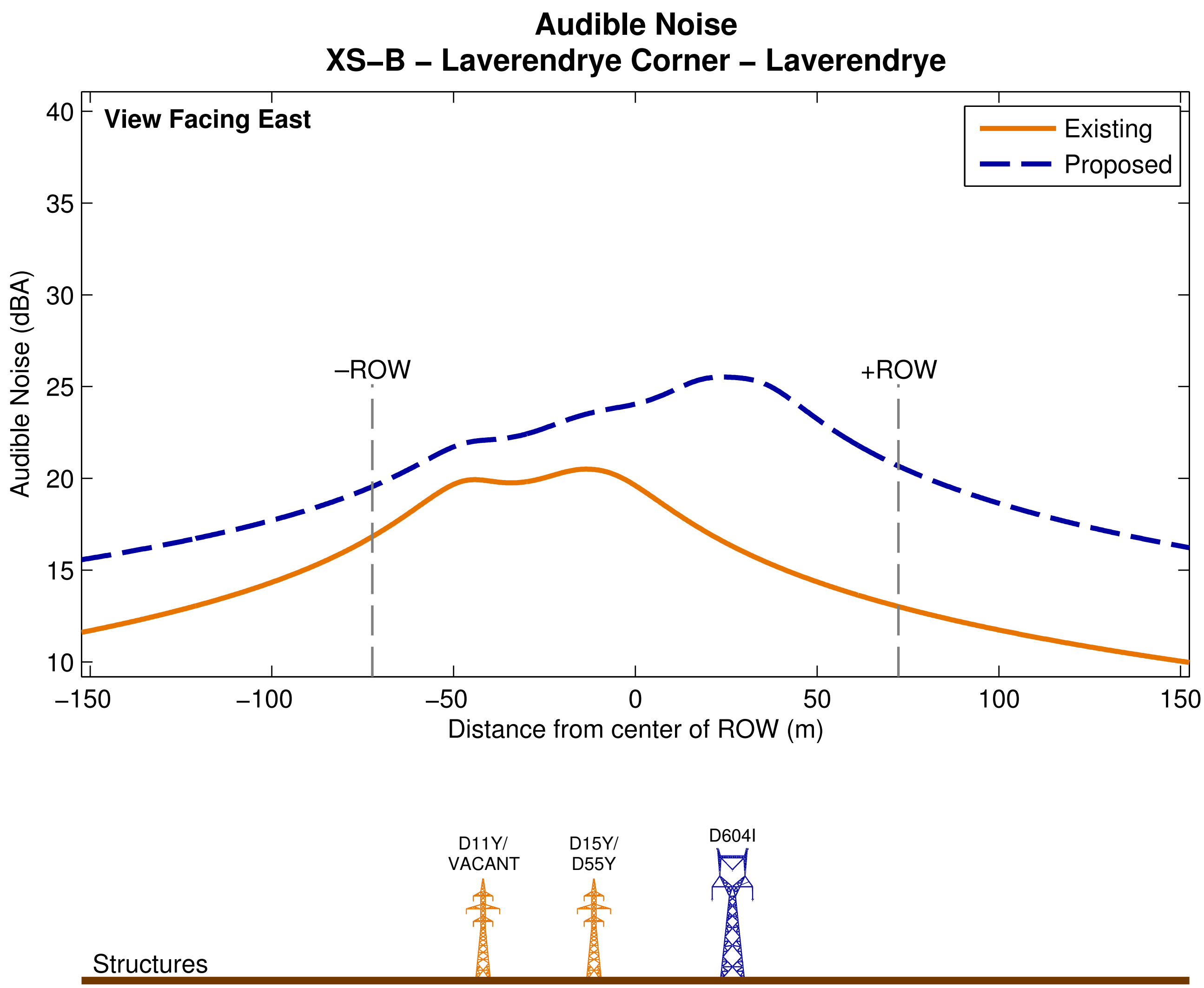

Figure B-20. Audible noise profile in fair weather along XS-B - Laverendrye Corner - Laverendrye.

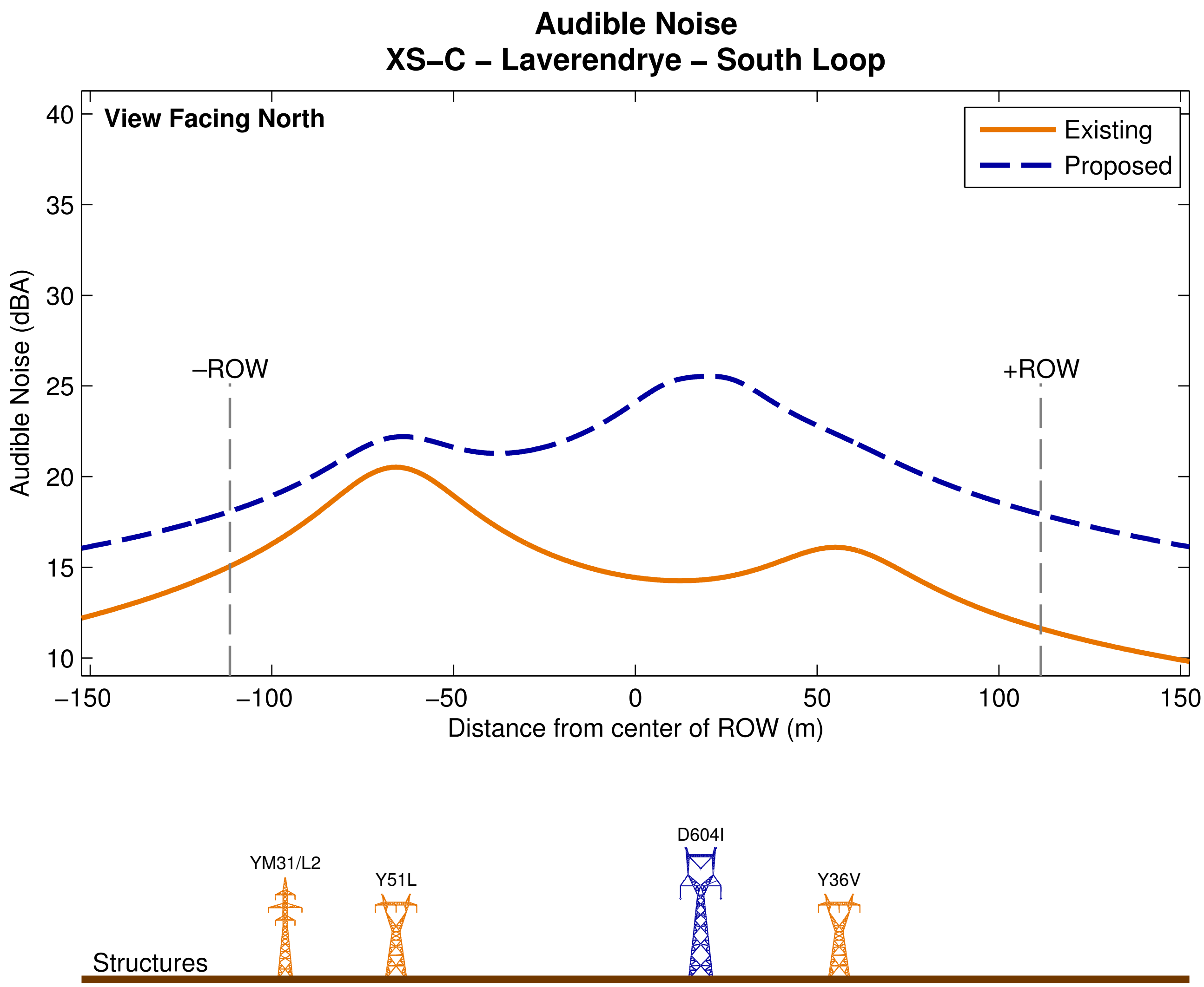

Figure B-21. Audible noise profile in fair weather along XS-C - Laverendrye - South Loop.

