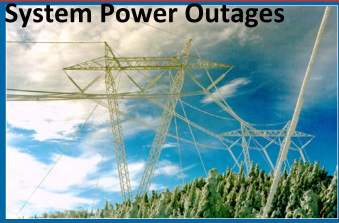
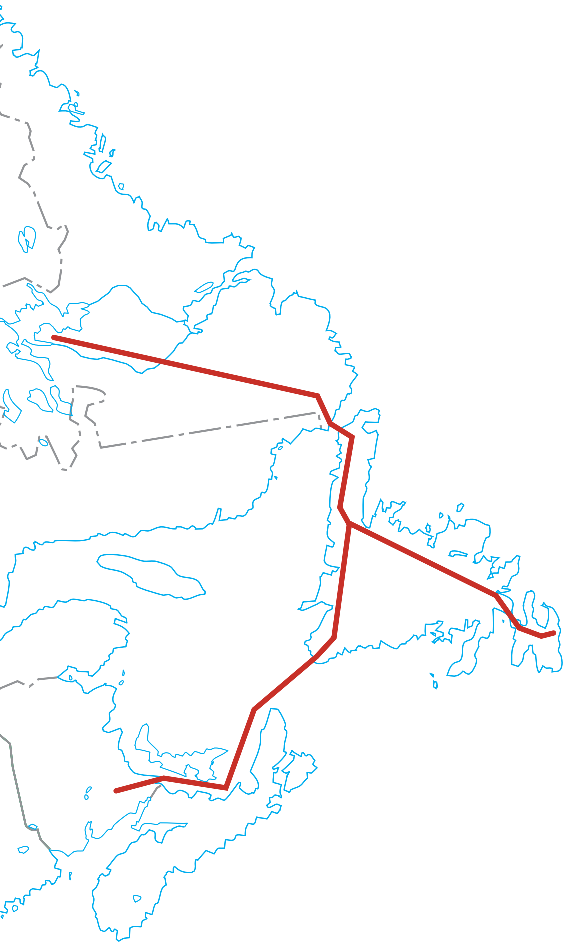
Q. **Reference: PUB-NLH-496:** Figure 1 in the response provides the LIL delivered power profile following a permanent pole fault, a period of 30 minutes. Have studies been completed to estimate the amount of the electrode current that may return through unintended paths such as power transformer neutrals? If so, please provide the studies for review. If not, does Hydro intend to complete these studies and if so, when?

A. Studies have been completed to estimate the potential for unintended neutral currents in ac power transformers during operation of the Labrador – Island HVdc Link in monopolar mode. CA-NLH-107 Attachment 1 provides a copy of the report *DC1250 – Electrode Review Types and Locations*.

nalcor energy





THE Lower Churchill PROJECT

March 2010

DC1250 - Electrode Review Types and Locations

prepared by

HATCH

nalcor energy

THE Lower Churchill PROJECT

March 2010

DC1250 - Electrode Review Types and Locations

REGISTERED PROFESSIONAL ENGINEER
ROBERT WOOLGAR
SIGNATURE
Apr. 15, 2010
DATE
NEWFOUNDLAND & LABRADOR

PROVINCE OF NEWFOUNDLAND AND LABRADOR
PEG Newfoundland and Labrador
PERMIT HOLDER
This Permit Allows
HATCH LTD.
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by PEG D0090
which is valid for the year 2010

prepared by

HATCH™

HATCH™

Table of Contents

Appendices

List of Tables

List of Figures

Executive Summary

As part of the Lower Churchill Project (LCP), Nalcor Energy – Lower Churchill Project (NE-LCP) is planning to install a three-terminal HVdc system linking Labrador, Newfoundland, and the Maritime provinces. The proposed HVdc bipole system will involve submarine cable and overhead line. The Gull Island terminal in Labrador will operate only as a rectifier, while the Soldiers Pond terminal in Newfoundland and the Salisbury terminal in New Brunswick will operate as either a rectifier or an inverter.

Previous studies undertaken by Nalcor Energy related to the proposed HVdc system have included a review of HVdc electrode requirements for the Gull Island and Soldiers Pond converter sites. Sea locations were identified as viable options in the Strait of Belle Isle (SOBI) and in Lake Melville for the Gull Island electrode, and in several bays around the Avalon Peninsula for the Soldiers Pond electrode.

It is likely that electrode selection for the Gull Island and Soldiers Pond converters will be a key issue during public consultations and through the regulatory process. NE-LCP felt that the current body of work upon which the presently preferred sea electrodes was based needed further review. As such, NE-LCP undertook additional work in order to further review the viability of alternate electrode types and locations for the Gull Island and Soldiers Pond converters. To accomplish this, NE-LCP brought together a team of experts in HVdc electrodes and local geology and geophysics. The panel participants and their specific areas of expertise are as follows:

Donald Gordon – HVdc land electrode;

Terry Treasure – HVdc shore electrode;

Calvin Miles – Geotechnical;

Hugh Miller – Geophysics; and

Peter Kuffel – HVdc systems and panel coordinator.

This work was conducted as WTO DC1250 "Electrode Review – Types and Locations".

The main objectives of this review were to identify alternate HVdc electrode sites and to evaluate the viability of these sites for the Gull Island (Labrador) and Soldiers Pond (Island) converter station electrodes.

The electrode review panel held a working session meeting in St. John's in June, 2009 in conjunction with NE-LCP during which the panel identified the following:

- comparative advantages and disadvantages of different types of electrodes,
- basic selection criteria for each type of electrode, and
- potential sites for both the Gull Island and Soldiers Pond electrodes,
- criteria for determining the viability of the potential sites identified.

From a regulatory perspective, it was determined that a land electrode would be the preferred type, followed by a shoreline pond electrode and then by a sea electrode.

A number of potential sites for a land electrode and a shoreline pond electrode in Lake Melville were identified in Labrador. Since the task of undertaking field work in Labrador would take some time, preliminary electric field calculations were carried out to calculate the ground potential rise (GPR) at various locations of interest based on the anticipated soil data, including earth resistivity, thicknesses and the extent of geological units. A preliminary electrode design was developed based on the calculated electrode duty and the anticipated electrical and thermal properties of the soil. Soil modeling scenarios of varying resistivities and thicknesses were prepared and a sensitivity analysis was performed.

The results of the simulations produced high GPR levels which would indicate significant mitigation measures for infrastructure in the electrode's zone of influence. Based on these results it was concluded that none of the potential land electrode sites identified in Labrador or a shoreline pond electrode in Lake Melville were viable sites. It was recommended that consideration be given to locating a suitable site for a shoreline pond electrode on the SOBI. A preliminary desktop review has identified L'Anse-au-Diable as one potential site.

A number of potential sites were identified on the Island for land and shoreline pond electrodes. Among these sites, the most suitable option was the candidate shoreline pond site at Dowden's Point, a location on the south shore of Conception Bay between Lance Cove Pond and Seal Cove Pond. Since Dowden's Point would provide a number of advantages over other potential sites on the Island and because the anticipated resistivity of the geology on the Island was similar to that of Labrador, the potential land electrode sites were discounted and only a shoreline pond electrode at Dowden's Point was analyzed. A preliminary field investigation was conducted in September 2009 to better identify soil conditions at Dowden's Point and allow a more accurate assessment of the viability of the site.

A preliminary electrode design was developed based on the calculated electrode duty and a safe voltage gradient. Electric field simulations were conducted to determine the GPR values in the vicinity of Dowden's Point. The simulations used soil models based on resistivities of shallow geological units determined during field measurements, anticipated resistivities of remaining geological units, accepted textbook values for seawater resistivity, and a conservative void ratio for the breakwater. The GPR values obtained in the electric field simulations were of the order in which mitigation measures would likely not be required, therefore an assessment of the impact on surrounding infrastructure was undertaken.

Models of existing infrastructure identified by NE-LCP were developed and the results of this analysis showed that, based on the known geological conditions, operation of a shoreline pond electrode at Dowden's Point would have minimal corrosive and electrical interference impacts on the existing infrastructure identified by NE-LCP. It is anticipated that a typical station terminal, multi-grounded neutral distribution network or pipeline will not be impacted significantly by the operation of the HVdc electrode and mitigation measures may be avoided. In all cases, preliminary investigations indicated that suitable, well-proven mitigation can be provided, if required.

Based on these results, it was concluded that a shoreline pond electrode at Dowden's Point is a viable alternative for the Soldiers Pond converter.

Since the soil model for the electrode was based on limited geophysical information, assumptions were made in the electrical model to evaluate potential impacts that would produce pessimistic results. It was therefore recommended that a more detailed study for a shoreline pond electrode at Dowden's Point be undertaken to improve the accuracy of the electrode model, re-evaluate the impact on infrastructure and review structural aspects of the electrode installation.

The next steps are to identify candidate sites on the SOBI for the Gull Island electrode and to qualify the evaluation of the Dowden's Point electrode. The shoreline pond electrode on the SOBI needs to be designed and to be evaluated for its impact on the surrounding infrastructure. A further evaluation of the Dowden's Point shoreline pond electrode is required to qualify the assumptions made and review structural aspects of the electrode installation.

1. Introduction

The Churchill River in Labrador is a significant source of renewable, clean electrical energy; however, the potential of this river has yet to be fully developed. The existing 5,428 megawatt Churchill Falls generating station, which began producing power in 1971, harnesses about 65% of the potential generating capacity of the river. The remaining 35% is located at two (2) sites on the lower Churchill River, known as the Lower Churchill Project (LCP).

The Lower Churchill Project consists of two (2) of the best undeveloped hydroelectric sites in North America: Gull Island, located 225 km downstream from the existing Churchill Falls generating station; and Muskrat Falls, located 60 km downstream from Gull Island. The 2,250-megawatt project at Gull Island has the potential to produce an average of 11.9 terawatt-hours of energy annually. The 824 megawatt project at Muskrat Falls has the potential to produce an average of 4.8 terawatt-hours per year.

In addition to the development of these generating sites, the overall concept includes various potential alternative power transmission arrangements involving combinations of ac and dc lines of various capacities.

As part of the Lower Churchill Project, Nalcor Energy – Lower Churchill Project (NE-LCP) is planning to install a three-terminal HVdc system linking Labrador, Newfoundland, and the Maritime provinces. The proposed HVdc bipolar system will involve cable and overhead line, with about 40 km of cable between Labrador and Newfoundland and about 480 km between Newfoundland and New Brunswick. The Gull Island terminal in Labrador will operate only as a rectifier, while the Soldiers Pond terminal in Newfoundland and the Salisbury terminal in New Brunswick will operate as either a rectifier or an inverter. The proposed HVdc system is conceptually shown in Figure 1-1.

Previous studies undertaken by NE-LCP related to the proposed HVdc system have included a review of electrode requirements for the Gull Island and Soldiers Pond converter sites [1]. Sea electrode locations were identified in the Strait of Belle Isle (SOBI) and in Lake Melville for the Gull Island converter station and in Conception Bay for the Soldiers Pond converter station. Electrode alternatives for the Salisbury converter station were not reviewed in the previous report.

It is likely that electrode selection for the Gull Island and Soldiers Pond converters will be a key issue during public consultations and through the regulatory process. NE-LCP feels that the body of work upon which the presently preferred sea electrodes is based needs further review. As such, NE-LCP has retained Hatch to undertake additional work in order to further review the viability of alternate electrode locations and designs for the Gull Island and Soldiers Pond converters. To accomplish this, NE-LCP brought together a panel of electrode experts to conduct the review. This panel will provide guidance to establish a roadmap to carryout a thorough and comprehensive review of the viability of alternate electrode sites and designs for the Gull Island and Soldiers Pond converters.

Throughout this report, the terms "Labrador electrode" and "Island electrode" are used to refer to the Gull Island and Soldiers Pond converter station electrodes respectively.

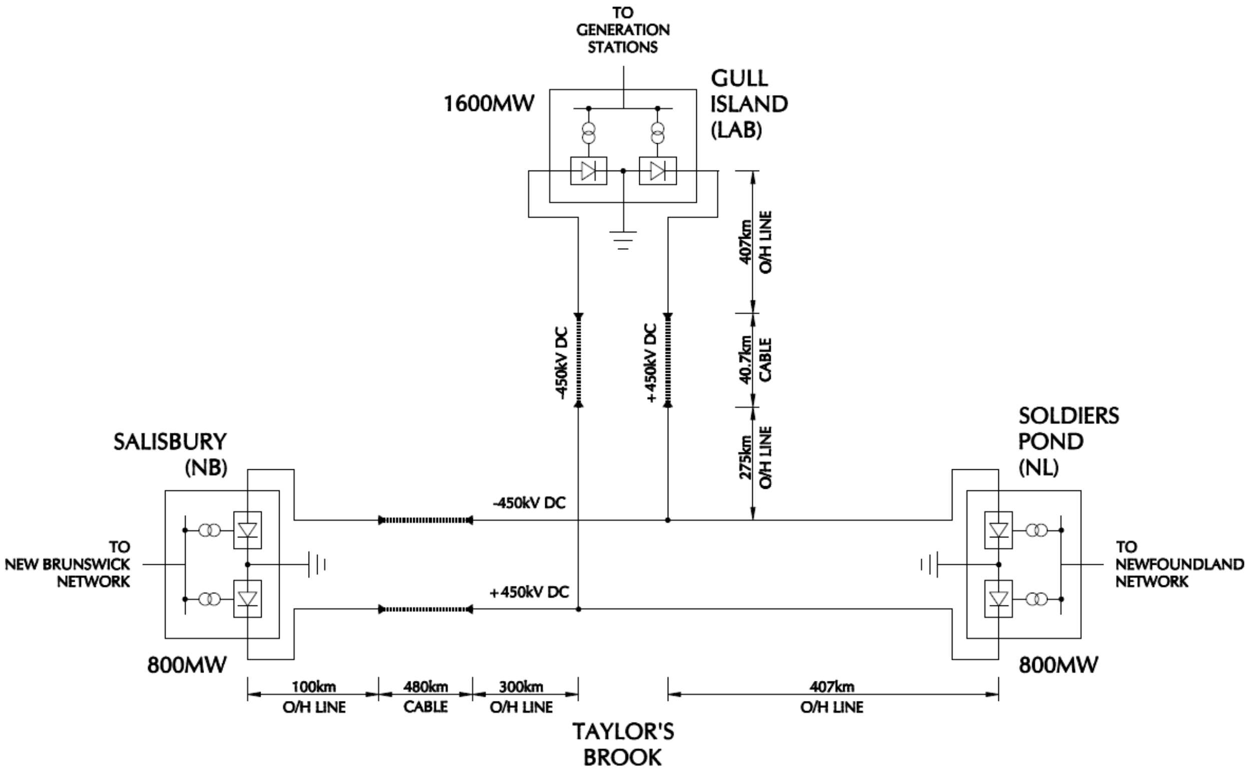


Figure 1-1: Proposed Lower Churchill Multi-Terminal HVdc System

nalcor energy	FIGURE 2.2
	Labrador - Island Transmission Link: Project Overview

Figure 1-2: Proposed HVdc Transmission Link

2. Terms of Reference

The main objectives of this review were to identify alternate HVdc electrode sites and to evaluate the viability of these sites considering typical electrode designs for the Gull Island and Soldiers Pond converter stations. Previously, sea electrodes in the SOBI and in several bays around the Avalon Peninsula were identified as viable options [1] for the Gull Island and Soldiers Pond converter stations, respectively.

The review was conducted by a panel consisting of experts in HVdc electrodes and local geology and geophysics. The panel participants and their specific areas of expertise are as follows:

Donald Gordon – HVdc land electrode;

Terry Treasure – HVdc shore electrode;

Calvin Miles – Geotechnical;

Hugh Miller – Geophysics; and

Peter Kuffel – HVdc systems and panel coordinator.

The scope of the review was limited to the Gull Island and Soldiers Pond converter stations only and included the following main tasks:

- Review previous work and in particular the basis upon which the presently preferred sea electrodes were selected.
- Prepare a summary of the comparative advantages and disadvantages of each type of electrode taking into account the known requirements of the LCP.
- Identify the criteria to be applied to determine the viability of a land or shore electrode.
- Identify potential land and shore electrode sites
    - Identify the requirements for locating a suitable electrode site.
    - Identify types and potential sources of existing data.
    - Review available data to determine the likelihood of locating a potential site.
    - Identify a search area.
    - Assess the likelihood of finding a suitable site within the identified search area.
    - Identify potential viable sites.
    - Identify further steps to be taken to confirm the viability of a site.
    - Identify and discuss potential issues and benefits.
- If potential sites are identified, perform a preliminary investigation to determine the viability of the identified sites.

- If further investigations are warranted, identify "next steps" to be undertaken by NE-LCP to fully assess the potential sites and ultimately determine preferred electrode types and locations.
- Participate in associated discussions and workshops within LCP and with applicable regulators.
- Prepare a report with recommendations.