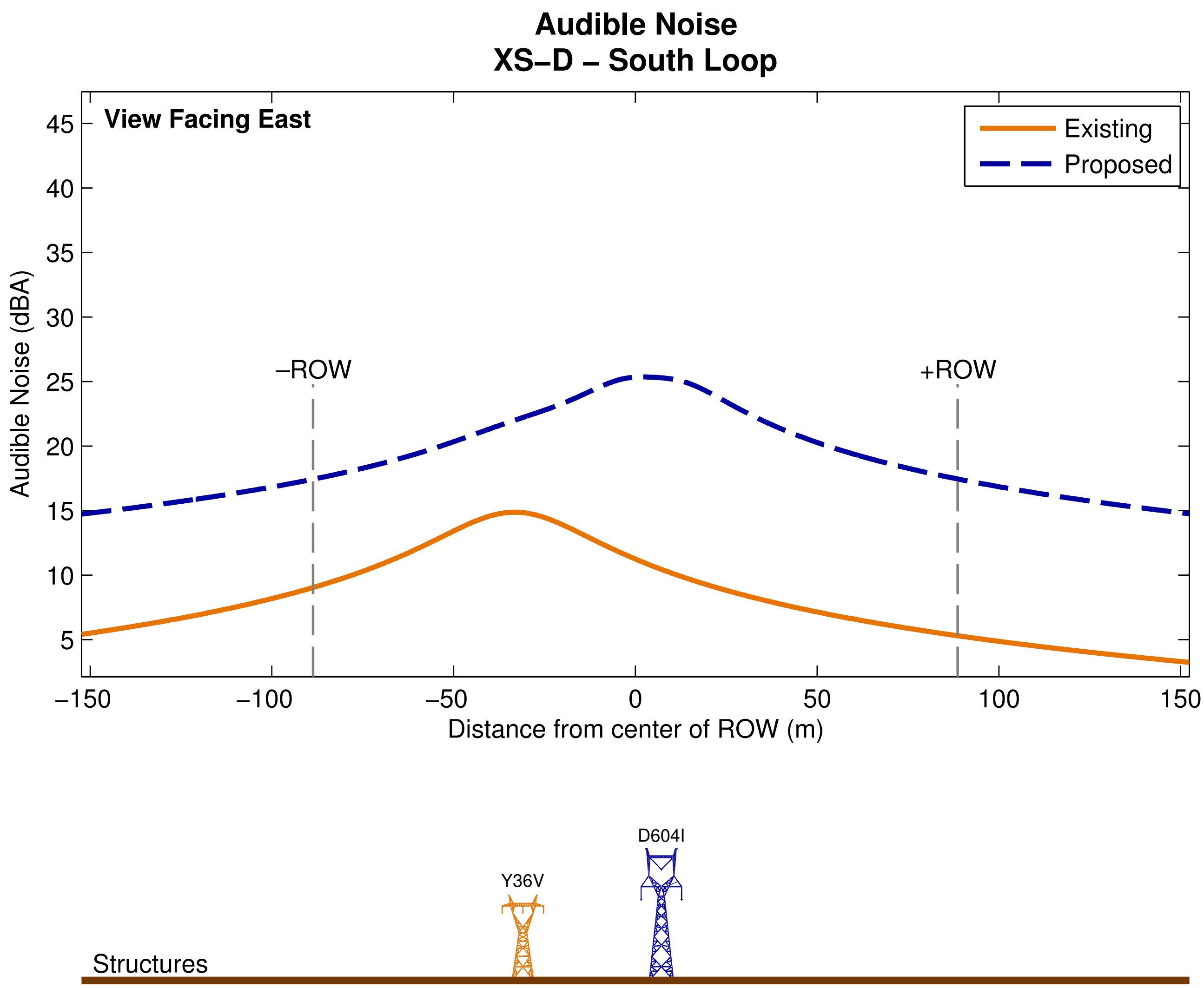

Figure B-22. Audible noise profile in fair weather along XS-D - South Loop.

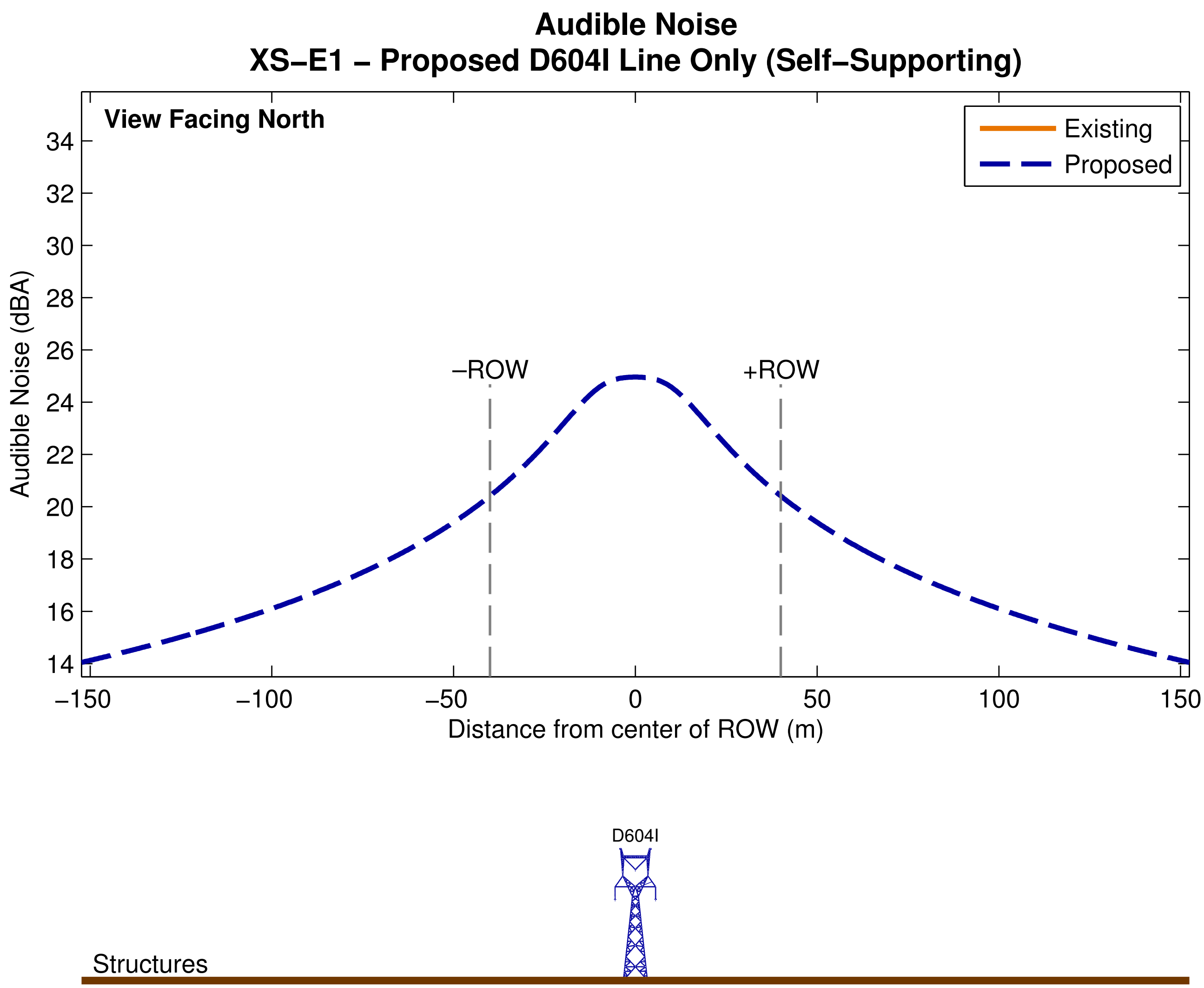

Figure B-23. Audible noise profile in fair weather along XS-E - Proposed D604I Line Only (Self-Supporting).