It was recognized that there may be a need to adapt the tasks during the course of the work in response to the results obtained.

3. Review of Previous Electrode Studies

In 2007 NE-LCP undertook the following high level analysis to assess the viability of HVdc electrodes for the converter stations:

Hatch Ltd[1] *, "Newfoundland and Labrador Hydro – Lower Churchill Project, DC1110 Electrode Review – Gull Island and Soldiers Pond, Final Report", March 2008 (DC1110).*

The DC1110 study included: a review of electrode requirements for the Gull Island and Soldiers Pond converter stations; electric field simulations of sea electrodes; an assessment of the feasibility of a land electrode at Gull Island, and alternative sea electrodes for Gull Island and Soldiers Pond; a review of possible impacts and typical mitigation measures; a typical sea electrode design; and installation cost estimates of the sea electrode.

Based on a geological literature review and the resistivity measurements made in 2007, the DC1110 study concluded that a land electrode for either the Gull Island or Soldiers Pond converter sites would not achieve the required grounding. Sea locations were identified as viable options in the SOBI and in Lake Melville for the Gull Island electrode, and in several bays around the Avalon Peninsula for the Soldiers Pond electrode. DC1110 also stated that sea electrodes are preferred to shore electrodes because (i) there is less uncertainty with respect to achieving the required grounding since resistivity is better known and (ii) overheating of the electrode is not normally a concern.

Another study which contains reference to electrodes is:

Teshmont, "Newfoundland and Labrador Hydro – Gull Island to Soldiers Pond HVdc Interconnection, Engineering Review and Update of Capital Cost Estimate", 1998 (Teshmont Study).

The Teshmont study pertained to reviewing previous studies and updating cost estimates for the proposed HVdc interconnection. The study found that very little field work had been carried out to identify a suitable electrode site for the Gull Island converter station. Typically the Canadian Shield is an area underlain by high resistivity rock. Significant ground potentials due to high currents flowing to or from an electrode could extend for distances of up to 50 km or more. A sea electrode was assumed in Lake Melville for the Labrador converter and in Conception Bay for the Island converter. Further review/studies/investigations were recommended to determine type, location and design of the electrodes.

No field investigation or actual soil resistivity measurements for electrode installation had been made at any locations up to 2007; however, soil resistivity measurements at Gull Island and Soldiers Pond converter locations were made during the 2007 field program conducted by AMEC for NE-LCP. These resistivity investigations reached median depths of 38 m at Gull Island and 29 m at Soldiers Pond. The median depth is defined as the depth for a given resistivity array geometry such that one half of the current introduced into the ground flows between the surface and the median depth, with the remainder flowing between the median depth and an infinite distance below the surface. At both converter station locations, these median depths were much greater than the depth to the "native

[1] The lead consultant on this study was Statnett; and the report was the result of their analysis and investigations together with contributions from other members of the consortium.

soil", geologically termed bedrock. At the Gull Island converter site, a low resistivity layer close to the surface was identified.

4. Electrode Types

Types of electrodes used in HVdc systems can be categorized as land, shore and sea types according to their installation locations. A land electrode can be either a shallow or deep burial type depending on ground conditions. Shore electrodes are divided into beach and shoreline pond electrodes, with beach electrodes located 10 m to 50 m inside the waterline and shoreline pond electrodes located within a man-made pond filled with sea water near the shore and protected by some form of breakwater. Sea electrodes are located farther from shore.

The CIGRÉ 1998 Guide [2] notes that sea and shore electrodes are generally preferred over land electrodes for the following reasons:

- there is less uncertainty with respect to achieving the required grounding since resistivity is better known,
- overheating of the electrode is not normally a concern.

In general, when selecting an appropriate location for an electrode the following factors are taken into consideration:

- Land ownership and the matter of obtaining permission to establish and operate the electrode at the intended site, including the use of land for shore-based installations in the case of a sea electrode.
- The characteristics of the site with respect to resistivity, moisture content, thermal conductivity, water exchange, water depth, sedimentation, and exposure to environmental elements.
- Potential impacts on infrastructure including the converter stations, the ac system, metallic objects such as pipelines, cables, etc.
- Consideration of potential conflicting activities such as shipping or boating activities in the case of sea electrodes.
- Potential influences on the marine environment, in the case of sea electrodes.
- Cost considerations for alternative locations.

4.1 Sea Electrode

A sea electrode is an electrode which is typically located more than 100 m off the coast at water depths which may range from approximately 5 m to 30 m.

Potential advantages of a sea electrode include:

- Low ground resistance.
- Minimum visual impact.
- No risk of overheating.
- Lower level of interference.

Potential disadvantages of a sea electrode include:

- High initial capital cost due to marine work.
- Very high repair and inspection costs.
- Potential impact (real or perceived) on the environment.
- Susceptible to damage from icebergs, ships anchors and fishing operations.

The earlier DC1110 study [1] had concluded that a sea electrode for the Gull Island converter located in the Straight of Belle Isle or Lake Melville and a sea electrode for the Soldiers Pond converter located in several bays around the Avalon Peninsula would be feasible.

As the main objective to this study was to investigate alternative locations and configurations for land and shore electrodes, alternate locations or configurations for sea electrodes were not considered.

4.2 Land Electrode

Land electrodes can be either shallow burial, vertical well or deep well types. The most common type of land electrode design is the shallow burial type. Vertical well land electrodes are typically used when sufficient space is not available for shallow burial types or when a better conducting stratum is present at depth. Such installations would likely be more costly than a shallow burial because the electrode elements would be installed in individual boreholes to depths of typically more than 100 m. A deep hole electrode was constructed as a prototype on the Swedish converter site of the Baltic Cable link, but was decommissioned due to a malfunction. It was determined that the cables inside the electrode were damaged due to a large pH drop created by a low buffer effect.

Potential advantages of a land electrode include:

- Avoids long electrode lines if converters are far inland from sea.
- Ease of access for maintenance for shallow burial types.

Potential disadvantages of a land electrode include:

- Difficult to locate suitable sites.
- Large area for site may be required depending on geological conditions.
- Likely to have interference issues.
- Has higher ground resistance compared to other electrode types and therefore higher losses.
- Risk of overheating and resultant failure.

Different configurations of shallow burial land electrodes are possible, with the most common being a ring-type electrode due to the resultant symmetrical current distribution.

The potential land electrode sites evaluated in this study assumed a ring-type electrode.

4.3 Shore Electrode

Shore electrodes are subdivided into beach and shoreline pond electrodes. A beach electrode is located 10 to 50 m inside the waterline either buried in the beach or in shallow wells, and a shoreline pond electrode is located in a seawater-filled shoreline pond and protected by some form of breakwater if exposed to significant wave action. Factors which generally favour the use of shoreline pond electrodes over beach electrodes include efficient dissipation of heat generated at the electrode-water interface, easier control of accessibility to the general public, smaller footprint, and ease of maintenance and inspection.

Potential advantages of a shore electrode include:

- Very low repair and inspection costs.
- Lower level of interference as compared to a land electrode.
- Minimal environmental impact.
- No risk of overheating.
- Much smaller site than a land electrode.

Potential disadvantages of a shore electrode include:

- Potentially higher initial capital cost compared to a land electrode.
- Suitable sites may be difficult to locate.
- Some visual impact.
- Must be protected from pack ice and tidal activity.

The potential shore electrode sites evaluated in this study assumed a shoreline pond-type electrode.

5. Methodology

As part of their ongoing work, the panel held working session meetings in St. John's on June 11 and 12, 2009 (see Appendix J for summary of proceedings). The main goals of the working session included the following:

- Clarify requirements of NE-LCP.
- Clarify applicable regulatory and environmental requirements.
- Identify requirements to determine viability for each of the land and shoreline pond electrodes.
- Identify type and potential sources of existing data.
- Identify preliminary search regions.
- Identify criteria that can be applied in order to determine viability of potential electrode sites.
- Develop scope of work for preliminary field investigations to collect data to confirm viability of potential sites.
- Develop framework for the analysis of viable sites.

In discussions with NE-LCP it was determined that from a regulatory perspective, a land electrode would be the preferred type, followed by a shoreline pond electrode and then by a sea electrode.

The requirements identified to determine the viability of the electrode sites include: (i) for a land electrode, a nominal resistivity of 100 Ωm or less is desirable at the electrode location and a thickness of 20 m or more for the low resistivity layer is desirable, and (ii) for a shoreline pond electrode, a maximum electric field gradient of 1.25 V/m [3,4,5] is desirable in the water at the public access point.

Based on the known geological conditions in Labrador and on the Island, a number of potential electrode sites were identified and ranked according to criteria established by the team during the course of the working session meetings.

The following sections describe the methods used to analyze the feasibility of the proposed electrode sites for Labrador and the Island.

5.1 Labrador

Since the task of undertaking field work in Labrador would take some time, it was decided that preliminary electric field calculations should be carried out based on the anticipated earth resistivity data. The findings of these calculations would then be used to confirm the initial rankings of the sites and to develop a field program for Labrador.

Manual design calculations would be carried out based on the system current and the electrical and thermal properties of the soil in contact with the electrode elements to establish a preliminary electrode design. Soil modeling data (including resistivities and thicknesses of geological units) based on currently known information would be prepared. A number of scenarios would be evaluated in order to undertake a sensitivity analysis for variations in soil data.

Electric field simulations for the potential sites for land and shoreline pond electrodes would be performed to calculate the GPR at various locations of interest. If the results of the simulations indicated reasonable GPR levels, an analysis of the potential impact on the surrounding existing and planned infrastructure – including at the Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, Churchill Falls generating station, and the town of Happy Valley-Goose Bay – would be performed.

5.2 Island

Among the potential sites identified for land and shoreline pond electrodes on the Island, the highest ranked option was the candidate shoreline pond site at Dowden's Point, a location on the south shore of Conception Bay between Lance Cove Pond and Seal Cove Pond. Since Dowden's Point would provide a number of advantages over other potential sites on the Island and because the anticipated resistivity of the geology on the Island was similar to that of Labrador, the potential land electrode sites were discounted and only a shoreline pond electrode at Dowden's Point was analyzed. The viability of an electrode at Dowden's Point would be reviewed thoroughly until results indicated otherwise.

Given that mobilizing field staff would be relatively easy, a preliminary field investigation was conducted in September 2009 to better identify shallow soil characteristics at Dowden's Point. Soil data based on this field work, standard textbook values for seawater resistivity and resistivity values based on an analysis of the rock types in the area would be used to define soil modeling scenarios.

A preliminary basic design of a shoreline pond electrode would be carried out based on the calculated duty and the safe voltage gradient.

Electric field simulations for the shoreline pond electrode would be performed to calculate the GPR at various locations of interest. If the results of the simulations indicated reasonable GPR levels, nearby infrastructure would be identified and the impact on the infrastructure would be assessed.

6. Potential Sites

The basic requirements discussed during the working session meetings for land and shoreline pond electrodes were considered for identifying potential sites. The requirements include: (i) for a land electrode, a nominal resistivity of 100 Ωm or less is desirable at the electrode location and a thickness of 20 m or more for the low resistivity layer is desirable, and (ii) for a shoreline pond electrode, a maximum electric field gradient of 1.25 V/m [3,4,5] is desirable in the water at the public access point.

Figure 1-1 and Figure 1-2 show the potential electrode locations for land and shoreline pond electrodes for the Gull Island and Soldiers Pond converter stations respectively identified during the working session which meet the basic requirements stated above. Estimates of soil resistivities, distance relative to the converter station and technical issues associated with sites are also identified in the tables. The ranking of the electrode sites in the tables was based on a preliminary review of pros and cons considering access, electrode line length, proximity to existing and planned infrastructure, known area conditions, and anticipated geological conditions.

During the June working session meetings, it was noted that one of the fundamental criteria for the selection of a land electrode site is the presence of a relatively low resistivity layer of suitable thickness near the surface. The 2007 AMEC resistivity investigations of the vertical resistivity profile at the Gull Island generation, switchyard and converter station sites revealed low resistivities at shallow depth associated with clay layers in the unconsolidated surficial sediments (the overburden). This suggested that there may be suitable units in the surficial cover in which a land electrode could be located. Accordingly, several sites were identified during the discussions. At all of these sites, there are either surficial sediments or other material such as a bog which would have low resistivity.

During the working session meetings, the soil resistivity structure in the general Seal Cove/ Conception Bay South area was discussed since it was proposed that there may be low resistivity unconsolidated sediments present which may be acceptable for a land electrode. Based on the currently known geological conditions it was concluded that no viable sites for a land electrode on the Island would be likely. Therefore, the potential shoreline pond electrode site at Dowden's Point was identified as the prime candidate since it was located on the sea shore, was relatively close (<15 km) to the converter station site at Soldiers Pond, had an existing transmission line right of way from the nearby Holyrood generating station to the converter station area, and was a brownfield site of a former cement plant operation.

Locations of the identified potential land electrodes for Labrador are shown in Figure A-1 in Appendix A, and Dowden's Point site for a potential shoreline pond electrode is shown in Figure C-1 in Appendix C.

Table 6-1: Potential Electrode Sites Identified in Labrador

Rank	Site	Estimated Resistivity Note 1		Land Area Available (km²)	Land Ownership	Distance From Converter Station (km)	Nearest Infrastructure (km)	Electrode Line New ROW/total length (km)	Environmental Considerations	Technical Issues	Questions
		Shallow (Ωm)	Deep (Ωm)								
1	Bog near Pinus River	50	5000	1.5	Crown	10	10	2/12	Bog		
2	Lower/Upper Brook between Gull Island and Muskrat Falls Sites (LUB)	50	5000 (Fault)	60	Crown	30	30	0/30	Bog, forest	Proximity to reservoir	Electro-osmosis
3	Bog near TLH south of new bridge (TLH)	50	5000	infinite	Crown	40	15	60/120	Bog		
4	Bog near Kenamu	50	5000	infinite	Crown	60	15	60/120	Bog		
5	Shoreline near Kinriakak (KIN)	2	5000	infinite	Crown	60	?	90/150	Bog, shoreline	Freezing, access	
X	Low ground NW of converter station	50	5000	16	Crown	4 - 5	4 - 5	0/4-5	Bog, forest	Proximity to converter station	

Note 1. The resistivities used in the modeling scenarios are different than those initially identified during the working session meetings.

Table 6-2: Potential Electrode Sites Identified on the Island

Rank	Site	Estimated Resistivity Note 1		Land Area Available (ha)	Land Ownership	Distance from Converter Station (km)	Nearest Infrastructure (km)	Electrode Line New ROW/total length (km)	Environmental Considerations	Technical Issues	Questions
		Shallow (Ωm)	Deep (Ωm)								
1	Dowden's Point	2	2000	3	Private	3	0.5	short	Brownfield	Proximity to houses and possible infrastructure, freezing	Existing infrastructure
2	Indian Pond	2	2000	10	Crown	0.30	0.3	short	Fish, ocean	Proximity to Holyrood, converter stations, & other infrastructure, freezing	Existing infrastructure
3	Chapel Cove	2	5000	2	Private, crown	3	0.05	long	Fish, ocean	Proximity to houses and possible infrastructure	Existing infrastructure
X	Soldiers Pond	500?	5000	infinite	Crown	10	1	medium	Forest	Proximity to infrastructure, high shallow earth resistivity	
X	Area south of Holyrood GS	50?	2000?	1-2	Hydro, crown	<1	0.2	short	Cleared	Proximity to Holyrood, converter stations, & other infrastructure	
X	St. John's shale	500	2000	infinite	Crown	5	5	medium	Forest	Proximity to Holyrood, converter stations, & other infrastructure, high shallow earth resistivity	

Note 1. The resistivities used in the modeling scenarios are different than those initially identified during the working session meetings.

7. Electrode Design Criteria

The basic function of an electrode in an HVdc system is to transfer the system current from metallic conductors to the earth. Therefore, the electrode for an application shall have the capacity to carry the system current, shall be suitable for the specified operating duty over the life cycle of the project, shall meet the overall system reliability requirements, and shall have minimal impact on the environment.

The HVdc system configuration and modes of operation, geology structures of area soil and the infrastructure in the vicinity of the electrode site provide the basic electrode design parameters. Details of an electrode design will depend on the nature of the site where the electrode will be built. A systematic approach is needed to define the design criteria, design an electrode to meet the design criteria, review multiple electrode locations and design alternatives to select the optimal site, and evaluate the electrode's impact on the environment and infrastructure.

The criteria used for this study to define the electrode design and evaluate its impact on the environment and infrastructure is documented in the following sections.

7.1 System Currents

The current carrying requirements for the Gull Island, Soldiers Pond and Salisbury terminals in monopolar operation are shown in Table 7-1.

Table 7-1: Terminal Station Monopolar Current Duties

	Gull Island	Soldiers Pond	Salisbury
Nominal current, I_{nom} (A)	1780	890	890
Maximum continuous current, $I_{max,\ cont.}$ (A)	2320	1340	980
Maximum 10-minute overload, $I_{max,\ 10min.}$ (A)	2760	1780	980

7.2 Operating Duties

In general terms, electrode duties are based on the anticipated pole outage rates which result in the need for monopolar operation of the HVdc system, load factors and planned operating modes of the HVdc transmission system. Preliminary design duties were calculated based on the specified electrode currents, and a pessimistic estimate of pole outages, load factors and HVdc system modes of operation.

The preliminary duties of both electrodes for the Gull Island and Soldiers Pond converter stations were estimated based on the following parameters:

- The current ratings of maximum continuous current ($I_{max,\ cont}$) and maximum 10-minute overload, ($I_{max,\ 10min}$) are in accordance with Table 7-1.
- The time period for determining permissible loss of material from electrolytic corrosion for the electrode elements and surrounding infrastructure caused by electrode operation is assumed to be 40 years.

- In order to consider worst case conditions, the load factor is assumed to be 100%. The actual load factor is contingent on the load demand and will be less than 100%.
- A complete loss of the cables within one pole across the SOBI is considered to occur once in 40 years from an electrical failure or a mechanical damage and will result in the need to operate monopolar, electrode return for one year at the continuous current rating ($I_{max, cont}$).
- A scheduled pole outage rate of 0.5% is considered as a typical value for modern HVdc systems. It is further assumed that prior to a scheduled outage, the bipolar dc power will be such that when entering monopolar operation the resultant electrode current will be equal to the maximum continuous current ($I_{max, cont}$). It is expected that many of the scheduled pole outages will use the transmission line conductors of the out-of-service pole as a metallic return path, with the result that electrode current will be zero. However, as a conservative design, it is assumed that the electrode will operate at maximum continuous current ($I_{max, cont}$) for 70% of the scheduled outage time.
- A forced pole outage rate resulting in monopolar ground return operation of 0.5% is considered based on published data of transmission line outages for existing HVdc systems. It is further assumed that prior to a forced outage the bipolar dc power will be such that when entering monopolar operation the resultant electrode current will be equal to the maximum 10-minute overload level ($I_{max, 10min}$). In order to consider worst-case conditions, electrode operation will continue at this overload level for the entire duration of the forced outage. This assumes that there will be many short duration forced outages, each lasting less than 10 minutes, allowing operation at the maximum 10-minute overload current level.
- In steady-state bipolar operation, a typical continuous imbalance current of +/-1% of the nominal current rating is assumed. The imbalance current is assumed to be 10 A for the Soldiers Pond converter station and 25 A for the Gull Island converter station.
- During the installation and commissioning period, when only one pole of converter equipment may be available, the system will operate monopolar, metallic return. Also, a monopolar earth return operation will be required during the commissioning stage to quantify its impact; this monopolar operation will not contribute significantly to the total electrode duty.

The design duty of an electrode is measured in ampere-hours (Ah) of service over the design life.

Table 7-2 shows the calculation of the Gull Island and Soldiers Pond electrode duties based on the above assumptions.

Table 7-2: Gull Island and Soldiers Pond Electrode Duties over 40 Year Life Cycle

Description	Anodic Operation Duty (Ah)		Remarks
	Gull Island	Soldiers Pond	
Scheduled outages	2,845,248	1,643,376	$I_{max,\ cont.}$ *0.5%*70%*8760 h/y*40 y
Forced outages	4,835,520	3,118,560	$I_{max,\ 10min.}$*0.5%*8760 h/y*40 y
Continuous imbalance	8,760,000	3,504,000	I_{nom}*1%*8760 h/y*40 y
Cable outage (one year)	20,323,200	11,738,400	$I_{max,\ cont.}$ *8760 h/y*1 y
Total Duty (40 years)	**36,763,968**	**20,004,336**	**Ampere hours**

The electrode design and its impact on infrastructure will be assessed assuming the above duty in both anodic and cathodic operation.

A very pessimistic operation of the HVdc link was considered to establish the electrode duties. As seen in Table 7-2, a significant portion of the calculated electrode duty is due to the continuous imbalance in bipolar operation which can be minimized through control algorithms. A safety factor is not considered in the electrode duty calculation given the pessimistic parameters used in establishing the duty. The electrode duty needs to be reviewed based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation.

7.3 Temperature Rise

For a land electrode, temperature rise at the electrode element and soil interface is a key parameter in the design of the electrode. The temperature rise for a sea or shoreline pond electrode is not a design concern since the heat is dissipated efficiently into the surrounding water.

Heating of the soil surrounding the electrode elements resulting from electrode operation must not result in temperatures above 100°C in order to avoid evaporation of the moisture in the soil. As the soil temperature increases, moisture will be driven off at increasing rates. If the soil around the electrode elements dries out, the soil resistivity will increase which is not desirable. Therefore when designing the electrode, a maximum allowable temperature rise must be selected based on the expected average ambient temperature of the soil at the electrode location such that the resultant temperature during continuous electrode operation will remain well below 100°C.

The maximum soil temperature at the depth of the electrode at the potential land electrode sites identified in Labrador is likely to be near the yearly average ambient temperature available for Happy Valley-Goose Bay of approximately 0°C [6]. As the heating of the soil surrounding the electrode elements from electrode operation must not result in temperatures above 100°C a conservative allowable temperature rise of 60°C under continuous operation of the land electrode was used.

7.4 Safety

The safety of an electrode design is determined from the step potentials at the maximum rated current and the touch potentials on exposed parts at maximum current on land, and voltage gradients in the water.

7.4.1 On Land

The criteria for electrodes are not based on the elimination of potential gradients, but on the prevention of annoyance to a person or animal subject to the voltage. The tolerable dc currents through the body are based on experimental data. A set of experiments, reported by Dalziel [7], indicates that the threshold of perception where a slight tingling sensation is felt by the hand or finger occurs at an average level of 5.2 mA dc. Consequently, the level of 5 mA dc body current is currently accepted as the threshold of annoyance for a person walking on the energized earth. The threshold for a prone human (i.e. lying outstretched on the ground) is 22 mA dc and 160 mA dc for a large, standing animal. The tolerable step potentials on the land for a standing or walking human, a prone human and an animal are shown in Table 7-3 [8].

Table 7-3: Tolerable Body Current, Step Voltages and Voltage Gradient near a DC Electrode

Description	Human Walking or Standing	Human Prone	Cow or Horse Standing
Weight (kg)	70	70	500
Body Resistance (Ω)	1000	1000	140
Contact Resistance (Ω)	$6\rho_s$	$3\rho_s$	$3\rho_s$
Sensitivity	Annoyance	Pain	Pain
Tolerable Current (mA)	5	22	160
Voltage (V)	$5 + 0.03\rho_s$	$22 + 0.07\rho_s$	$22 + 0.48\rho_s$
Step (m)	1	2	2
Gradient (V/m)			
$\rho_s = 0$	5	11	11
$\rho_s = 50$	6.5	12.75	23
$\rho_s = 100$	8	14.5	35
$\rho_s = 10,000$	305	361	2411

7.4.2 In Water

Sensitivity to an electric field varies for different species in the water and depends on the size and weight of the animal; the body shape and electrical resistance; the resistivity of the water; the type of current; and the electric field configuration. Typical reactions to an electrical field include attraction, narcosis, convulsions (tetanus), and death. Published literature indicates that fish might be attracted to an anode at 5 V/m, tetanus could occur at 20 V/m and mortality is possible at 50 V/m. An average human may feel discomfort at a voltage gradient of 2.5 V/m in sea water. A value of 1.25 V/m is selected as safe design value [3,4,5] for large fish and humans.

8. Soil and Sea Models

The term soil model as used in this report refers to the model of the electrical resistivity properties of the earth. In the previous sentence, the word earth is used in the geological meaning of the word, not the electrical engineering meaning; the term ground is used in the electrical sense. As used here, the term soil encompasses both the unconsolidated sediments normally associated geologically with the word soil and the underlying rock units, normally referred to as bedrock. Bedrock can be geologically composed of consolidated sediments and rocks of plutonic and volcanic origin.

There are two (2) aspects of the models which have a bearing on the simulation outcome: the resistivity properties of the geological units and their spatial extent. An understanding of the geological setting and the resistivity of the geological units is fundamental to the assessment of the suitability of particular electrode models. The geology of the immediate site and the more distant earth controls the dispersion of the introduced currents and the development of the GPR. The distances over which the geological resistivity must be modeled depend upon the distances at which the GPR must be determined relative to the location of the electrode. This distance influences the depth below the surface to which the resistivity must be modeled. A simple rule of thumb is that the resistivity must be modeled to a minimum depth equal to the separation between the current injection point and the point at which the GPR is to be measured. For both land and shoreline pond electrodes, the resistivity distribution of surrounding soil and sea must be modeled. The resistivity is also required for the geological formations beneath the seabed.

In developing the resistivity models for use in the simulation of the GPR, the known geology of the sites was compiled from the electrode site extending to the GPR assessment locations. The geological units were assigned resistivity ranges based on published information where available, and on an interpretation of the most probable resistivity ranges based on an assessment of the specific rock types, ages and general geological criteria. These resistivity ranges were used to construct scenarios for GPR modeling. One set of scenarios was constructed encompassing all the Labrador electrode sites and GPR impact locations (Appendix N), and another set of scenarios was constructed for the Dowden's Point area on the Island of Newfoundland (Appendix O). These scenarios were used as input to the computer modeling packages.

9. Software

The electric field simulations for the land electrode were performed using the software CDEGS (**C**urrent **D**istribution, **E**lectromagnetic Fields, **G**rounding and **S**oil Structure Analysis), developed by SES (**S**afe **E**ngineering **S**ervices & technologies ltd.). For the shoreline pond electrode, both CDEGS and GRELEC (**GR**ound **ELEC**trode program), a software developed by Teshmont, were used for the electric field simulations.

CDEGS was used to assess the impact of ground potentials on the surrounding infrastructure. MATLAB, software by Mathworks, was used for creating some of the plots throughout the report.

10. General Electrode Impacts and Possible Mitigation Measures

When current flows through sea and earth, an electric field is created. The magnitude and distribution of this field will depend on the current transmitted and the resistivity of the earth layers and sea in the area.

The impacts on the surrounding infrastructure include electrolytic corrosion of buried and immersed metallic structures, and electrical interference with the utilities. The corrosion effect is cumulative in nature and the impact needs to be evaluated over the course of the electrode ampere-hour duty. The electrical interference is instantaneous in nature but may have long term impacts on certain equipment (e.g. heating of transformer from half cycle saturation).

Determination of acceptable GPR values depends on the electrode's impact on infrastructure which must be evaluated on a case-by-case basis.

10.1 Infrastructure Impacted by Corrosion

Steep gradients along a metallic structure caused by the electric field from the electrode current will cause corrosion where stray currents leave the structure. Corrosion on metallic structures can be mitigated in different ways, such as adding more material to sacrificial anodes, introducing insulating joints, or providing impressed current cathodic protection systems. In some cases automatically controlled cathodic protection rectifiers have been used.

The identified infrastructure which may experience corrosion due to HVdc electrode operation along with possible mitigation measures include the following.

10.1.1 Transmission Line Foundations

Corrosion of tower foundation steel and tower guy wire anchors may occur for transmission lines with overhead skywires. DC current dissipation through the foundation footing will cause corrosion of foundation steel, pole/tower guy wire anchors and grounding system. The level of dc current that will flow through the skywires and transmission tower footing depends on the HVdc electrode current, tower footing resistance, skywire size, and transmission line tower/pole spacing, and orientation relative to the electrode (i.e. radial or tangential). The acceptable dc stray current will depend on the size, age and design margin of these components.

If corrosion of the transmission line components is deemed to be a concern, the skywire connection can be isolated and/or sectionalized along the transmission line with low voltage insulators. The low voltage insulators will flashover for a lightning strike and still provide the desired lightning protection.

10.1.2 Station Grounding Grid

The dc stray current through the station grounding grid depends on its conductive connections to the remote earth. A typical material loss of 10% is acceptable for a new installation. The loss of material for an existing installation needs to be reviewed based on the condition and size of the existing grid.

A monitoring and replacement plan is a typical way to address the loss of grounding grid material.

10.1.3 Above Ground Pipeline Installation

The dc stray current through an above ground pipeline depends on its size and its bonding to the earth along the run and at the two (2) ends. There are no set criteria for the acceptable loss of material.

Isolation of the pipeline from the main grounding grid and sectionalization of the line using insulating joints are typical mitigations. Another common form of mitigation is the addition or modification of existing cathodic protection to the pipeline.

10.1.4 Multi-grounded Distribution Neutral

The dc stray current through the distribution neutral network depends on the location of the distribution substation relative to the HVdc electrode, distribution neutral ground impedance, population of pole grounds, and expanse of the distribution network. Typically a loss of 50% of pole ground rod is acceptable for new installations. The permissible loss of existing rods will depend on their age and condition. The current will flow through the residential or industrial neutral and dissipate via a residential or plant electrode.

A monitoring and replacement plan is a typical way to address the loss of material for distribution pole ground rods.

10.1.5 Bridges and Miscellaneous Infrastructure

The potential difference across a typical bridge or structure of 100 m in length or smaller will be negligible. In case the structure is connected to remote earth via a distribution circuit or any other conductive connection, the dc current will not cause significant corrosion to a large foundation.

If the connection to the remote earth is a concern for the system connected at the other end (e.g. distribution transformer), the system can be isolated.

10.2 Infrastructure Impacted by Electrical Interference

When a potential difference exists between terminal stations located in the electric field of an HVdc electrode, a dc stray current may flow in the circuit connecting the terminals.

The identified infrastructure which may be impacted due to HVdc electrode operation along with possible mitigation measures include the following.

10.2.1 Converter Transformer/Power Transformer/Distribution Transformers

The current from the anode may enter the wye-grounded neutral of a transformer leading to a constant magnetizing of the core which, superimposed on the symmetrical ac magnetizing, allows the flux to vary in an unbalanced way and to possibly cause saturation of the core. This vulnerability to dc magnetizing is different for different core types. Large monophase, and to a lesser extent, three-phase, five-legged transformers may be affected. Three-phase, three-legged transformers are not affected in the same manner and will withstand a high level of dc current excitation because the dc flux is developed only to a small degree due to the high magnetic reluctance from the top yoke to the bottom yoke.

The extent of the effect on converter and other transformers will depend on the voltage at the affected location. If the voltage is <10 V, there appears to be no effect while voltages in the range of

30 V to 100 V would definitely require mitigation measures for certain types of transformers, according to CIGRÉ, 1998 [2]. A first indication of a transformer saturation problem is the increased noise level caused by second order harmonics.

The value of acceptable dc stray current through a transformer winding depends on the transformer size and design. A dc current level in excess of 1.5 times that of the excitation current [8] can cause operational problems.

The problem can be mitigated by introducing current limiting devices in the transformer neutral. Alternatively, series capacitors in the transmission lines would block the dc current.

For a few existing HVdc systems, there has been the need to install current limiting resistors in the neutrals of transformers near the dc electrode in an effort to mitigate the potentially damaging effect of dc currents on the transformers. The resistors result in higher neutral voltages on the transformer during ac system faults, increasing the risk of transformer neutral arrestor or transformer damage. In cases where large resistors were required, the resistors were equipped with a bypass device. Failure of the bypass device would probably result in damage to the neutral resistor, failure of the transformer neutral arrestor and damage or failure of the transformer. In most cases where neutral resistors were installed to mitigate effects of HVdc electrode operation, they were installed when problems were encountered during system operation after the HVdc systems were commissioned. Neutral resistors, especially if bypass devices are required will add complexity and decrease reliability of the scheme.

Blocking devices in the neutral circuit such as capacitors are an alternative mitigation measure; however, they will require development, add complexity and degrade reliability.

Series capacitors in the transmission lines would block stray dc currents in transformers; however, the cost and complexity make this solution unattractive unless the series capacitors are required by the transmission scheme because of the line length or capacity.

The ideal solution is to locate the electrode far enough away such that transformers are not affected.

10.2.2 Generator Units, Filters and Capacitors

Normally, dc stray currents do not flow through these pieces of equipment but the harmonics produced by half cycle saturation of the transformers may impact these types of equipment significantly.

Typically mitigating the transformer half cycle saturation is prudent way of addressing these concerns. If required, the impacts of harmonics can be mitigated by the addition of filters or detuning the existing ones, if feasible.

10.2.3 Telephone Infrastructure

A ground potential of up to 70 V does not cause any operational issues and does not constitute a safety hazard since the insulated telephone circuits do not allow stray current through the network, and the combined potential difference (a GPR of 70 V and a telephone loop voltage of 48 V) is a non-lethal hazard to telephone company personnel.

Normally, telephone infrastructure is not impacted by the electrode operation.