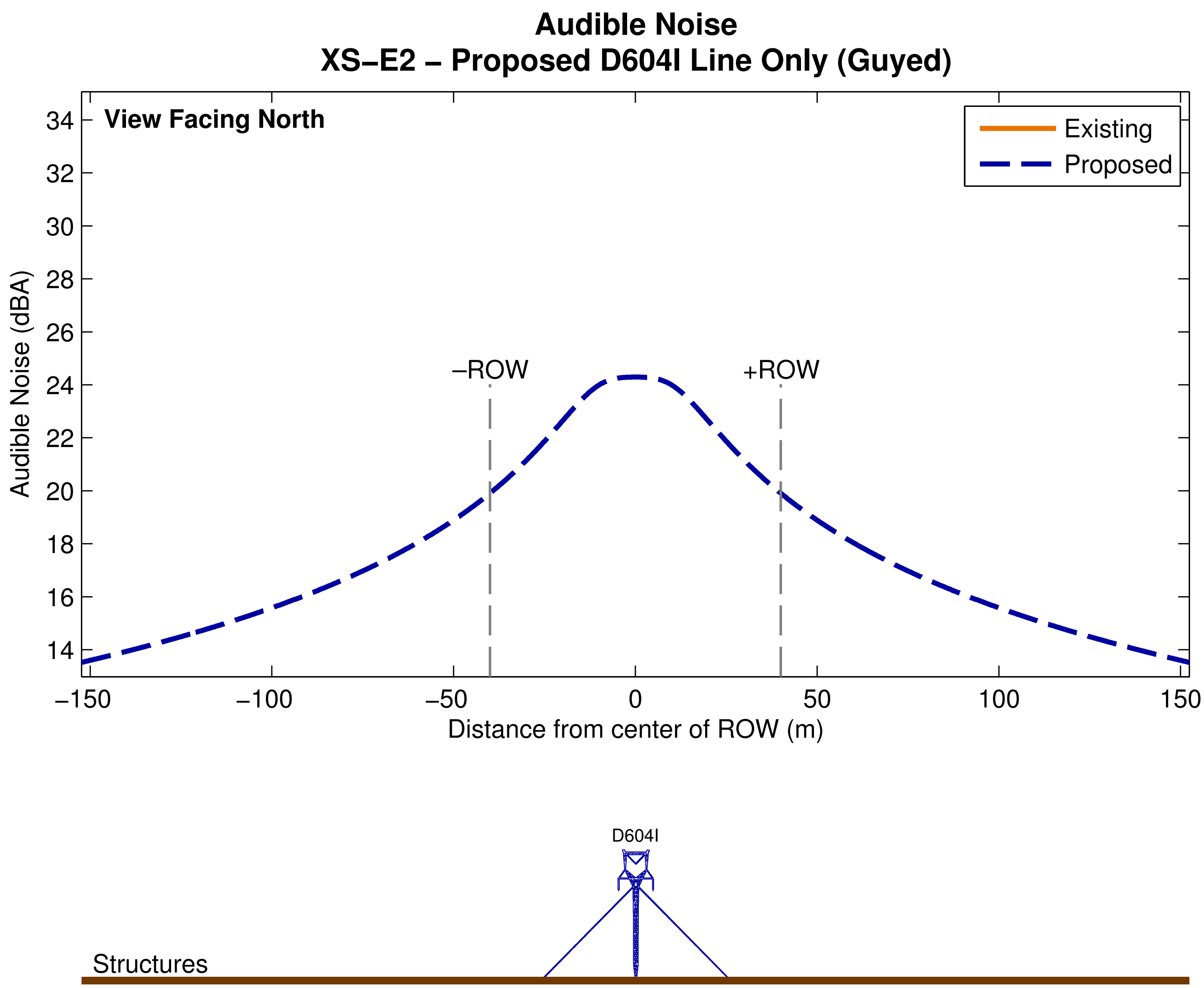

Figure B-24. Audible noise profile in fair weather along XS-E - Proposed D604I Line Only (Guyed).

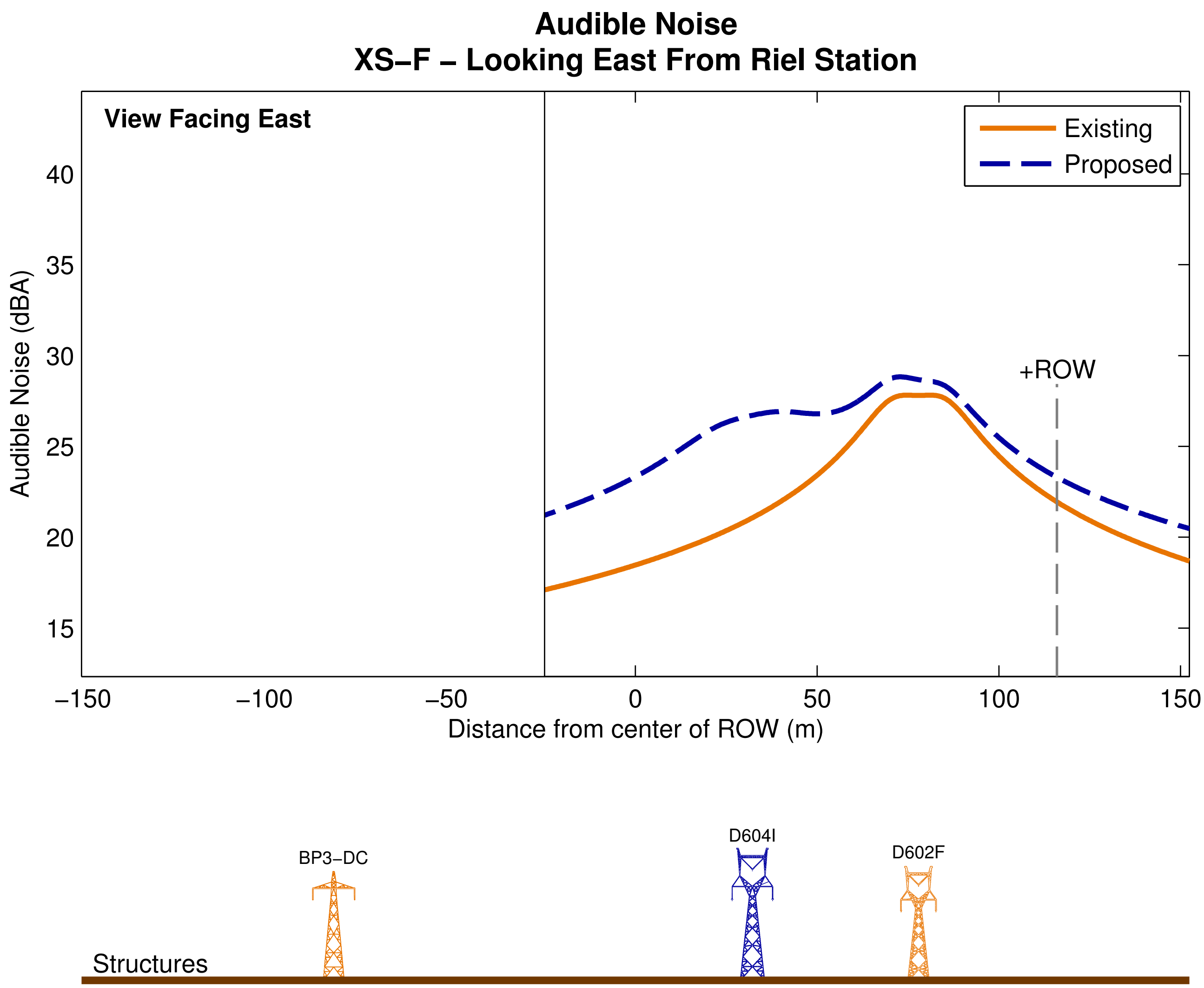

Figure B-25. Audible noise profile in fair weather along XS-F - Looking East From Riel Station. The audible noise from the Bipole III DC line is not shown here. Including contributions from the Bipole III DC line would increase audible noise levels to approximately 27 dBA at the southern edge of the right-of-way.

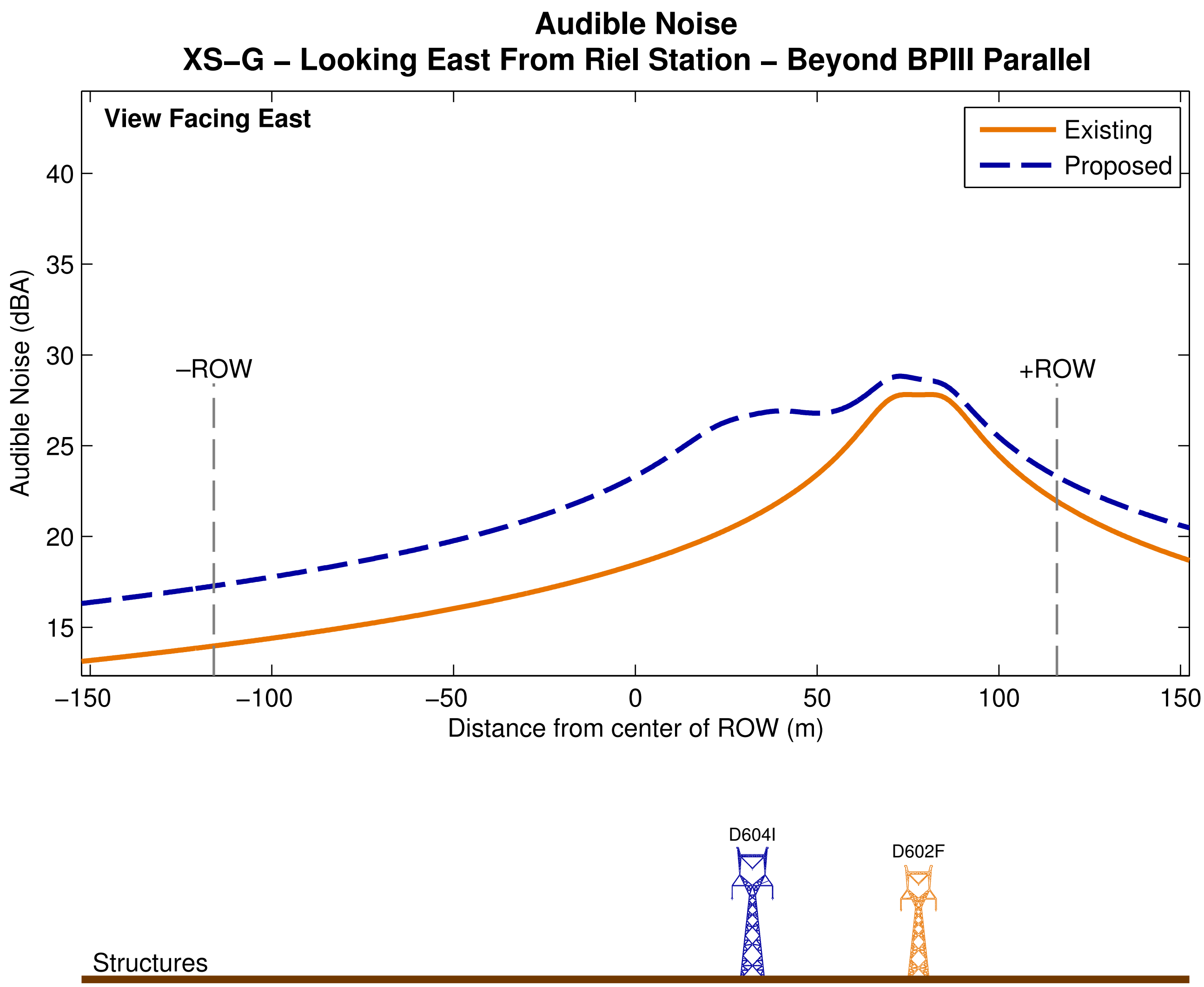

Figure B-26. Audible noise profile in fair weather along XS-G - Looking East From Riel Station - Beyond Bipole III Parallel.