11. Labrador (Gull Island)

The potential sites identified for the Gull Island converter station electrode were evaluated based on the defined design criteria for their suitability and potential impact on the surrounding infrastructure. The town of Happy Valley-Goose Bay and the Churchill Falls generating station are the known, existing, significant infrastructures. The planned infrastructure includes the Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, and all associated transmission lines. The impact assessment was limited to establishing the GPR potentials at these locations of interest.

11.1 Site Descriptions

The proposed locations at Lower/Upper Brook (LUB) and Trans Labrador Highway (TLH) were such that the electrode was adjacent to the boundary of the body of surficial sediments in which it was located. In order to avoid numerical issues with the simulation software and make the electrode effective, it is desirable to maintain a minimum separation equal to the diameter of the electrode between the electrode and the boundary of the body of surficial soil containing the electrode. As a result, the originally proposed locations of LUB and TLH electrodes were adjusted as indicated in Table 11-1.

Table 11-1: Locations (Original and Revised) of Potential Electrode Sites

Rank	Site	Electrode Location*				Difference	
		Original		Revised			
		Easting	Northing	Easting	Northing	Δ E	Δ N
1	Bog near Pinus River	617655	5877340	617655	5877340	0	0
2	Lower/Upper Brook between Gull Island and Muskrat Falls (LUB)	631716	5894792	636716	5896792	-5000	-2000
3	Bog near TLH south of new bridge (TLH)	671013	5898962	673013	5896962	-2000	2000
4	Bog near Kenamu	702116	5920896	702116	5920896	0	0
5	Shoreline near Kinriakak (KIN)	721938	5935115	721938	5935115	0	0
X	Low ground NW of converter station	607665	5871312	607665	5871312	0	0

* Easting and Northing in UTM Zone 20 Datum NAD 83.

Although the location near Pinus River was ranked the highest during the working session meetings, it was decided that the first location which should be considered for the electric field simulations was LUB. This decision was based on the relative proximity of the potential sites to the converter station location. If results for LUB were promising, then sites closer to the converter station would be investigated; however if the results for LUB indicated high GPR values at the converter station, then sites farther away from the converter station would be considered.

11.2 Electrode Design

Temperature rise at the electrode element and soil interface, step potential, and available space were the main parameters that determined the size of the Labrador land electrode. The availability of space was not a constraint rather surficial geology (width of low resistivity top layer of soil) was a limiting factor.

The soil adjacent to the electrode coke bed is important for thermal stability of the electrode and is considered in the design of the electrode. Ring electrodes of diameter 1000 m, 1500 m and 2000 m were analyzed; Table 11-2 shows the design calculation results for these ring electrodes in 50 Ωm and 100 Ωm surficial soil.

Table 11-2: Preliminary Electrode Designs Considered

Parameter Description		Ring Electrode Options					
		1000A	1000B	1500A	1500B	2000A	2000B
Diameter of Ring Electrode (m)	D =	1000	1000	1500	1500	2000	2000
Coke Bed side (m)	s =	0.5	0.5	0.5	0.5	0.5	0.5
Average Resistivity (Ωm)	ρ =	50.0	100.0	50.0	100.0	50.0	100.0
Electrode Perimeter (m)	P =	3142	3142	4712	4712	6283	6283
Depth of Electrode (m)	h =	2.5	2.5	2.5	2.5	2.5	2.5
Electrode Resistance in Uniform Soil (Ω)	R_e =	0.041	0.082	0.029	0.057	0.022	0.044
Electrode GPR (V)	V_e =	94	188	66	132	51	102
Rated Current (A)	I_r =	2300	2300	2300	2300	2300	2300
Current Density (A/m^2)	J =	0.37	0.37	0.24	0.24	0.18	0.18
Soil Conductivity (W/m°C)	λ =	0.833	0.833	0.833	0.833	0.833	0.833
Heat Capacity (MJ/m^3 °C)	y =	2.200	2.200	2.200	2.200	2.200	2.200
Max. Temperature Rise (C)	θ_{max} =	105.89	211.78	51.91	103.83	31.22	62.44
Time Constant (days)	T =	402.43	402.43	443.93	443.93	474.61	474.61
Time to 60°C Rise (days)	t_{60} =	337	134	N/A	383	N/A	1539

Electrode GPR (V_e) in uniform infinite soil model to remote earth

$V_e = \sqrt{(2\lambda\rho\theta)}$

Where:

λ = Heat conductivity of the soil (W/m°C)

θ = Design temperature rise of electrode above earth ambient temperature (°C), 60°C considered in the calculations for a conservative design. The yearly average ambient temperature at Happy Valley-Goose Bay is approximately 0°C, which will approximate the soil temperature at a depth of 2.5 m. A higher design temperature rise can be justified.

ρ = Resistivity of soil (Ωm)

Electrode resistance to remote ground (R_e) in infinite uniform soil resistivity

$R_e = (\rho/(\pi^2 * D)) * \ln(4D/b)$

Where:

ρ = soil resistivity (Ωm)

D = diameter of the electrode ring (m)

$b = \sqrt{dh}$

d = equivalent diameter of the electrode (m) = $4 * s/\pi$

s = length of side of square cross section of coke bed (m)

h = depth of burial (m)

Maximum Temperature (θ_{max}) $\theta_{max} = V_e^2/2\lambda\rho$ Time to 60°C Temperature Rise (t_{60}) $t_{60} = T^*\ln(1\text{-}60/\theta_{max})$

The values calculated in Table 11-2 assume an infinite uniform soil body which is a valid assumption for the calculation of maximum temperature rise since this depends on the soil adjacent to the electrode elements. This assumption however does not hold true for the GPR distribution and electrode impedance which depend on local as well as remote geological conditions. The actual electrode GPR and electrode impedance will be higher than the values calculated values in Table 11-2.

Based on the results of maximum temperature rise and the soil data, an electrode with a diameter of 2000 m was selected for the study. It should be noted that beyond the electrode site, the GPR values will depend on the geology of the site and not the actual design of the electrode.

11.3 Description of Simulation Model

The simulation model is comprised of three major parts:

- the soil model,
- the electrode conductor model, and
- the observation profiles and points.

11.3.1 Soil Model

There are two (2) aspects to the models which have a bearing on the simulation outcome: the resistivity properties of the geological units and their spatial extent. The details of assigning these parameters and the development of the specific models for use in simulation are provided in Appendix N - Labrador Electrode Sites, Ground Potential Simulation Sites, and Suggested Models.

The spatial extent of the various geological units was determined by extracting the appropriate polygons from digital versions of the 1:250 000 scale provincial geology maps, hence there is an uncertainty in position of the coordinates of the nodes of the polygons associated with this process.

The geological units and their assigned resistivities are:

- Surficial sediments. The surficial sediments in the Lower Churchill River valley consist primarily of glaciofluvial and marine sediments in which there can be clay and silt layers of varying thickness. The actual thickness varies from place to place. The assigned resistivity is 50 Ωm.
- Bedrock sediments. The bedrock sediments in the area under consideration consist of arkoses and conglomerates of the Double Mer formation. The Double Mer formation is present in a fault bounded graben. The best estimate of the thickness is 2000 m to 3000 m. In modeling the resistivity has been assigned as 2000 Ωm to 3000 Ωm.

- Granitoid rocks occupy most of the area. Elsewhere, there are numerous faults cutting to unknown depths in the granitoid rocks. The resistivity assigned for the granitoid rocks is 5000 Ωm to 10,000 Ωm.
- The assigned resistivity for Lake Melville is that for sea water, 0.2 Ωm.

A map of the surficial geology of the area is included in Appendix A. This spatial and resistivity information was used to produce the scenarios for simulation. The spatial extent for the surficial sediments and Double Mer formation were simplified to rectangular finite volumes. For each electrode location, only the surficial sediment bodies containing the electrode and the underlying Double Mer formation were modeled in native granitoid; the remaining geological units of the surficial sediments and Double Mer formation that will have negligible impact on the simulation results were not included in the soil models.

The conductive bodies of Lake Melville and the Churchill River were not considered in the model.

11.3.2 Electrode Model

The electrode itself was modeled as a piecewise linear ring consisting of 78 conductor sections surrounded by a conductive coke bed layer and coke bed sections to connect the conductor sections. Insulated distribution cables are considered to connect the electrode sections and distribution junction box at the centre of the electrode. Figure 11-1 shows the conductor network used for the simulations. The number of conductor sections was selected to match the calculated electrode resistance in uniform soil model.

The electrode was energized for anodic operation for current dissipation to the remote earth. A return electrode (other end of the HVdc link) was not considered since this will have a minor impact on the voltage distribution in the zone of interest as the separation between the HVdc terminals is large compared to the zone of interest. For cathodic electrode operation, the GPR levels will be of the same magnitude but of opposite polarity.

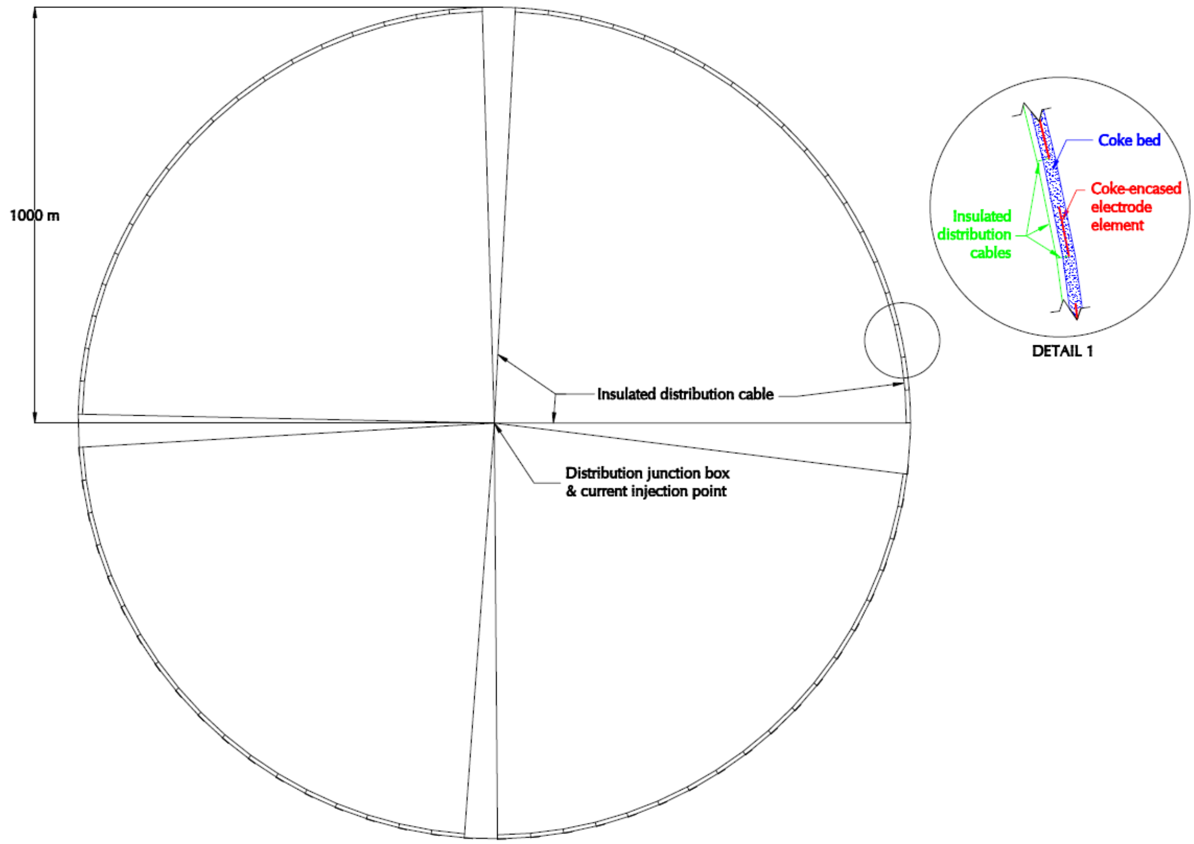


Figure 11-1: Land Electrode Model

11.3.3 Observation Profile and Points

GPR levels were monitored at five observation points at locations of interest along with a rectangular surface profile covering an area of nine square kilometres encompassing the electrode. The observation points are listed in Table 11-3. The observation points, designated by yellow placemarks, are shown in Figure 11-2.

Table 11-3: Observation Points

Observation Point	Observation Point	
	Easting*	Northing*
Gull Island Converter Station	607750	5870650
Gull Island Generating Station	605200	5869650
Muskrat Falls Generating Station	649200	5901800
Happy Valley-Goose Bay	672140	5908972
Churchill Falls Generating Station	434562	5931162

* Easting and Northing in UTM Zone 20 Datum NAD 83

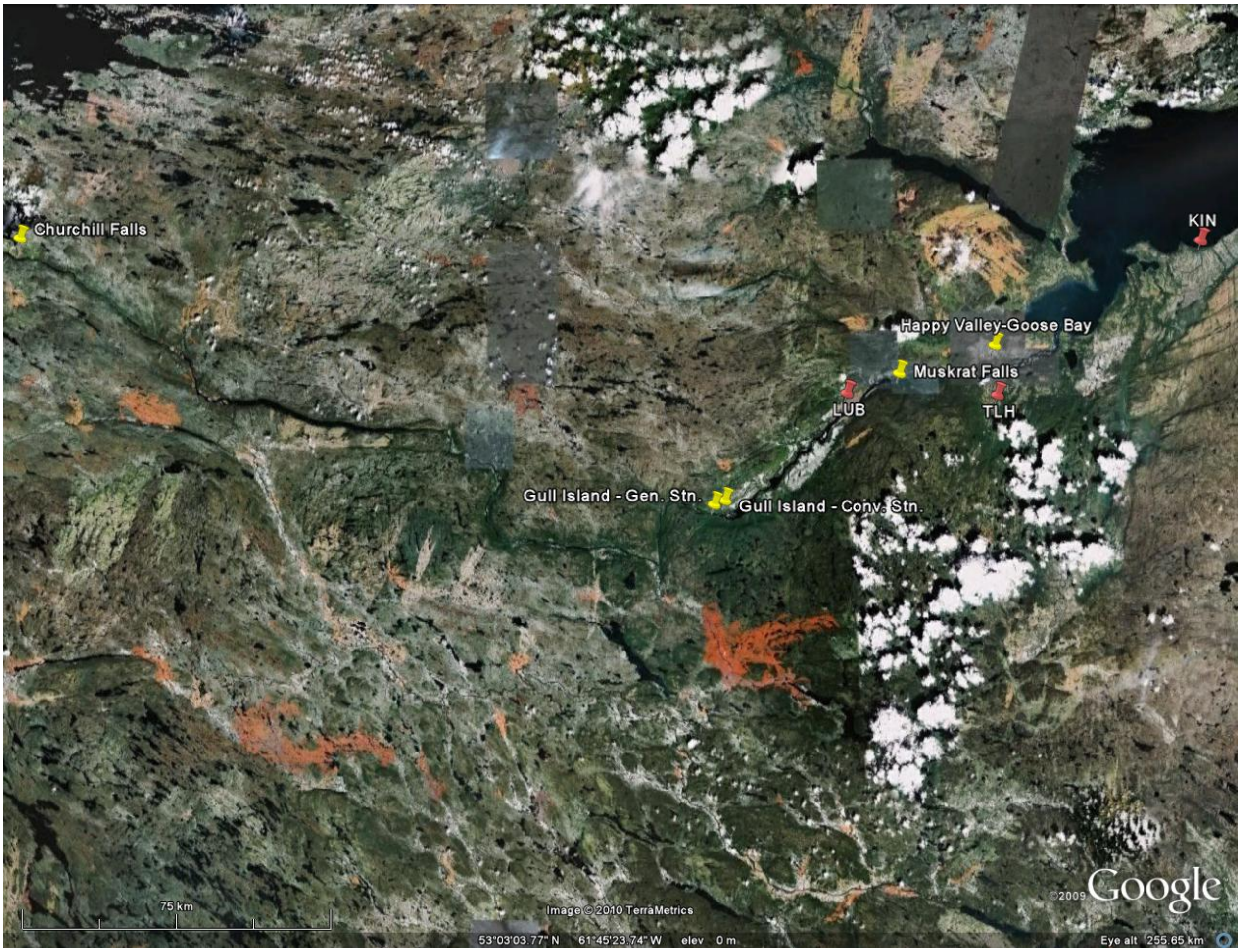


Figure 11-2: Labrador Observation Points and Electrode Locations

11.4 GPR Simulation Results

Based on the suggested modeling scenarios from AMEC (Appendix N), a set of five (5) scenarios was established to perform a sensitivity analysis on the parameters defining the soil model. The scenarios are listed in Table 11-4.