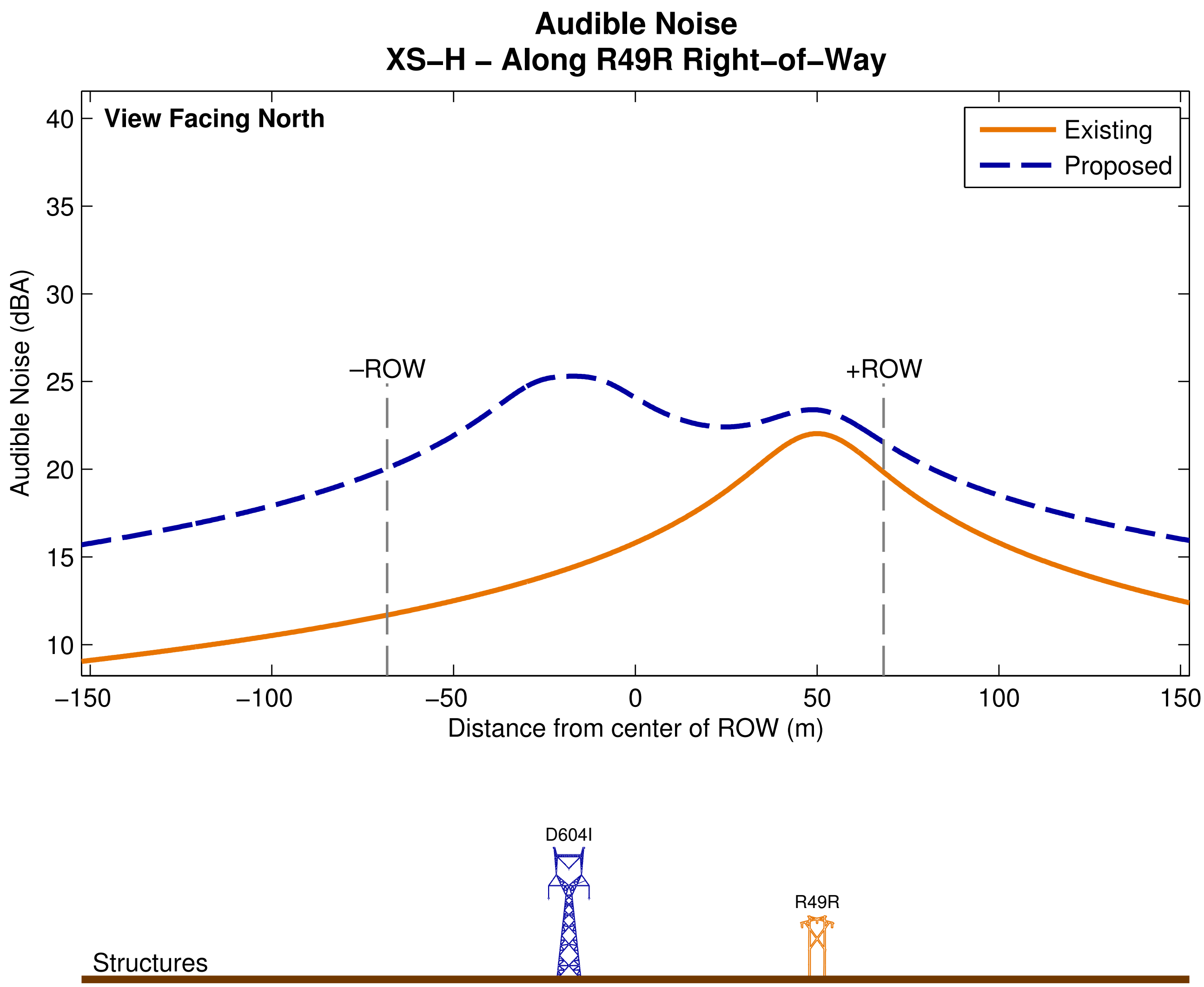

Figure B-27. Audible noise profile in fair weather along XS-H - Along R49R Right-of-Way.

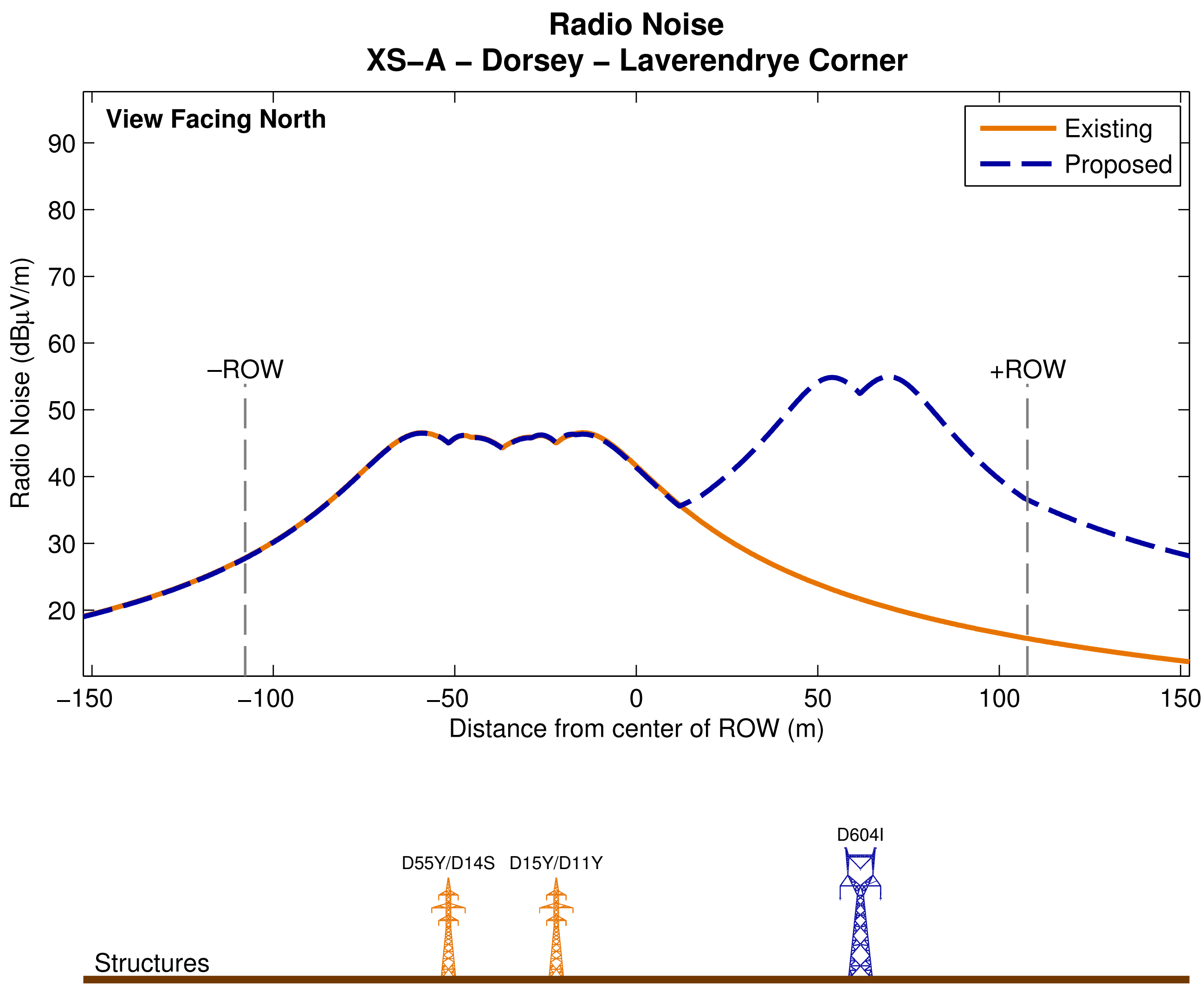

Figure B-28. Radio noise profile in fair weather along XS-A - Dorsey - Laverendrye Corner.

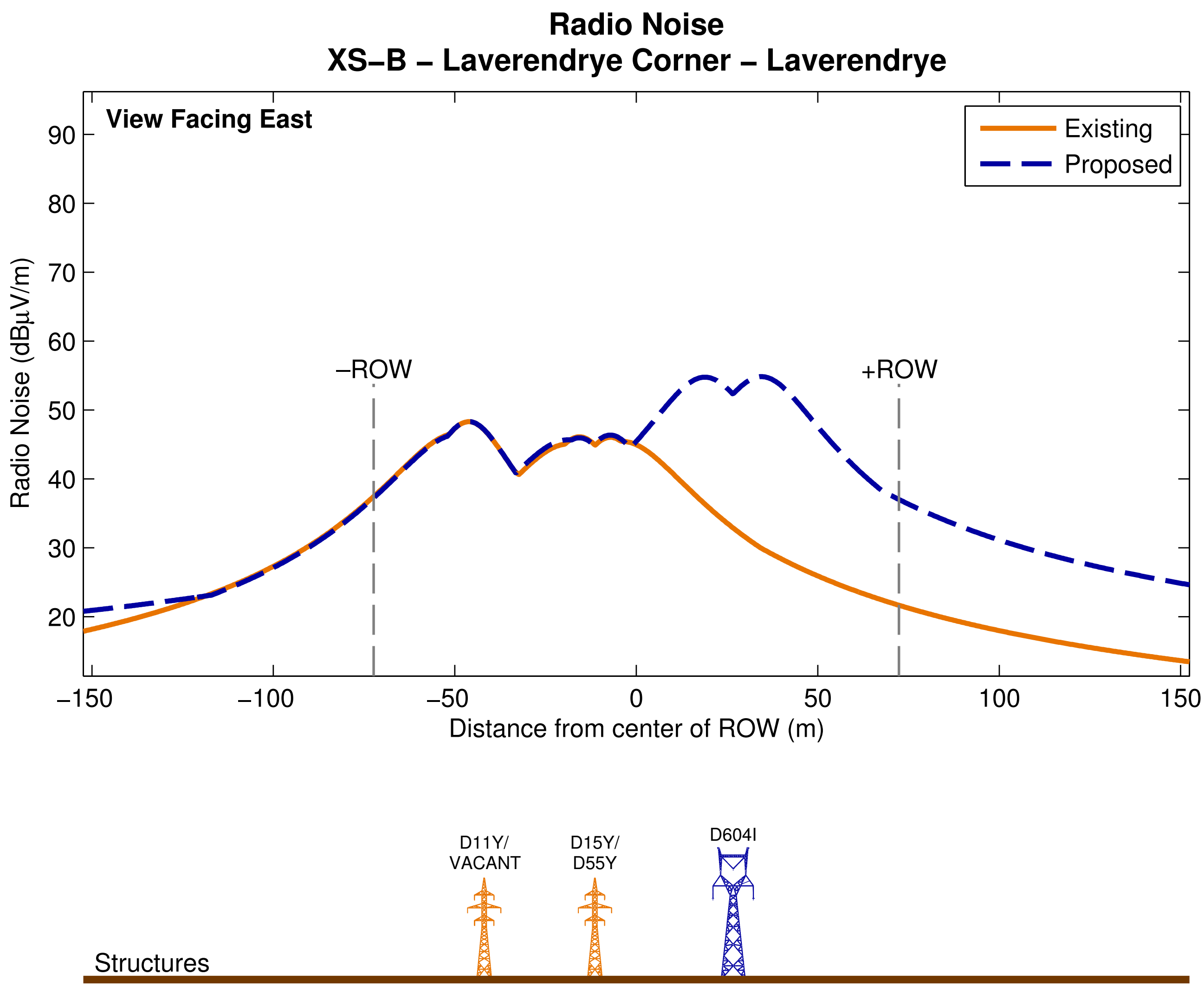

Figure B-29. Radio noise profile in fair weather along XS-B - Laverendrye Corner - Laverendrye.

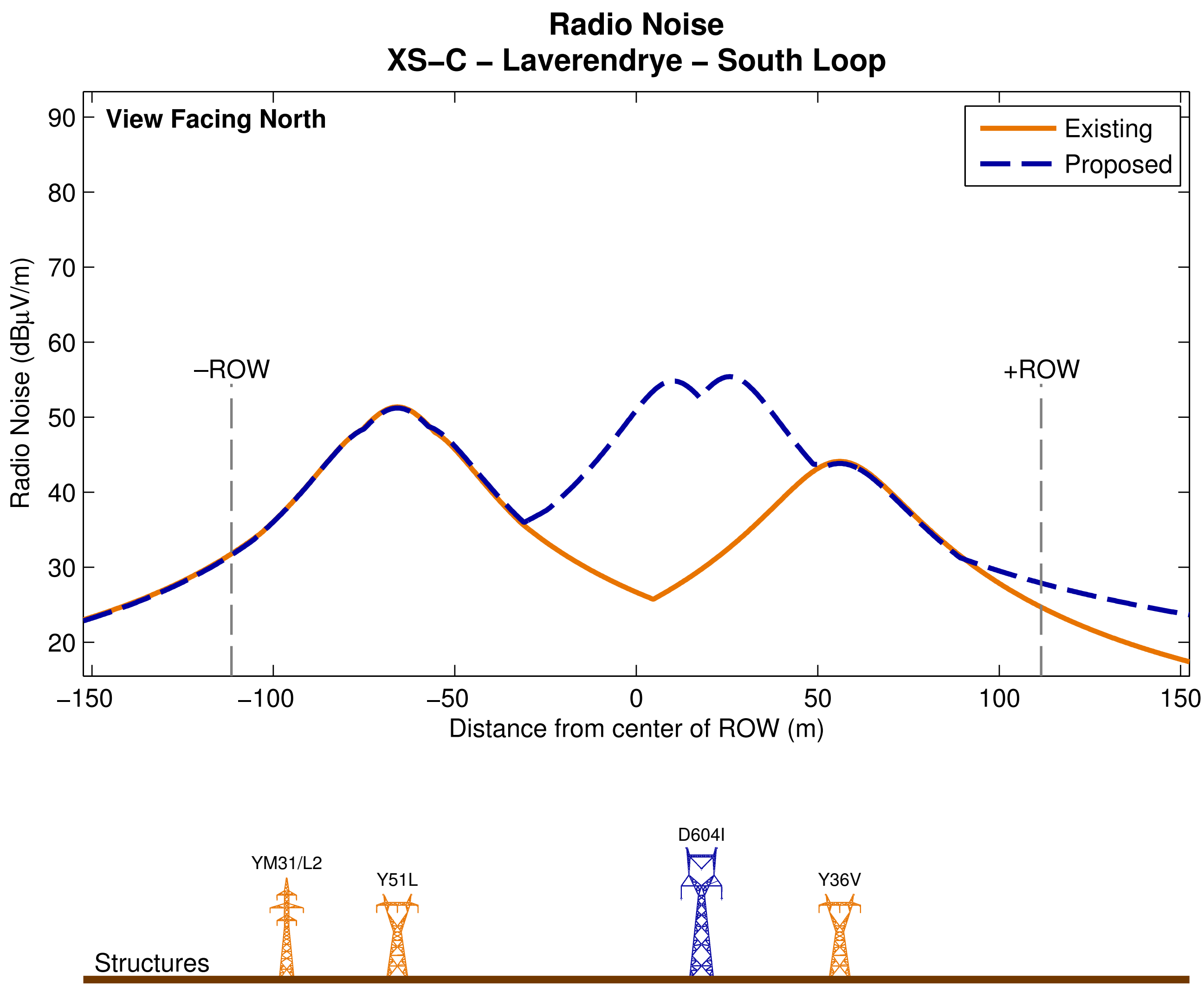

Figure B-30. Radio noise profile in fair weather along XS-C - Laverendrye - South Loop.