Table 11-4: Modeling Scenarios

Scenario	A	B	C	D	E
Surficial					
Resistivity (Ωm)	50	50	100	50	50
Thickness (m)	50	100	100	50	50
Double Mer					
Resistivity (Ωm)	2000	2000	2000	2000	2000
Thickness (m)	2000	2000	2000	3000	2000
Granitoid					
Resistivity (Ωm)	10000	10000	10000	10000	5000
Thickness (m)	infinite	infinite	infinite	infinite	infinite

Simulations were initially performed for the site at LUB. Based on the results obtained, additional simulations were performed for the potential sites at TLH and Kinriakak Point (KIN). The GPR values obtained at each of the observation points for each location and scenario considered are given in Table 11-5.

Table 11-5: Simulation Results for LUB, TLH, and KIN Electrode Sites

Ground Potential Rise (V)							
	Max GPR	Center of Electrode	Gull Island Conv. Station	Gull Island Gen. Station	Muskrat Falls Gen. Station	Happy Valley-Goose Bay	Churchill Falls Gen. Station
Lower/Upper Brook (LUB)							
Scenario							
A	1079.99	1035.14	92.20	86.55	322.13	101.26	17.97
B	1002.86	973.01	92.16	86.51	323.34	101.34	17.97
C	1130.99	1067.19	92.50	86.82	317.06	100.82	17.98
D	1011.66	966.50	92.19	86.54	319.64	101.21	17.97
E	737.29	696.55	46.31	43.47	154.98	50.19	8.99
Bog Near Trans-Labrador Highway (TLH)							
Scenario							
A	752.32	708.01	47.93	46.26	129.06	323.80	15.02
B	713.85	683.23	48.14	46.45	130.33	325.81	15.03
C	881.78	817.95	48.81	47.08	134.04	325.92	15.08
D	710.29	665.08	47.89	46.23	128.80	317.97	15.02
E	578.60	539.49	24.49	23.62	67.39	162.46	7.55
Kinriakak Point (KIN)							
Scenario							
A	561.20	512.60	30.93	30.22	55.39	92.63	13.20
B	538.68	505.65	30.63	29.94	54.45	90.03	13.16
C	711.77	645.01	30.04	29.38	52.58	84.74	13.08
D	491.54	452.01	31.19	30.47	56.22	95.03	13.24
E	486.47	443.10	15.02	14.69	26.25	42.11	6.54

GPR gradients near the electrode elements are in the range of 2 V/m to 3 V/m for the scenarios reviewed at the various locations. The corresponding step potentials for these gradients will be 3 V for a standing human and 6 V for a prone human or large animal.

11.5 Discussion of Results

The results show that the most sensitive parameter in the soil model at a given electrode location was the resistivity of the native granitoid. A significant drop in GPR was observed at all observation points in Scenario E when the resistivity of the native granitoid decreased from 10,000 Ωm to 5,000 Ωm.

Table 11-5 indicates there is an almost linear relationship of the GPR with the granitoid resistivity, so the presence of higher resistivity for the granitoids would result in higher GPR's at all locations. The most likely case is that the actual resistivity of the granitoids may be greater than 10,000 Ωm. Therefore Scenario E is considered a very optimistic case.

The GPR contour plot for Scenario A at the KIN site is shown in Figure 11-3. Remaining GPR plots of the three (3) sites considered for Scenarios A and E are included in Appendix B.

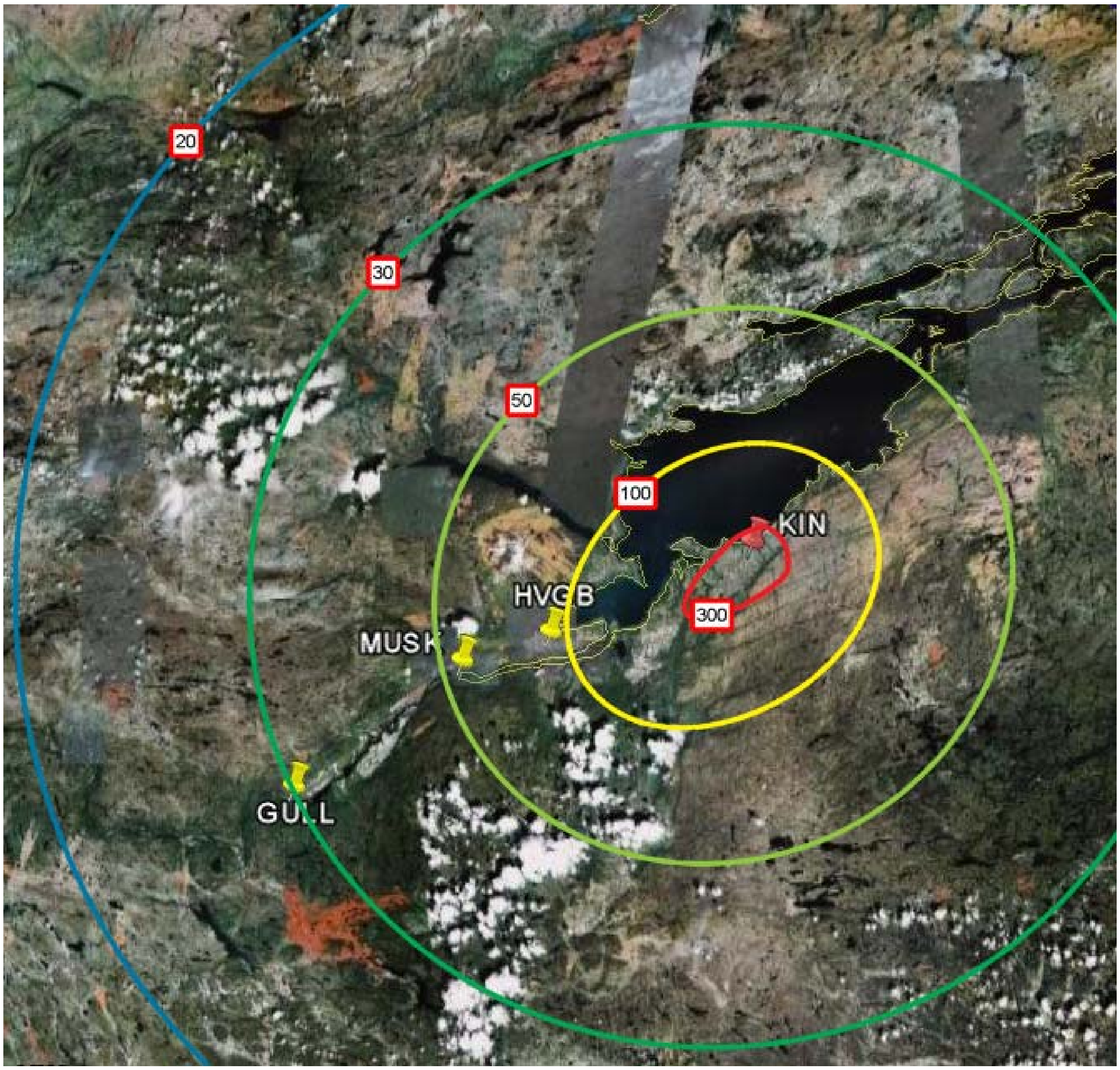


Figure 11-3: GPR Contour Plot for Kinriakak Point, Scenario A

Excluding Scenario E, the remaining scenarios showed subtle changes in the voltage levels at a given observation point and electrode site. This indicated that the sensitivities of the thicknesses and resistivities of the surficial and Double Mer layers in the ranges considered were small.

In general, Scenario D showed the next lowest voltage levels, followed by Scenarios B, A, and C. This order of voltage levels is consistent with the expected variations from one scenario to the other.

For example, when increasing the thickness of the surficial layer from 50 m to 100 m, it was expected that the GPR values would decrease. With the exception of the observation point right at the electrode itself, the variations of GPR values for Scenarios A, B, C, and D were minimal.

Discounting the optimistic case of Scenario E, the range of calculated voltages at each observation point were quite narrow, especially as the observation points became farther from the electrode. This is consistent with the fact that GPR beyond the actual electrode site depends on the geology of the site and is not affected by the design of the electrode. Table 11-6 captures the observed trends for each case, taking the average values for Scenarios A, B, C, and D.

Table 11-6: Observed Trends in GPR

Ground Potential Rise (V)						
Max GPR	Center of Electrode	Gull Island Conv. Station	Gull Island Gen. Station	Muskrat Falls Gen. Station	Happy Valley-Goose Bay	Churchill Falls Gen. Station
Lower/Upper Brook (LUB)						
1056	1010	92	87	321	101	18
Bog Near Trans-Labrador Highway (TLH)						
765	719	48	47	131	323	15
Kinriakak Point (KIN)						
576	529	31	30	55	91	13

The observation points at which the highest GPR values occurred were Muskrat Falls and Happy Valley-Goose Bay. This was true for all three (3) electrode sites since in all three cases, these points were located closest to the electrode. High GPR values were also observed at the Gull Island converter and generating stations for the LUB electrode site because these locations were also relatively close to the LUB electrode.

The expanse of surficial sediments and the location of the electrode with reference to the boundary of surficial sediments influence the electrode maximum GPR significantly. The maximum GPR values in Table 11-6 of the LUB electrode located in a smaller area of surficial layer, the TLH electrode located close to the boundary of the surficial sediments, and the KIN electrode located in the centre of a larger surficial sediment are indicative of this influence.

According to CIGRÉ [2], the need for a current-limiting device in the neutrals of a transformer providing a conductive path through its windings between two grounding grids, based on the GPR difference between the grids is summarized in Table 11-7.

Table 11-7: GPR Difference Between Grounding Grids and Corresponding Need for Mitigation

Ground Potential Rise Difference (V)	Need for Current-Regulating Equipment
GPR < 1	Mitigation not required
1 < GPR < 10	Mitigation probably not required
10 < GPR < 30	Mitigation possibly required
30 < GPR < 100	Mitigation required

Comparing the GPR trends in Table 11-6 with the GPR difference ranges indicating the need for mitigation in Table 11-7, it can be seen that the GPR levels at all observation points except Churchill Falls are greater than 30 V and a voltage difference of >30 V between two grounding grids is possible. Thus it is expected that mitigation measures are probably required at all locations. Furthermore, GPR levels at Churchill Falls are in excess of 10 V and therefore mitigation measures may still be required.

In addition to mitigation on transformer neutrals, the GPR values obtained indicate that mitigation measures on existing infrastructure at the town of Happy Valley-Goose Bay would be required for all potential electrode sites. As the infrastructure is not currently known, the type and extent of mitigation cannot be determined at this point.

The calculated step potentials of 3 V for a standing human and 6 V for a prone human or large animal are less than the tolerable step potentials shown in Table 7-3, and therefore the area would be safe for access. However, access to the distribution junction box and other equipment that may come in contact with the distribution conductors must be restricted to avoid touch potential hazards.

11.6 Shoreline Pond Electrode in Lake Melville

During the working session meetings, Kinriakak Point was identified as a candidate site for either a land electrode in the bog adjacent to Lake Melville or a shoreline pond electrode inside Lake Melville. Given the poor results found in the case of the land electrode at Kinriakak Point, it was anticipated that a shoreline pond electrode configuration in the same vicinity and with the same current rating would not produce significantly better results; an analysis was undertaken to verify this.

Lake Melville is a finite volume embedded in a vast body of high resistivity bedrock; therefore the benefit of its comparatively low resistivity on resulting GPR values will be negligible due to the dominance and abundance of the surrounding high resistivity granitoid. In addition, the exposure to the sea at Kinriakak Point via Lake Melville is limited since the expanse of water for an inland shoreline pond electrode is poor compared to that of a shoreline electrode located on the coast, directly exposed to the open sea. Moreover, the low resistivity influence of Lake Melville will only noticeably improve GPR values locally whereas remote GPR’s will remain relatively unchanged. Given the large distance between the electrode and the locations of interest, the GPR values at these points will not improve considerably.

Different electrode configurations will impact GPR values locally; however the electric field profiles will converge radially from the electrode site long before reaching any of the locations of interest. Therefore, the difference in GPR values for a shoreline pond configuration versus a land configuration at a given point will become less as one moves away from the electrode.

11.6.1 GPR Simulation Results

Lake Melville was modeled as a single volume. Its surficial expanse was represented conservatively and its volume was represented very conservatively, assuming a uniform depth of 100 m and disregarding the slope in the bed of the lake. The salinity of Lake Melville is anticipated to be low at shallow depths (4 m to 5 m). In order to gain insight into the sensitivity of the resistivity of the lake, the following scenarios were considered:

Table 11-8: Lake Melville Modeling Scenarios

Scenario	1A	1E	2A	2E
Lake Melville - Shallow				
Resistivity (Ωm)	0.2	0.2	25	25
Thickness (m)	5	5	5	5
Lake Melville - Deep				
Resistivity (Ωm)	0.2	0.2	0.2	0.2
Thickness (m)	95	95	95	95
Surficial				
Resistivity (Ωm)	50	50	50	50
Thickness (m)	50	50	50	50
Double Mer				
Resistivity (Ωm)	2000	2000	2000	2000
Thickness (m)	2000	2000	2000	2000
Granitoid				
Resistivity (Ωm)	10000	5000	10000	5000
Thickness (m)	infinite	infinite	infinite	infinite

The following Table 11-9 compares the results of a shoreline pond electrode near Kinriakak Point – considering a combination of varying Lake Melville models (1 layer vs. 2 layer) and granitoid resistivities (10,000 Ωm vs. 5,000 Ωm) – with GPR values of the land electrode at Kinriakak Point from Table 11-5.

Table 11-9: Comparison of GPR's for Shoreline Pond and Land Electrodes at Kinriakak Point

Ground Potential Rise (V)						
	Center of Electrode	**Gull Island Conv. Station**	**Gull Island Gen. Station**	**Muskrat Falls Gen. Station**	**Happy Valley-Goose Bay**	**Churchill Falls**
Kinriakak Point (KIN)						
Shoreline Pond Electrode						
Scenario						
1A	210.59	29.06	28.44	51.02	79.40	13.12
1E	113.88	14.35	14.05	25.02	38.21	6.55
Shoreline Pond Electrode						
Scenario						
2A	650.81	31.19	30.48	61.96	100.70	14.22
2E	689.11	14.51	14.20	25.12	39.00	6.50
Land Electrode						
Scenario						
A	512.60	30.93	30.22	55.39	92.63	13.20
E	443.10	15.02	14.69	26.25	42.11	6.54

The difference in GPR results observed at the locations of interest for a shoreline pond electrode and those for a land electrode at Kinriakak Point is marginal. In the most likely case of the high resistivity bedrock (10,000 Ωm granitoid in Scenario A), the GPR values at most locations of interest are greater than 30 V, indicating the need for mitigation. Even in the optimistic case of low resistivity bedrock (5,000 Ωm granitoid in Scenarios E), mitigation measures would be required at Happy Valley-Goose Bay due to high GPR values. Therefore, it is concluded that an inland shoreline pond type electrode in Lake Melville is not a viable option for the Gull Island converter station.

Scenarios 1A and 1E for the shoreline pond electrode in Lake Melville are shown below in Figure 11-4 and Figure 11-5, respectively.