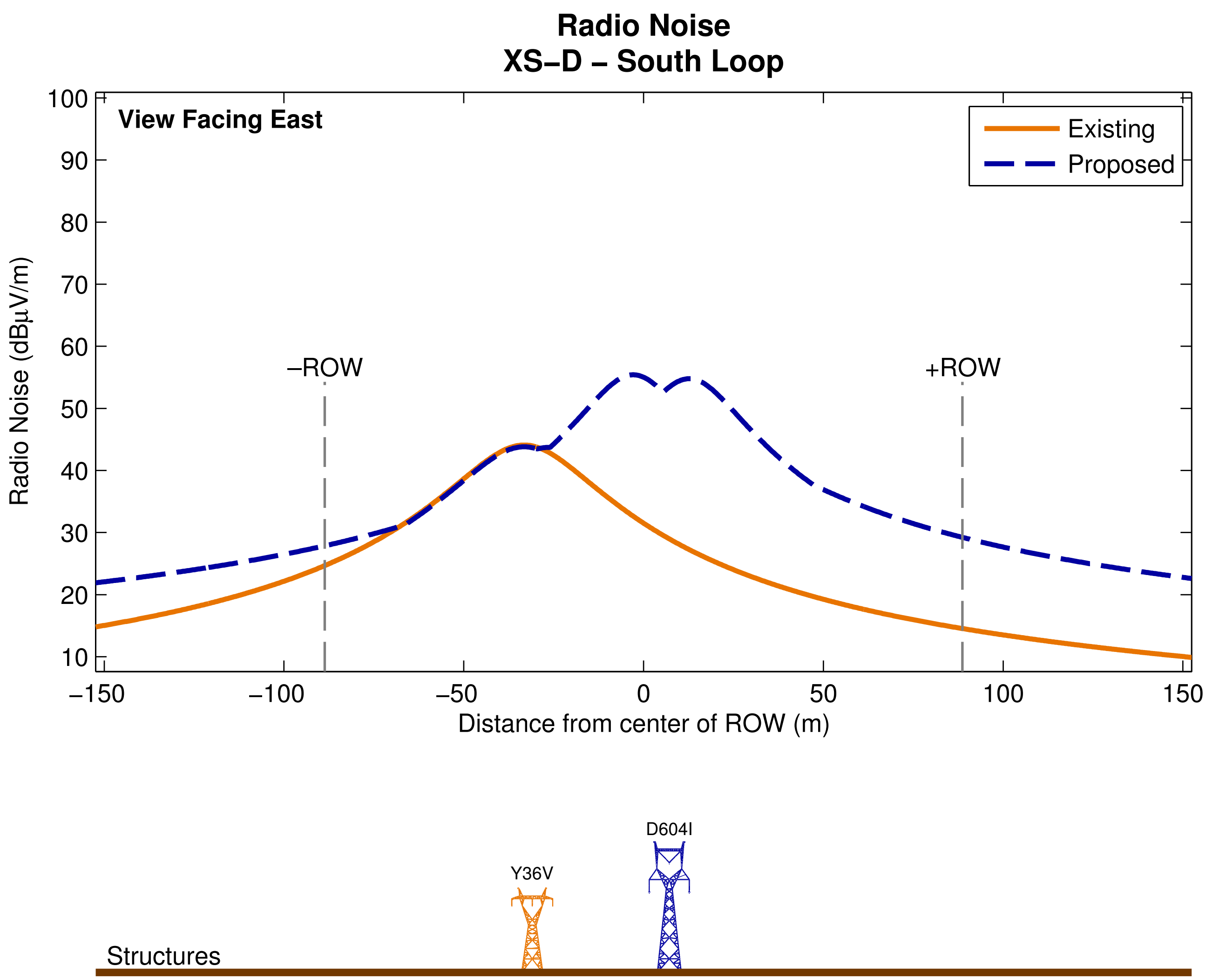

Figure B-31. Radio noise profile in fair weather along XS-D - South Loop.

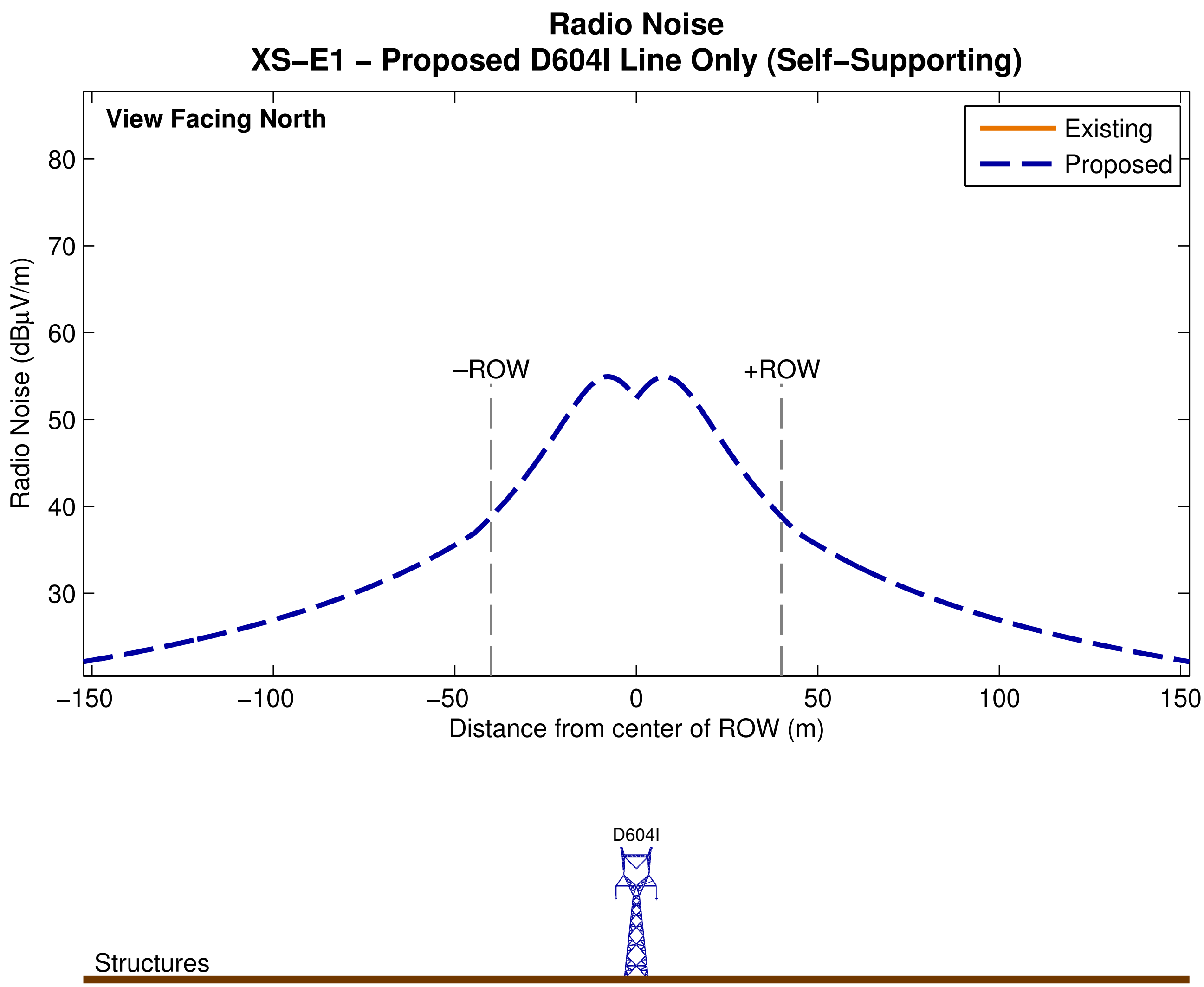

Figure B-32. Radio noise profile in fair weather along XS-E - Proposed D604I Line Only (Self-Supporting).

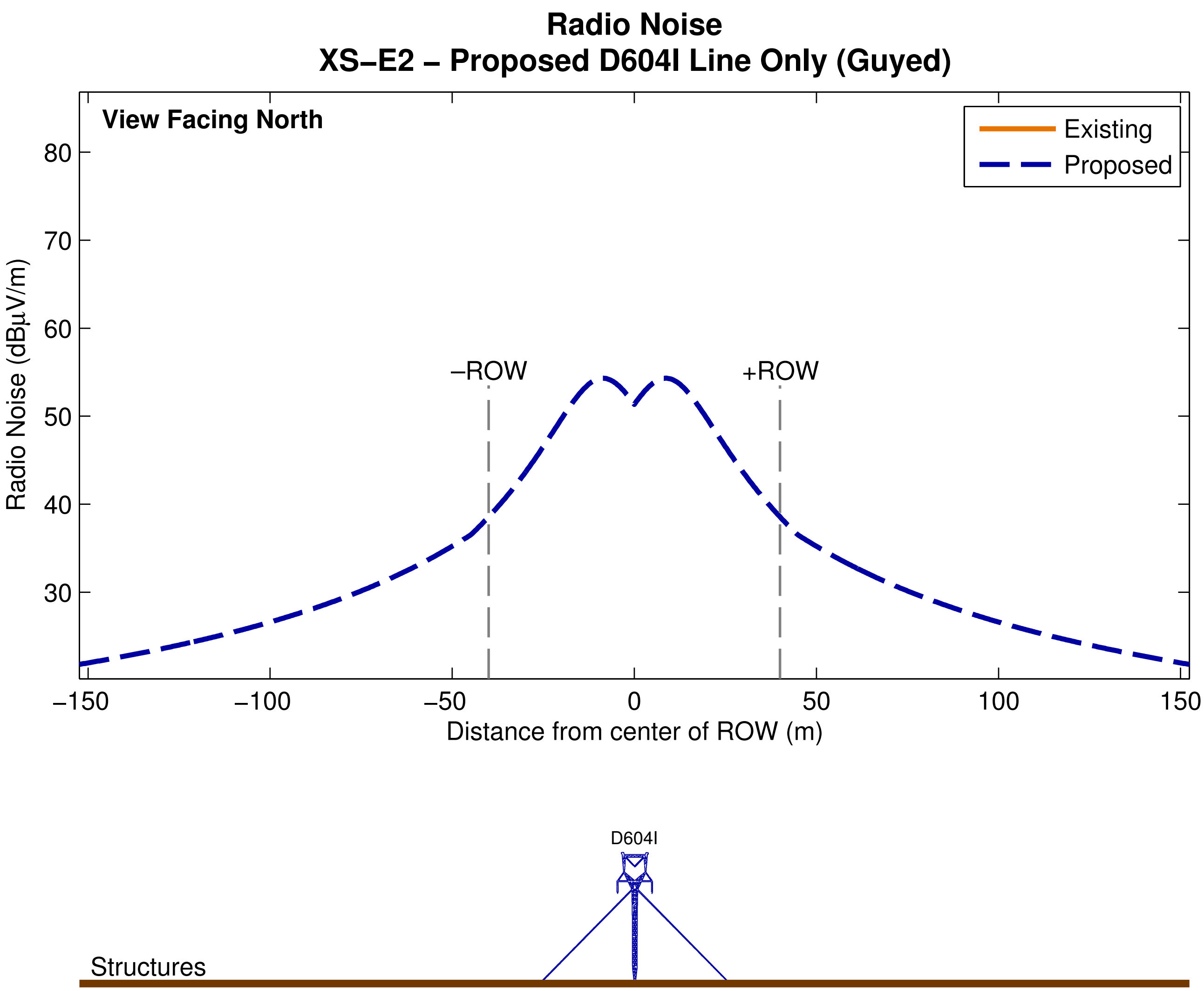

Figure B-33. Radio noise profile in fair weather along XS-E - Proposed D604I Line Only (Guyed).

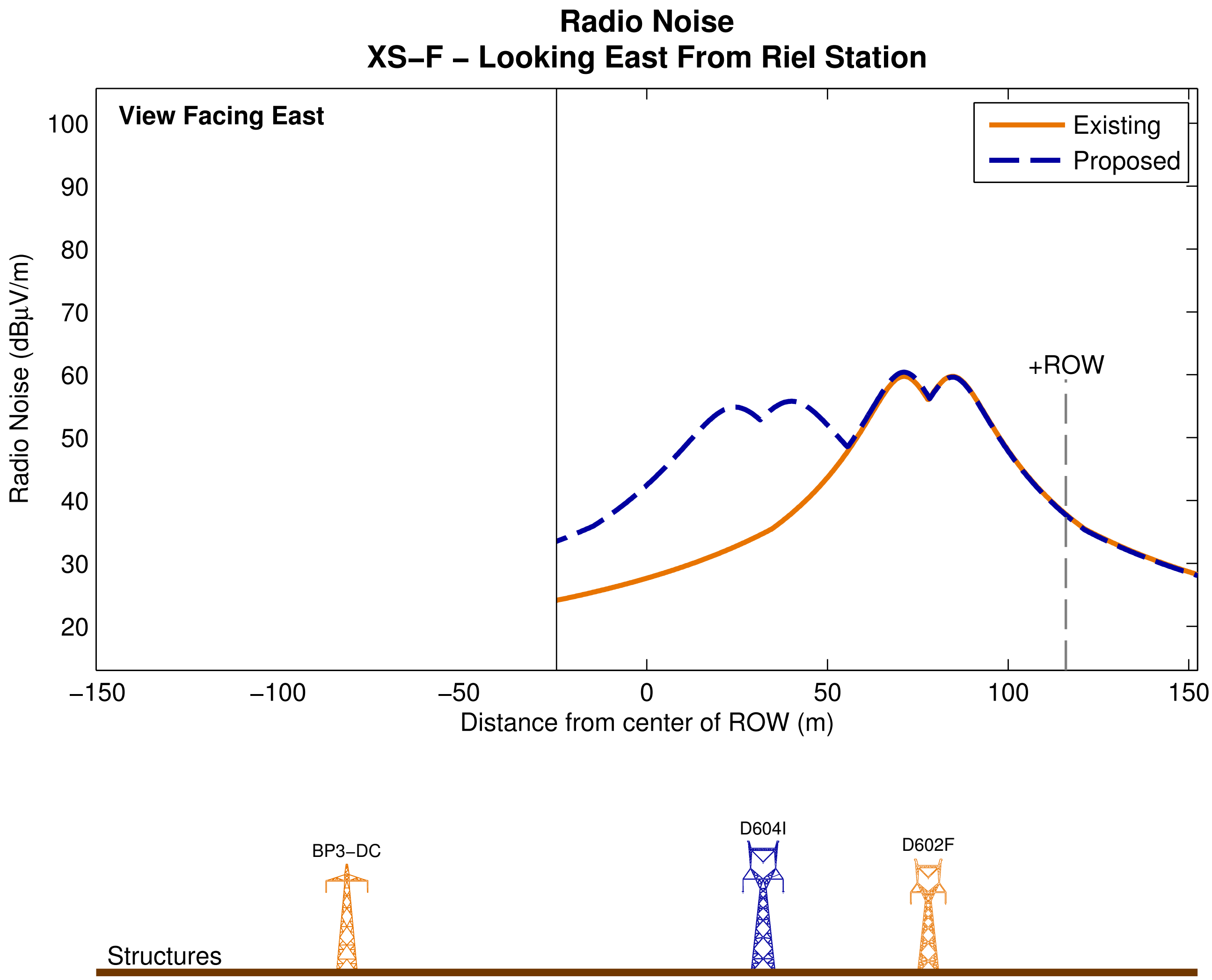

Figure B-34. Radio noise profile in fair weather along XS-F - Looking East From Riel Station. The radio noise from the Bipole III DC line is not shown here as the line is too far from the southern edge of the right-of-way to meaningfully affect the calculated radio noise level in the profile further to the south. Including contributions from the Bipole III DC line would increase radio noise levels by less than 0.1 dBμV/m at the southern edge of the right-of-way.

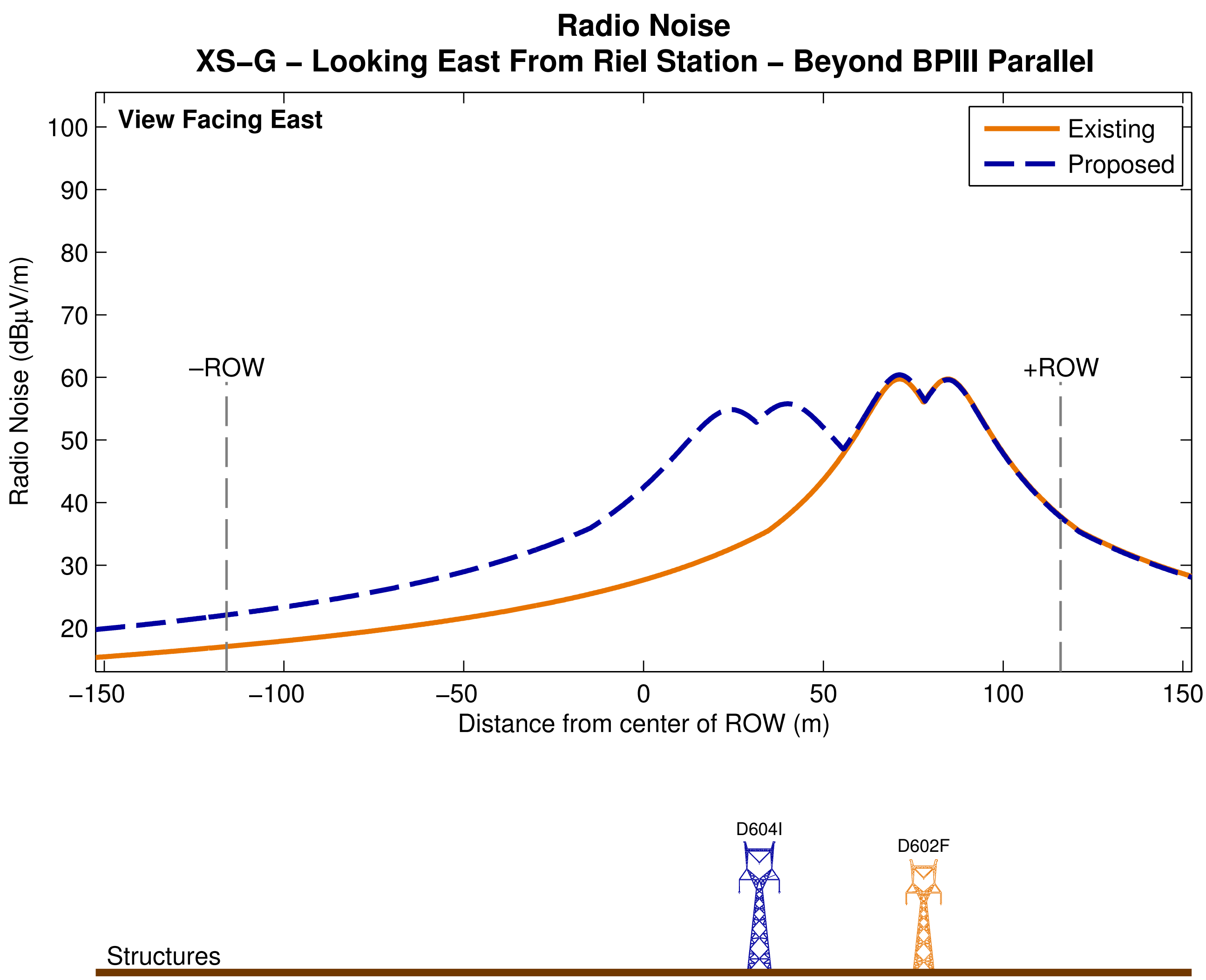

Figure B-35. Radio noise profile in fair weather along XS-G - Looking East From Riel Station - Beyond Bipole III Parallel.