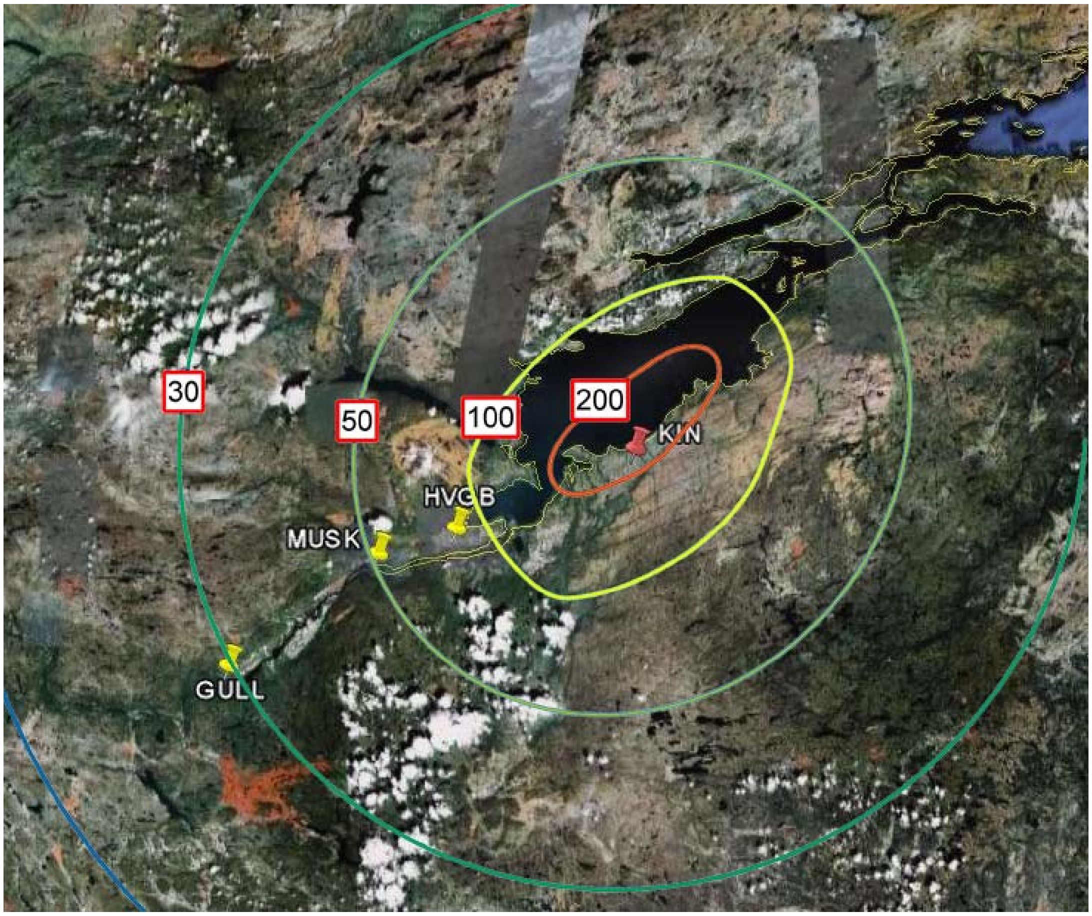


Figure 11-4: GPR Contour Plot for Shoreline Pond Electrode at Kinriakak Point, Scenario 1A

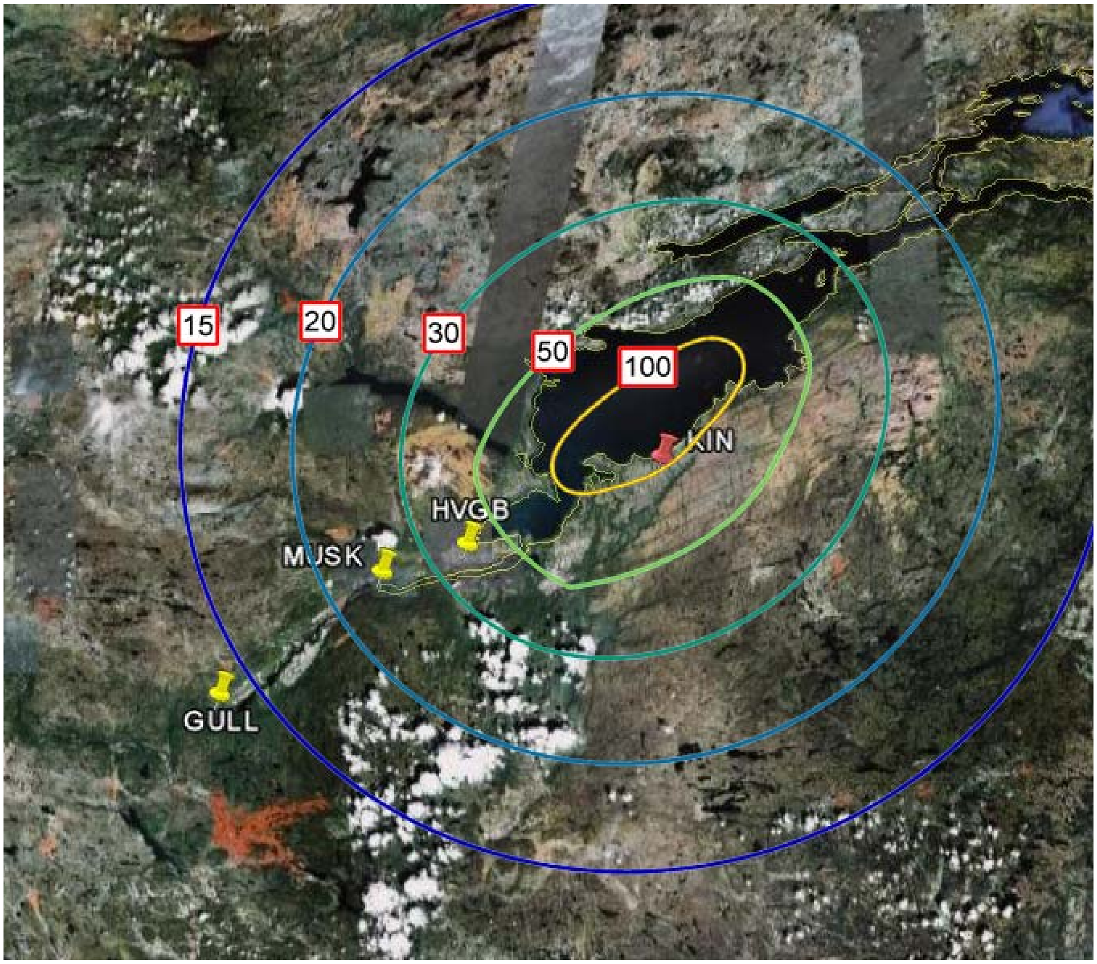


Figure 11-5: GPR Contour Plot for Shoreline Pond Electrode at Kinriakak Point, Scenario 1E

11.7 Summary of Findings

Based on the results obtained, it was found that all proposed land electrode sites and the proposed shoreline pond electrode site in Lake Melville will result in GPR values (>30 V in most scenarios) which require mitigation measures at the existing and planned infrastructure locations of the Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, and the town of Happy Valley-Goose Bay. Mitigation measures may also be required at remote stations, including Churchill Falls. Furthermore, the high GPR values would complicate the development of any future infrastructure within a large radius of the electrode.

For a few existing HVdc systems, to mitigate the electrical interference in the zone of influence, measures such as current-limiting devices in the neutrals of transformers have been implemented. In most instances, the need for these measures was only identified after commissioning when operational issues were encountered and no other course of action was available. These mitigation measures are unique and their reliability is not well documented. In the case of blocking devices, their use would require development, increase complexity and degrade reliability. Moreover, misoperation of such devices may result in forced outages and transformer damage.

It is the opinion of the electrode review panel that the use of current limiting devices should be avoided if possible.

Mitigation of problems in Happy Valley-Goose Bay due to the high GPR would be extensive and difficult to implement and control. Therefore it is concluded that none of the identified electrode sites in Labrador are viable sites.

It was indicated to NE-LCP that consideration be given to locating a potential site for a shoreline pond electrode in the SOBI.

11.8 Potential Alternate Shoreline Pond Electrode Sites

The key criterion used to identify a potential shoreline pond electrode site on the north shore of the SOBI is that the site be relatively close to the crossing site at L'Anse Amour, but not close enough to cause problems to the HVdc submarine cables. A desktop review was undertaken and two possible locations were identified on topographic maps, L'Anse-au-Loup and L'Anse-au-Diable. Upon further inspection of the maps, the L'Anse-au-Loup site was dismissed as it was too close (< 10 km) to L'Anse Amour.

There would appear to be possibilities at the shoreline in L'Anse-au-Diable Bay. The latest Canadian Census (2006) does not give any population data for L'Anse-au-Diable and in Wikipedia it is listed as a small village. The nearest populations are at Capstan Island (pop. 69), West St. Modeste (pop. 140) and L'Anse-au-Loup (pop. 593).

The site is > 10 km from L'Anse Amour cable location and > 3 km from significant population. There would most likely be little infrastructure in these communities, especially Capstan Island and West St. Modeste. A Google search of L'Anse-au-Diable turned up an application for a mink farm at L'Anse-au-Diable with construction to commence in 2005 and be completed in 2008. There is a communication tower about 3 km SW from L'Anse-au-Diable.

A brief field visit to the site in November 2009 noted:

- The site is part of a small cove located on a high-energy coast. A shoreline pond electrode will require a substantial breakwater structure. The cove is roughly 6 m to 8 m deep and bottom of the cove is visible.
- The site is surrounded by a high-resistivity rock formation.
- A fresh water inlet is roughly 1 km away from the cove location. The water current in the SOBI is swift and the mixing of fresh water with sea water is expected to be quick.
- Sand dunes are roughly at a distance of 100 m from the cove.
- The main infrastructure in the vicinity of electrode includes a marine slipway for small vessel haul-out roughly 300 m away, three operational barns and one under construction, and a three phase 12.47 kV distribution line.

12. Island (Soldiers Pond)

The electrode at Dowden's Point was evaluated based on the defined design criteria and for its impact on the surrounding infrastructure. The known infrastructures and their locations relative to the Dowden's Point electrode location are identified in Appendix E. The main infrastructure includes the Holyrood generating and terminal station, Seal Cove generation and distribution station, transmission lines, multi-grounded distribution system, and miscellaneous structures.

12.1 Electrode Design

A preliminary basic design of the shoreline pond electrode based on the calculated duty was carried out. Figures C-1 and C-2 in Appendix C show the location, plan and section of the proposed electrode in a man-made shoreline pond. It consists of the 50 high silicon cast iron electrode elements each capable of 30 A continuous discharge. The shoreline pond size of 102 m(L) x 20 m(W) x 4 m(D) is selected to accommodate the electrode elements at a typical spacing of 2 m and to satisfy a voltage gradient of 1.25 V/m on the sea side of the breakwater barrier. The breakwater barrier is tentatively selected considering the operational requirement of access and electrode installations. The details of the electrode design basis are included in Appendix C. The design shall be verified for structural integrity during the detailed engineering stage.

The calculated voltage gradient at the surface of electrode is 6.56 V/m and drops to an acceptable level of 1.25 V/m at a distance of 0.5 m from the electrode element surface assuming the elements carry equal currents. Some measures will be required to limit public access to the electrode. The design does not take into account the current imbalance among the electrode elements. Typically the elements in the middle carry less current than the end elements if uniformly spaced. This aspect shall be studied during the detailed engineering stage to establish an optimal current distribution among the electrode elements and to adjust the shoreline pond dimensions if required.

The high resistivity of surficial sediments at Dowden's Point would require a very large diameter land electrode buried to a depth of 4 m to 5 m. This size of electrode would come very close to the existing built up areas. Thermal characteristics of the soil would probably be satisfactory but due to the size, the land electrode was not investigated further.

12.2 Description of Simulation Model

The simulation model is comprised of three major parts:

- the soil and sea model,
- the electrode, shoreline pond and breakwater model, and
- the observation profiles and points.

The GPR values for various locations used in the impact analysis are based on the simulation results performed in GRELEC.

12.2.1 *Soil and Sea Model*

There are two (2) aspects of the models which have a bearing on the simulation outcome, the resistivity properties of the geological units and the water bodies, and their spatial extent. Field work in the form of resistivity soundings, test pits, thermal property investigations and boreholes was undertaken at the site in September 2009 [9]. Three (3) resistivity soundings were recorded, test pits were dug at seven locations and there were two (2) boreholes. Three (3) samples from test pits were submitted for thermal property measurements.

The resistivity and lithology data obtained from the field investigation along with assessment of the nature of geological and water units not assessed during the field study were used to assign resistivity and thickness criteria in developing the scenarios for simulation of the GPR response. The details of assigning these parameters and the development of the specific models for use in simulation are provided in Appendix O – Dowden's Point Electrode, Ground Potential Simulation, and Suggested Models.

The spatial extent of the various geological units was determined by extracting the appropriate polygons from digital versions of 1:50 000 and 1:250 000 scale provincial geology maps; hence there is an uncertainty in position of the coordinates of the nodes of the polygons associated with this process.

The geological and water units and their assigned resistivities are:

- Surficial sediments. The surficial sediments in the Seal Cove area consist primarily of glaciomarine and marine sediments in which there can be clay and silt layers of varying thickness. Adjacent to this area in the Seal Cove valley there is a region of undifferentiated thin till veneer to the NE and poor drift to the SW. The field work investigated the glaciomarine sediments in the Seal Cove valley at the Dowden's point location.
    - The glaciomarine top layer was assigned a thickness of 4 m and a resistivity of 5000 Ωm or 10,000 Ωm.
    - The glaciomarine middle layer was assigned a thickness of 3 m and a resistivity ranging from 100 Ωm to 500 Ωm.
    - The glaciomarine bottom layer was assigned a thickness of 5 m and a resistivity ranging from 3000 Ωm to 10,000 Ωm.
    - The undifferentiated till layer was assigned a thickness of 5 m and a resistivity of 2000 Ωm.
    - The poor drift till layer was assigned a thickness of 5 m and a resistivity of 2000 Ωm.
- Bedrock sediments. The bedrock sediments in the area under consideration are the Cambro-Ordivician Manuels River Formation comprising black shale and lenses of limestone, mafic and pillow lavas, and pyroclastics underlain by the Chamberlains Brook Formation consisting of green and red shale and slate, thin limestone beds, a thin manganiferous bed near the base, and spillite cherty pillow lavas. The resistivity assigned for simulation ranges from 500 Ωm to 2000 Ωm based on measurement in the Conception Bay South area for

other projects and the unit has been assigned a thickness of 500 m based on its outcrop width and dip.

- Granitoid and volcanic rocks underlie these consolidated bedrock sediments throughout the area. These granitic and volcanic rocks also directly underlie the surficial cover in regions where the Cambro-Ordovician sediments are not present. These rocks are the most resistive in the area and have been assigned resistivities ranging from 5000 Ωm to 10,000 Ωm based on field measurements at the Soldiers Pond converter site in 2007.
- The nature of the bedrock geology beneath the Conception Bay portion of the area is inferred and extrapolated from the geology around the nearby regions. The surficial geology at the seabed is also inferred from the adjacent land geology.
- The water bodies for modeling were all assigned a depth of 10 m except for Conception Bay for which the bathymetry information was available.
    - Conception Bay and the further ocean were assigned a resistivity of 0.2 Ωm, a standard textbook value for seawater.
    - Seal Cove Pond was considered to be fresh water and was assigned a resistivity of 100 Ωm.
    - Lance Cove Pond was considered to be brackish water and was assigned a resistivity of 10 Ωm.
    - Indian Cove Pond was considered to be seawater and assigned a resistivity of 0.2 Ωm.

The soil model used for GRELEC was based on modeling Scenario 2 identified in Appendix O. However, Seal Cove Pond, Lance Cove Pond and Indian Cove Pond were not modeled as they are too small compared to Conception Bay to have a significant effect on the electrode resistance or the GPR.

12.2.2 *Electrode, Shoreline Pond and Breakwater Model*

The electrode itself was modeled as a conductive body of very low resistivity (0.01 Ωm) with an average width of 20 m, depth 4 m and length 100 m, representing the shoreline pond with the 50 electrode elements distributed along its length.

A calculated resistivity value of 1.5 Ωm was used for the breakwater assuming a conservative void ratio of 19.3%.

Modeling the electrode as a conductive body does not provide representative GPR distributions within the shoreline pond, however, does provide GPR distribution outside the shoreline pond and breakwater. The GPR values for various locations used in the impact analysis are based on the simulation results.

12.2.3 *Observation Profile and Points*

GPR levels were monitored at five observation points at locations of interest along with a circular surface profile with a radius of 120 km centered about the electrode. These observation points and profile are listed in Table 12-1.

Table 12-1: Observation Points

Observation Point	Observation Point	
	Easting*	Northing*
Holyrood Generating and Transmission Station	341900	5257650
Seal Cove Generating and Distribution Station	344150	5258050
Distribution Pole closest to the Electrode	343250	5259650
Bay Roberts Station	328350	5273100
Kelligrews Station	349400	5262500

* Easting and Northing in UTM Zone 22 Datum NAD 83.

12.3 GPR Simulation Results

Figure 12-1 shows the ground potential rise contours in the vicinity of the electrode based on simulations. These contours would be expected to be smooth. The contour configuration with abrupt changes as presented in Figure 12-1 arises from the limited number of elements in the GRELEC model. The model is based on a polar coordinate system (i.e. elements are spaced every 10°) and therefore the size of each element increases the farther the element is from the center of the model. Consequently, as equipotential contours become more skewed (i.e. less circular), the difference in GPR between adjacent elements increases. The algorithm used for generating the contours does not adequately smooth large abrupt changes in the GPR contour. The purpose of the simulation was to assess the scale of the GPR's at various distances and specific locations for use in further analysis of the impact of such GPR's and the associated gradients.

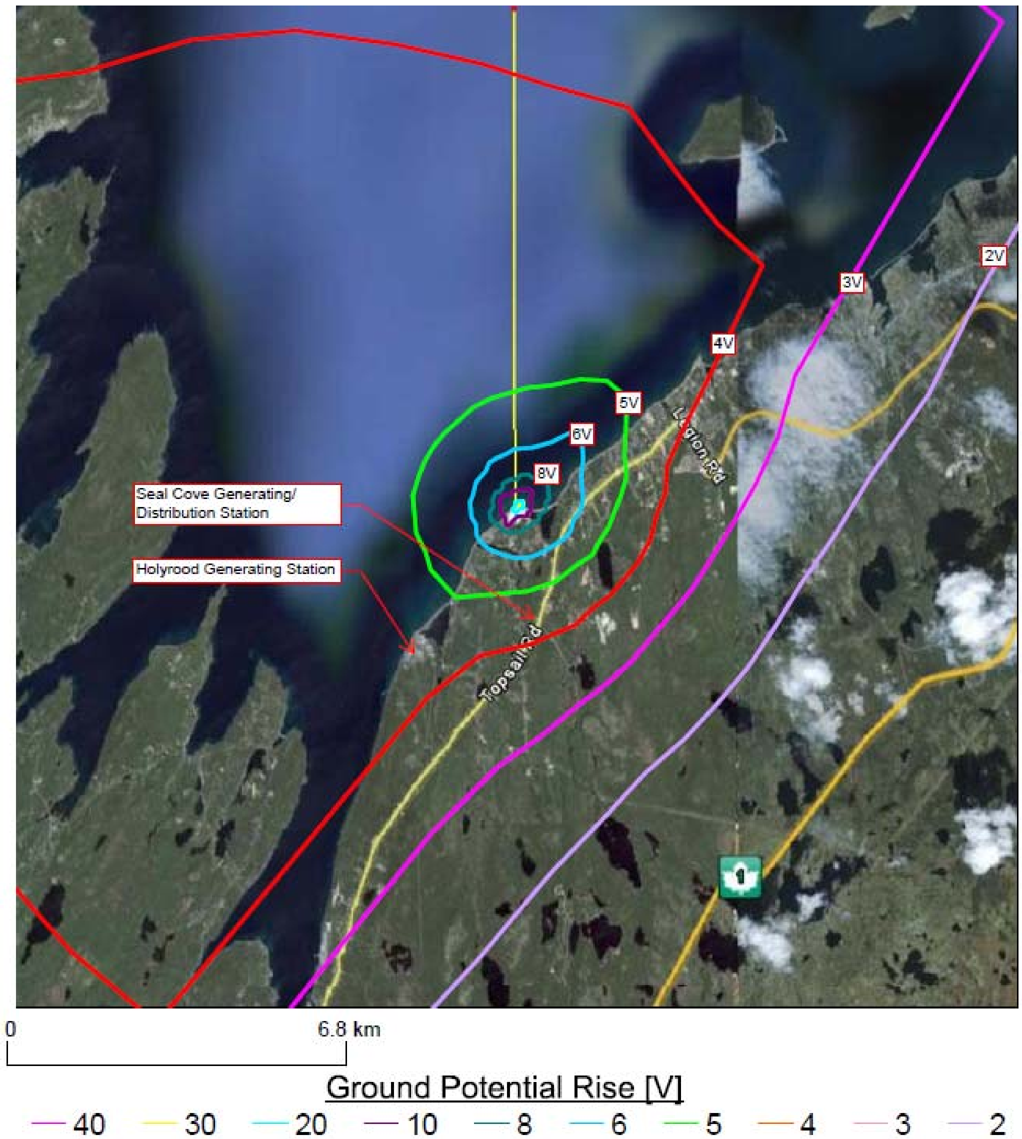


Figure 12-1: GPR Contours for Dowden's Point Electrode Monopolar Operation

Figures D-1 through D-4, in Appendix D show the electrode model and detailed simulation results of GPR contours around the electrode location.

Table 12-2 shows the simulated GPR values at the locations of interest in the zone of influence.

Table 12-2: GPR Values at Locations of Interest

Description	GPR Value (V) Note 1	Remarks
Holyrood Generating and Terminal Station (HRD)	4.5	2.6 km from electrode
Seal Cove Generating and Distribution Station (SCV)	4.0	2.2 km from electrode
Distribution Pole closest to the Electrode	6.5	
Bay Roberts Station (BRB)	3.0	On the north side of Conception Bay
Kelligrews Station (KEL)	4.0	6.0 km from electrode
Western Avalon Station (WAV)	0	Assumed Note 2
Oxen Pond Station (OPD)	0	Assumed Note 2
Hardwoods Station (HWD)	0	Assumed Note 2

Notes:

1. The positive GPR values in the table are for the HVdc electrode in anodic operation; the values will be negative for cathodic operation.
2. At the time of the study, the coordinates for these stations were unknown. The GPR levels at these stations are non-zero; however the assumed GPR's of 0 V will produce pessimistic results.

12.4 Discussion of Results

The maximum voltage at the electrode location is of the order of 45 V and the voltage falls off rapidly inland. The GPR at a distance of 1000 m inland is approximately 6.5 V. The voltage along the shore line drops off gradually due to the conductive body of sea water and therefore the zone of the electrode influence extends farther along the shoreline and also to the north side of Conception Bay. It must be noted that the exact boundary between the sea and the land is not represented in detail in the soil model and therefore the resultant voltages obtained inland along the shore will be pessimistic.

Actual GPR values will depend on the location of electrode and the above values are for the assumed location near Lance Cove. Determination of acceptable GPR values depends on the impact on environment and infrastructure which must be evaluated on a case-by-case basis. In the sea water, the preliminary electrode design results in a GPR gradient of less than 1.25 V/m therefore the safety requirement is satisfied. The potential impacts of the resultant GPR values on infrastructure will determine if the proposed electrode is acceptable. Absolute GPR values at locations of interest do not necessarily determine whether infrastructure will be affected; rather, the GPR difference across the expanse of the infrastructure must be examined individually to analyze the presence of dc stray currents.

12.5 Infrastructure Impact Assessment and Potential Mitigation Measures

This section presents a review of the infrastructure in the vicinity of the HVdc electrode and describes how the infrastructure was modeled for the impact assessment including the assumptions made to develop the model. The infrastructure models were analyzed using the CDEGS software by modeling equipment and circuits as resistance elements. GPR values at various locations as determined from the electrode simulations using GRELEC were used for energization of the infrastructure models. Permissible limits for dc stray currents were also identified where applicable. The models shall be refined during the detailed engineering stage based on information collected through the field program and more detailed electrode simulation results.

Appendix E lists the known infrastructure in the vicinity of the HVdc electrode as identified by NE-LCP.

The infrastructure that may be affected by corrosion or may have operational issues due to dc stray currents includes:

- Local structures including station grounding grids, well casings, transmission line tower grounding systems, and distribution line grounds dissipating dc stray currents into ground,
- Distributed immersed structures and electrodes having conductive connections such as transmission poles connected via a skywire, two facilities bonded by a pipeline, communication antennas, and pole grounds of a multi-grounded distribution system connected via a distribution neutral,
- Equipment such as power transformers and distribution transformers providing conductive connections between local grounding grids and remote stations via transmission and distribution circuits.

The infrastructure at a station including the station grid and conductive connections between the remote installations and station grid, form a common interdependent network. The values of dc current in the various elements of this network depend on the connections among various elements. For a conservative estimate of dc stray currents, various elements of network are analyzed independently without factoring in the impact of common elements (e.g. station grid resistance and auto transformer common windings). This approach will produce pessimistic results. The connections among the remote terminal stations and infrastructure are also ignored in the analysis where these connections will have a minor impact on dc stray currents.

As a conservative approach, the impedances of network elements such as station ground grids, tower footings and ground rods are assigned low values which will produce pessimistic results for dc stray current values observed in the network simulations. Actual impedances can be measured and analyzed in the detailed engineering stage.

The infrastructure farther away along the shore is not considered in this analysis but should be investigated during the detailed engineering stage.

12.5.1 Holyrood Generating Station and 230 kV Transmission Station

The known structures and conductive connections identified by NE-LCP at the Holyrood generating and transmission station together with its connections to the remote station and facilities are reviewed in the following sections.

12.5.1.1 Local Structures

The impact on the local grounding, foundation rebar and anchors, and buried conductive objects depends on the expanse of the generation and transmission line facility and GPR gradients. Typically the grounding grid of a facility creates a uniform potential plane for the facility and the impact on the foundation steel, fences (if bonded to grounding grid), and above ground conductive structures within the facility is negligible and is not of concern. Any buried metallic structure extending below the grounding grid (e.g. well casing or structural steel bonded to the grounding grid) or extending outside the grounding grid limits but not connected to the remote structures can dissipate a significant amount of current under cathodic operation of the HVdc electrode, and these structures should be identified and analyzed during the detailed engineering stage.

The estimated current through the conductive connection of the ground grid to remote earth from the GPR gradients caused by the operation of the HVdc electrode was found to be approximately 4.643 A, consisting of 0.201 A from the skywires, 4.082 A from the 230 kV system and 0.360 A from the 69 kV system. The 138 kV system does not contribute any current, rather it forms a parallel path and dissipates part of the current collected by the 230 kV system during cathodic operation of the HVdc electrode and contributes current for the 230 kV remote end dissipation during anodic operation of the HVdc electrode. The loss of grounding grid copper is estimated to be 75.36 kg resulting from this current over the life cycle of the electrode in cathodic operation. The generating facility is roughly 600 m wide and 680 m long and is expected to have a large ground grid. The size of grid and amount of copper should be verified along with the loss of material during detail engineering in order to define maintenance requirements and a replacement schedule of the grounding grid if necessary.

The allowed percentage loss will depend on the age and condition of the grounding grid. A loss of 10% of material for a new grounding grid is not of concern. A typical problem is point corrosion of copper bonded ground rods and grounding connections. Monitoring of the grounding grid and regular replacement as required should be implemented to ensure the integrity of grid system even if loss of material is acceptable for the electrode duty.

12.5.1.2 Conductive Connection of the Facility to the Remote Earth

The transmission line skywires and above ground fuel transfer pipeline of length 1.26 km provide conductive connections with the transmission station and generating station.

230 kV Line Skywires

Two (2) skywires are strung on each of the 230 kV transmission lines (TL217, TL218 and TL242) for a distance of only 1.6 km from the Holyrood transmission station. The potential difference between towers will result in dc stray current in the skywires. This dc current will cause corrosion of the steel grillage foundation for steel towers, the retaining plate of wood structures, the guywire anchors (if applicable), and the tower footing grounding system. Normally the foundation steel, guywire anchors and tower footing grounding system form a parallel circuit and the tower stray current will not divide between the foundation steel, anchors and grounding system equally. An approximation of the current division would be in proportion to the surface area in contact with soil.

The tolerable loss of steel during the life of the foundation will depend on the age of the foundation, area of foundation steel in contact with earth and the safety factor used in the design. As a conservative estimate it is assumed that a 1% loss over a 40 year life would be acceptable. A higher loss is acceptable if a higher design margin is used. In case only foundation anchors are in contact with the soil, the loss of anchor material needs to be considered. The guywire anchors are normally designed with a higher design margin of 3 or 4, therefore it is assumed a loss of 10% of anchor material is acceptable. The grounding system is effective even if 50% of the rod or counterpoise material is lost.

The highest dc stray current will flow through the tower footing farthest away from the station and therefore permissible dc stray current through the steel foundation, guywire anchors and tower grounding system is compared with 100% value of the current at this tower footing.

The permissible loss of material for foundation steel, guywire anchors and grounding grid was estimated. Based on the electrode duty, the corresponding maximum permissible dc stray currents were then calculated. These values along with the calculated dc stray current values based on simulation results are summarized in Table 12-3.

Table 12-3: 230 kV Tower Footing Permissible Material Loss and dc Stray Current

Description	Permissible Loss of Material (kg)	Permissible dc stray Current (A)	Calculated dc Stray Current (A)	Remarks
Foundation Steel	6.00[Note 1]	0.386	0.051	1% of 600 kg steel foundation
Guywire Anchors	1.78	0.114	0.051	10% of two (2) steel anchors, each 22 mm dia. and 3 m long.
Grounding System	7.57	0.427	0.051	50% of two (2) copper bonded rods, each 19 mm dia. and 3 m long.
Notes: 1. The permissible material loss of foundation steel anchors will apply in the case where only the foundation steel anchors are in contact with soil.				

Details of the model, permissible material loss over the life cycle of the electrode in operation as an anode and simulation results of the skywire network are included in Appendix F.

As seen in Table 12-3, the actual stray currents are less than the acceptable dc stray currents. The calculated loss should be verified based on the actual foundation steel, guywire anchors and structure grounding arrangement during the detailed engineering stage.

The 230 kV line TL218 is of wood pole construction with the poles supported on bearing plates. The pole grounding system consists of five turns of grounding wire wrapped around the buried section of the pole and its bonding to the bearing plate. The bearing plate is 6 mm thick and needs to be reviewed for acceptable loss of material.

If corrosion of the foundation steel for a steel tower, the bearing plate for a wood pole or guywire anchors is deemed to be a concern, a proven mitigation measure is to insulate the skywire connection to the station and sectionalize it along the transmission line with low voltage insulators. The low voltage insulators would spark over in the event of a lightning strike. Additional items like arcing horns across the low voltage insulators can be added to improve flash over reliability.

138 kV and 69 kV Lines

The lines are without skywires and conductive interference with structure foundations does not apply.

Above Ground Fuel Transfer Pipeline

The existing 18 inch main line between the generation station and storage facility and the 16 inch branch lines to the tanks at the storage facility are of carbon steel construction with 3/8 inch wall thickness and are insulated by a mineral-insulated fibre over its entire length. A heat tracing system is employed over the length of the pipeline to guard against freezing. The flow of current through the pipeline needs to be reviewed considering the grounding and bonding arrangement at the ends, and fuel terminal safety requirements. Corrosion along the pipeline run is not an issue since it is insulated.

The voltage across the two ends of the pipeline will be small since it runs parallel to the shoreline where the voltage gradient is low.

If the current flow through the pipeline is deemed a concern, the connection to the generating station can be insulated using an insulation flange or section if the pipeline provides conductive connections between the two facilities. The insulation of the pipeline into sections is a common practice for cathodic protection to insulate the cathodically protected sections from non-protected sections. Another mitigation measure could include adding or modifying cathodic protection to the pipeline.

12.5.1.3 Conductive Connection of the Facility through Equipment

The 230 kV, 138 kV, 69 kV and distribution phase conductors provide a connection through the facility equipment since the equipment phases are arranged in wye-grounded configuration at the local and remote ends, and the equipment neutrals are tied to the facility ground grid.

230 kV System

The dc current flowing through the neutral of a power transformer due to GPR produced by an HVdc electrode can be quantified by analyzing the dc equivalent circuit of transmission line phase conductors connecting various stations, station ground grids and transformer windings. A dc current level in excess of 1.5 times that of the excitation current [8] can cause operational problems.

Appendix G shows the equivalent circuit formed for the 230 kV system connecting the Holyrood transmission station 230 kV transformer windings with the remote Western Avalon, Oxen Pond and Hardwoods stations. The 230 kV windings of all transformers at Holyrood station except HRD_T5 and HRD_T10 provide a path to the remote stations.

The permissible limits and calculated dc stray currents in the transformer windings, and transformer winding dc resistance for transformers installed at Holyrood, Western Avalon, Oxen Pond and Hardwoods transmission stations are shown in Table 12-4. Detailed calculations are provided in Appendix G.

Table 12-4: Permissible and Calculated dc Stray Currents for 230 kV Transformers

Transformer Designation/Base Ratings	Transf. Winding dc Resistance Note 1 (Ω)	Permissible 1-Ø Limit of dc Current Note 2 (A)	Calculated 1-Ø Stray dc Current (A)	Remarks
HRD_T1/180 MVA	0.687	0.678	0.412	Acceptable
HRD_T2/115 MVA	1.002	0.722	0.282	Acceptable
HRD_T3/100 MVA Note 3	1.207	0.64	0.234	Acceptable
HRD_T6/25 MVA	5.284	0.094	0.051	Acceptable
HRD_T7/25 MVA	5.568	0.094	0.051	Acceptable
HRD_T8/75 MVA	0.862	0.282	0.328	Less than 2x excitation current
WAV_T1/15 MVA	13.90	0.094	0.012	Acceptable
WAV_T2/15 MVA	14.31	0.094	0.012	Acceptable
WAV_T3/25 MVA	5.645	0.094	0.030	Acceptable
WAV_T4/25 MVA	5.569	0.094	0.030	Acceptable
WAV_T5/75 MVA	0.870	0.282	0.194	Acceptable
OPD_T1/40 MVA	3.171	0.251	0.083	Acceptable
OPD_T2/75 MVA	0.856	0.471	0.309	Acceptable
OPD_T3/75 MVA	1.530	0.471	0.173	Acceptable
HWD_T1/40 MVA	3.861	0.251	0.092	Acceptable
HWD_T2/40 MVA	3.547	0.251	0.100	Acceptable
HWD_T3/40 MVA	4.025	0.251	0.088	Acceptable
HWD_T4/75 MVA	1.516	0.471	0.235	Acceptable

Notes:

1. The dc resistance is based on nameplate load loss data provided by NE-LCP. The split of the resistance is proportional to the square of the voltage ratio for two-winding transformers, as per typical industry practice.
2. Industry accepted values of the excitation current % of the rated base (OA) transformer rating current is typically less than 0.5% of rated current at base MVA for two/three winding transformers and 0.3% for auto transformers.
3. Transformer base rating calculated from OFAF rating of 170 MVA.