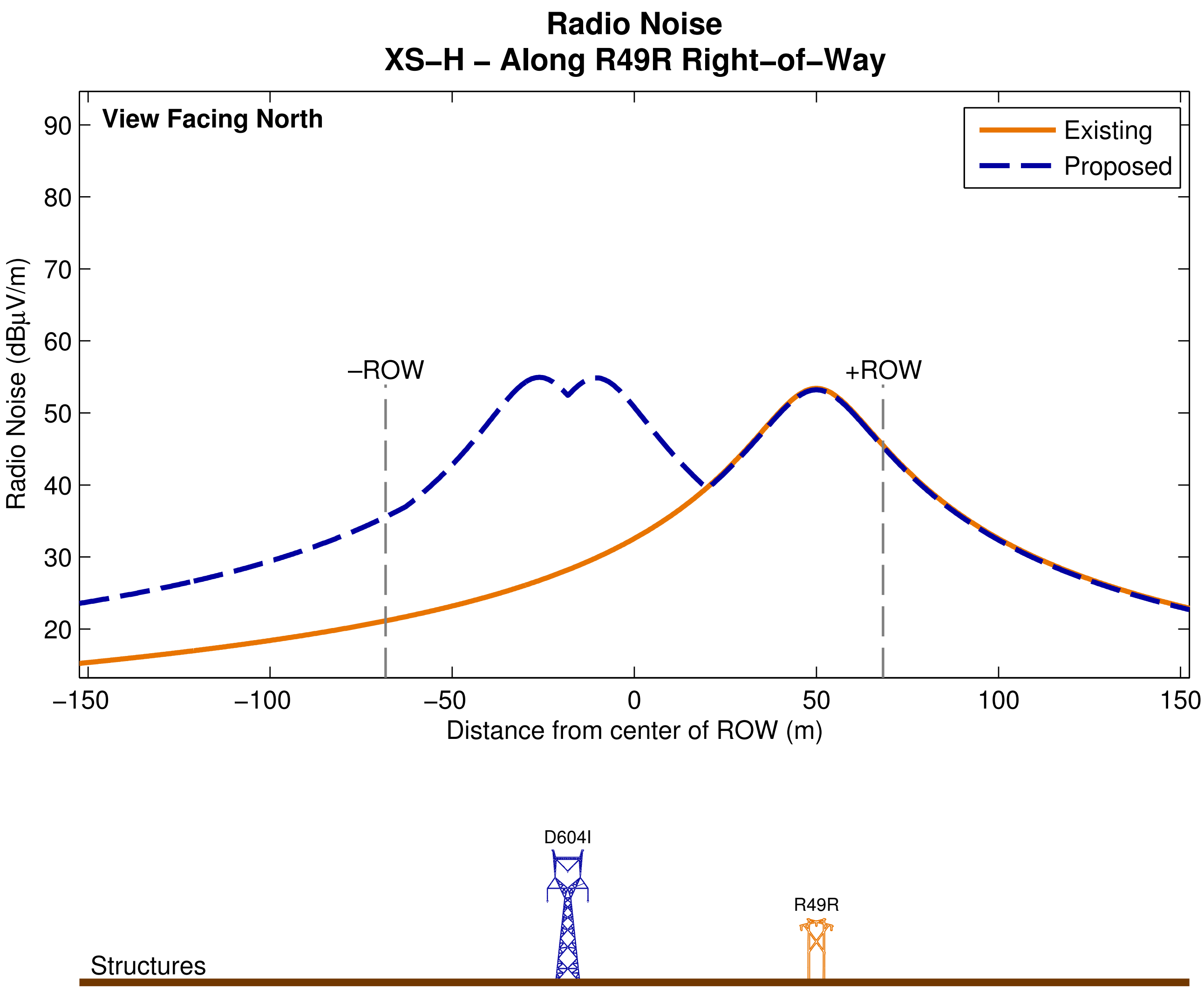

Figure B-36. Radio noise profile in fair weather along XS-H - Along R49R Right-of-Way.

Appendix C

Summary of ROW Configurations, Line Loading, and New Structure Diagrams

Table C-1. Summary of ROW configurations for each section

		Circuits											
Section	**Section Description**	**D604I**	**D55Y**	**D14S**	**D15Y**	**D11Y**	**YM31**	**L2**	**Y51L**	**Y36V[25]**	**D602F**	**BPIII**	**R49R**
A	Dorsey – Laverendrye Corner	P	E	E	E	E							
B	Laverendrye Corner – Laverendrye	P	E		E	E							
C	Laverendrye – South Loop	P					E	E	E	E			
D	South Loop	P								E			
E1	D604I Only (Self - Supporting)	P											
E2	D604I Only (Guyed)	P											
F	East of Riel Converter Station	P									E	E	
G	East of Riel, Beyond BPIII	P									E		
H	Along R49R	P											E

P = Proposed
E = Existing (not changed by project)

[25] The Y36V line is a proposed line for the separate St. Vital Transmission Complex project. It is included in this report as an existing transmission line to accurately analyze the cumulative effects of all currently anticipated transmission lines within the ROW.

Table C-2. Summary of line loadings of existing and proposed conditions used for modeling magnetic fields

Line	Sections	Voltage (kV)	Average		Peak	
			MW	MVAR	MW	MVAR
D604I*	All	500	881	62	1000	71
D55Y	A,B	230	183	5.3	269	7.8
D14S	A	230	144	12	197	16
D15Y	A,B	230	181	68	274	103
D11Y	A,B	230	180	5.2	269	7.8
YM31	C	115	28	14	51	25
L2	C	66	34	2.0	41	1.0
Y51L	C	230	115	3.7	139	4.4
Y36V	C,D	230	42	42	64	65
D602F*	F,G	500	1000	71	1770	118
BPIII	F	500 (DC)	1200	n/a	2000	n/a
R49R	H	230	120	18	149	22

* Loading on the proposed D604I line and the existing D602F line will be swapped in Sections F and G for the proposed configuration.

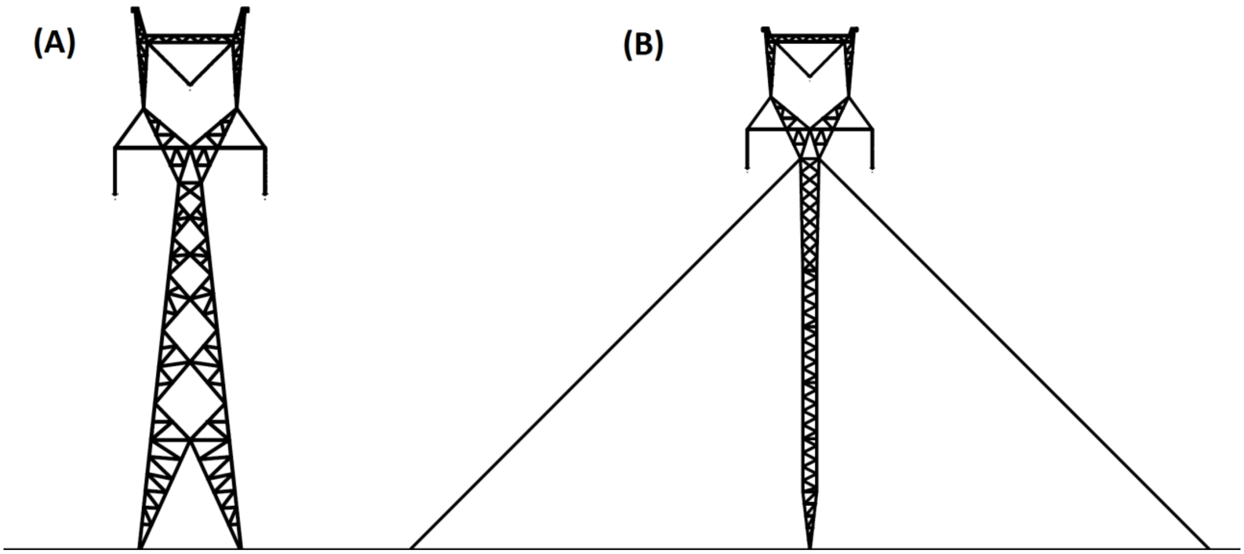

Figure C-1. Schematic of proposed structures for MMTP transmission line D604I.

(A) Self-supporting lattice steel structure.
(B) Guyed lattice steel structure.
(Structures not drawn to scale relative to one another)