As seen in Table 12-4, the calculated dc stray current levels at Holyrood generating station through the transformer windings are less than the tolerable limits, except for HRD_T8; the value of dc stray current is greater than 1.5 times the excitation current but less than 2 times the excitation current, the level at which transformer performance may be compromised [8].

The actual excitation current values, transformer core construction and permissible dc current values should be confirmed during the detailed engineering stage to verify the typical values used. Typically a higher level of dc stray current is tolerable for a three-limb core-type three-phase transformer than a shell–type, three-phase transformer or a single-phase transformer design [10]. The excitation current values can be confirmed either by contacting the transformer manufacturer or from test reports (if available). The acceptable stray dc current levels should also be confirmed by the manufacturers.

The dc stray currents of the magnitudes indicated in Table 12-4 will cause limited half cycle saturation of transformer cores which would result in additional harmonics on the system. The impact of this distortion on generator units, capacitors and filters should be reviewed and analyzed during the detailed engineering stage.

Suitable mitigation measures, if required, include the addition of neutral grounding resistors or the replacement of the transformer with a higher capacity unit.

138 kV System

The 138 kV windings of 230/138 kV auto transformers at Holyrood transmission station (HRD_T6, HRD_T7 and HRD_T8) provide limited connectivity to remote stations as there is only one wye-grounded transformer at Bay Roberts station.

The data for the 138 kV network model and results are shown in Appendix G. Although the GPR at Holyrood (4.5 V) is greater than the GPR at Bay Roberts (3 V), the current in the 138 kV system does not flow from Holyrood to Bay Roberts (assuming anodic electrode operation). Instead, Bay Roberts contributes current that is dissipated into the remote 230 kV network (Western Avalon, Oxen Pond and Hardwoods) via the 230/138 kV auto transformers at Holyrood because the GPR at Bay Roberts is relatively higher than the GPR at the remote stations (each considered to be 0 V). The current injected at Bay Roberts station is 0.132 A (0.044 A per phase). This 0.044 A per phase current is distributed among the three auto transformers HRD_T6, HRD_T7 and HRD_T8 and its contribution is negligible.

The loss of grounding grid material at Bay Roberts will depend on the current calculated there and the current dissipated through the local distribution neutral. It is expected that this will be a small loss of material for the substation grounding grid.

69 kV System

The 69 kV windings of 230/69 kV delta/wye-grounded transformers HRD_T5 and HRD_T10 provide a path to the remote Newfoundland Power Seal Cove and Kelligrews stations. The model of the network used in the analysis is included in Appendix G.

Table 12-5 shows the transformer winding dc resistance and permissible dc stray current values used in the analysis along with the calculated stray dc current values.

Table 12-5: Permissible and Calculated dc Stray Currents for 69 kV Transformers

Transformer Designation/Base Ratings	Transf. Winding dc Resistance Note 1 (Ω)	Permissible 1-Ø Limit of dc Current Note 2 (A)	Calculated 1-Ø Stray dc Current (A)	Remarks
HRD_T5/15 MVA	1.065	0.188	0.060	Acceptable
HRD_T10/15 MVA	1.065	0.188	0.060	Acceptable
KEL-T1/11.25 MVA	1.639	0.141	0.050	Acceptable
SCV-T1/2.5 MVA	15.217	0.031	0.007	Acceptable
SCV-T2/11.20 MVA	1.654	0.141	0.064	Acceptable

Notes:

1. The dc resistance is based on nameplate load loss data. The split of the resistance is proportional to the square of the voltage ratio for two-winding transformers, as per typical industry practice.
2. Industry accepted values of the excitation current % of the rated base (OA) transformer rating current is typically less than 0.5% of rated current at base MVA.

As seen in Table 12-5, the actual stray current values are less than the tolerable limits.

The actual excitation current values and the permissible dc current should be confirmed during the detailed engineering stage to verify the typical values used. The excitation current values can be confirmed either by contacting the transformer manufacturer or from test reports (if available). The acceptable stray dc current levels should also be confirmed by the manufacturers.

16 kV System, Plant Distribution and Holyrood Substation

The generator supplies the 16 kV delta connected windings of the transformer and therefore a path for dc stray path is not available through the generator windings. The impact of half cycle saturation of the 230/16 kV transformer units and its impact on the generator units should be investigated during the detailed engineering stage. The 2400 V, 600 V and 120/208 V plant distribution circuits are local and will not be impacted by dc stray current.

The only external distribution link is through Holyrood substation transformer T1 (69-2.4/4.16 kV) and may have issues if the link is supplying power during electrode operation. Information provided indicates that the external supply is required only if the plant supply is lost and therefore it was assumed that the probability of simultaneous electrode operation and requirement of external supply is low, and therefore was not considered in this analysis. This low probability event should be addressed during the detailed engineering stage.

12.5.2 Seal Cove Generating Station and NL Power Substation

The known infrastructure identified by NE-LCP at the Seal Cove generating station (Appendix E) is analyzed in the following sections.

12.5.2.1 Local Structures

The above analysis for the Holyrood generating station local structures is applicable for the Seal Cove facility. The site is approximately of size 80 m x 70 m. The estimated current from the local GPR gradient was found to be approximately 1.089 A, consisting of 0.211 A from 69 kV system and 0.878 A from distribution neutral; the current is injected into ground for anodic operation of the HVdc electrode. The loss of grounding grid copper resulting from this current over the life cycle of the electrode in anodic operation is estimated to be 16.93 kg. The value is sensitive to the location of the electrode and will change if the location of the electrode is adjusted. The allowed percentage will depend on the age and condition of the grounding grid. A loss of 10% of a new grounding grid shall not be a concern. A typical problem is point corrosion of copper bonded ground rods and grounding connections. The monitoring of the grounding grid and regular replacement as required should be implemented to ensure the integrity of the grid system even if loss of material is acceptable for the electrode duty.

12.5.2.2 Conductive Connection of the Facility to the Remote Earth

The transmission line skywires, distribution system neutral and the 1.2 km-long, above ground penstock can provide a conductive connection with the transmission station and generating station.

69 kV Line Skywires

The 69 kV lines (52L from Kelligrews station to Seal Cove generating station and 38L from Seal Cove generating station to Holyrood transmission station) are without skywires and therefore stray dc currents are not an issue.

12.47 kV Distribution Neutral

It is assumed that the generating station supplies the local multi-grounded neutral distribution system through the Newfoundland Power 69/12.47 kV substation. The simplified distribution system model and its impact on the distribution substation are analyzed in Section 12.5.3.

Penstock

Some of the penstock sections are of wood stave construction and it is expected the penstock will not be impacted significantly. The penstock installation, including supports and sections in contact with the earth, need to be reviewed during the detailed engineering stage to quantify the impact of the electrode operation. In the event that adverse impacts are found to exist, possible mitigation measures include isolation of the penstock from the station grid.

12.5.2.3 Conductive Connection of the Facility through Equipment

The 69 kV and 12.47 kV phase conductors provide a connection through the facility equipment since the equipment phases are arranged in wye-grounded configuration at both local and remote ends and the equipment neutrals are tied to the facility ground grid.

69 kV System

The analysis of 69 kV system is included in Section 12.5.1.3 as part of the Holyrood transmission station analysis. As seen in Table 12-5, the actual stray current value is less than the tolerable limits and mitigation is not required. The dc stray current levels are sensitive to the electrode location and dc stray current in SCV_T2 may become problematic if the distance between the electrode and the station is reduced.

12.47 kV Distribution Transformer

The distribution system and the impact of electrode operation on the distribution substation are analyzed in Section 12.5.3.

12.5.3 Multi-Grounded Distribution System

The impact of an HVdc electrode on a distribution system can be estimated by analyzing the dc equivalent circuit of the multi-grounded neutral, distribution transformers, phase conductors, and distribution station ground grids. Appendix H shows the equivalent network and assumptions made to simplify the network for this analysis.

The current through the substation distribution neutral is critical and depends on the location of the distribution substation relative to the HVdc electrode, distribution neutral ground impedance, population of the pole-mounted distribution transformers, and expanse of the distribution network. In general, lower rating pole-mounted distribution transformers are connected phase-to-ground on the HV side. The low side distribution neutral is normally connected to the pole ground and residential ground rod; the residential ground rod will provide a path in parallel with the pole grounds for dc stray currents. The current through the LV winding can be a concern if the distribution transformer and service entrance are separated by 400 m to 500 m and one (1) transformer supplies multiple locations. A typical transformer size of 25 kVA with a permissible dc stray current limit of 23 mA through the transformer was assumed for the analysis. It was assumed that the distribution transformers are spaced 200 m apart and as a conservative approach based on typical grounding practices [11,12], it was further assumed that the grounding points are spaced every 200 m. The actual population of the grounding points will influence the dc stray currents flowing through the distribution network's neutral, however the assumptions used in this analysis will produce pessimistic results.

Results of the analysis show that the highest dc stray current through a transformer winding is 2.4 mA, which is less than the permissible limit of 23 mA. The highest dc stray current through a distribution neutral ground is 62 mA near the electrode location which is less than the permissible current of 214 mA for a 50% material loss of a 19 mm diameter and 3 m long copper bonded ground rod.

In case a smaller size transformer of 5 kVA or 10 kVA is used and the transformers are located farther apart, the dc stray current may exceed the permissible limits. A detailed review of the existing transformer sizes should be undertaken during the detailed engineering stage and if deemed necessary replacement of smaller units with larger units (25 kVA) would provide suitable mitigation. The segregation of HV ground from LV neutral through a spark gap could eliminate some of the operational issues with the distribution circuit [3]. This spark gap isolates the distribution neutrals from HV multi-grounded neutrals and increases the dc stray current path resistance. The addition of a spark gap between the HV winding and LV winding neutrals will require separate grounds on the pole for the HV neutral and the distribution neutral.

There may be situations where the dc stray current through a pole ground rod can exceed the permissible limit, especially for poles in close proximity to the HVdc electrode and where large GPR differences exist between the grounded locations. The loss of pole ground rods is not an issue since these can be inspected and replaced as required, and a material loss of 50% for a ground rod is acceptable. Alternatively, the ground rods could be replaced with high silicon chromium steel electrodes.

12.5.4 Bridges, Other Infrastructure and Utilities

The potential difference across a typical bridge or structure of 100 m in length or smaller will be negligible. In case the structure is connected to remote earth via a distribution circuit or any other conductive connection, the dc current will not cause significant corrosion to a large structure. If the connection to the remote earth is a concern for the system connected at the other end (e.g. distribution transformer), the system can be isolated.

Telephone lines and facilities in the area will not be impacted. A ground potential of up to 70 V does not cause any operational issues and does not constitute a safety hazard since the insulated telephone circuits do not allow stray current through the network, and the combined potential difference (a GPR of 70 V and a telephone loop voltage of 48 V) is a non-lethal hazard to the telephone company personnel. The actual GPR values are less than 70 V.

12.6 Summary of Findings

The results of this analysis show that based on the currently known geological conditions, operation of a shoreline pond electrode at Dowden’s Point would have minimal adverse impact on the existing infrastructure identified by NE-LCP.

Any critical infrastructure along the shoreline and on the northern side of Conception Bay should be identified and analyzed for potential adverse impacts. Based on the present analysis, it is anticipated that a typical station terminal, multi-grounded neutral distribution network or pipeline will not be impacted significantly by the operation of the HVdc electrode and mitigation measures may be avoided. Considering the GPR profiles obtained in the vicinity of the shoreline pond electrode, any adverse affects not captured in this preliminary screening can be reliably mitigated.

Based on the results to date, a shoreline pond electrode at Dowden’s Point is a viable alternative for the Soldiers Pond converter station and would be a preferred alternative to a sea electrode in Conception Bay. If a shoreline pond electrode at Dowden’s Point is to be pursued, additional site surveys will be required to further investigate geological conditions and to identify physical impediments which may impact the size and location of the shoreline pond. Assumptions on the existing infrastructure, power transformer excitation currents and tolerable dc stay currents used in this analysis should be verified. Additional simulations should be undertaken during the detailed engineering stage to further substantiate the results of this preliminary analysis and to quantify the impact of the limited transformer half cycle saturation caused by dc stray currents on the system.

13. Conclusions and Recommendations

13.1 Labrador

The results of the Labrador electrode study indicate that all of the potential land electrode sites and the potential shoreline pond electrode site identified in Lake Melville will result in GPR values which require mitigation measures at the Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, and the town of Happy Valley-Goose Bay. Furthermore, mitigation measures may also be required at remote substations, including Churchill Falls.

In a few existing HVdc systems, there has been the need to install current limiting devices in the neutrals of nearby transformers in an effort to mitigate the potentially damaging effect of ground currents on the transformers. In most instances, the need for current limiting devices was only identified after commissioning. These mitigation measures are unique and their reliability is not well documented. Moreover, their misoperation may result in forced outages or transformer damage. It is the opinion of the electrode review panel that the use of current limiting devices should be avoided if possible.

Series capacitors in the transmission lines would block stray dc currents in the transformers, but they are expensive and would not be justified unless required by the transmission system.

Mitigation of problems in Happy Valley-Goose Bay due to the high GPR probably would be extensive and difficult to implement and control.

Thus, it is concluded that none of the identified land or shoreline pond electrode sites in Labrador are viable sites.

It is therefore recommended that consideration be given to locating a suitable site for a shoreline pond electrode on the SOBI. A preliminary desktop review has identified L'Anse-au-Diable as one such potential site.

13.2 Island

The results of the Island electrode study indicate that based on the currently known geological conditions, operation of a shoreline pond electrode at Dowden's Point would have minimal adverse impact on the existing infrastructure identified by NE-LCP.

Electric field simulations indicate that GPR values and the resultant impact on the identified surrounding infrastructure do not require mitigation measures. Considering the GPR levels at the locations of interest, a suitable and well-proven mitigation can be provided, if required.

Based on these results, it is concluded that a shoreline pond electrode at Dowden's Point is a viable alternative for the Soldiers Pond converter and would be a preferred alternative to a sea electrode in Conception Bay.

Since the electrical model for the electrode was based on limited geological and geophysical information and assumptions were made in the model, it is therefore recommended that a more detailed study for a shoreline pond electrode at Dowden's Point be undertaken to improve the accuracy of the model and re-evaluate the impact on infrastructure.

14. Next Steps

The work completed under WTO DC1250 "Electrode Review – Types and Locations" identifies a potential site at L'Anse-au-Diable for a shoreline pond electrode for the Gull Island converter station and concludes that a shoreline pond electrode at Dowden's Point for the Soldiers Pond converter station is viable. The following next steps should be considered to proceed with a detailed project plan for the Lower Churchill HVdc system:

- Select a location for the shoreline pond electrode site on the north shore of the SOBI.
- Gather applicable geotechnical and geophysical data for the purpose of detailed design and GPR assessment of the electrode sites at SOBI and Dowden's Point.
- Complete a final assessment of the impact of corrosion and electrical interference on infrastructure, based on the location of the selected sites.
- Complete a detailed civil, mechanical, and electrical design of both electrode sites.
- Provide preliminary cost estimates.
- Collect information required for Environmental Assessment process.

The following is a suggested scope of work based on the electrode site location.

14.1 Labrador Electrode Site

Preferred search areas and areas of exclusion along the SOBI should be identified to facilitate the task of locating candidate sites for a shoreline pond electrode. A shortlist of potential sites should be identified for both a direct subsea cable crossing and a tunnel crossing. The candidate sites should be ranked considering factors such as proximity to cable crossing, proximity to major infrastructure, anticipated resistivities of surrounding geology, vulnerability to wave action, etc. Once a shortlist of potential sites has been identified and ranked:

Collect Data for GPR Electrical Modeling Scenarios

- Compile resistivity properties of the geological units and develop modeling scenarios.
- Review of sea water resistivities considering the fresh water inlets in the area and seasonal resistivity variation.
- Compile bathymetric data.
- Assess the effect of the tide on the water level in the shoreline pond.

Collect Data for Assessment of Electrical Interference on Infrastructure

- Details of nearby 12.47 kV distribution system including distribution transformer ratings, pole grounding details and area map indicating route and distribution transformer locations.
- Identify structures (e.g. marine slipway, farm, communications tower) and installation details that may be impacted by the electrode operation.

- Other infrastructure including residential infrastructure in close proximity to the electrode.

Detailed Assessment of Impact of Electrical Inference on Infrastructure

- Qualify the electrode operation duty.
- Develop electrode model.
- Assess the impact on the infrastructure, and identify mitigation requirements (if any).

Civil and Mechanical Requirements for Design and Construction of Breakwater and Electrode

- Precipitation and snow melt run-off water issues for the cove.
- Erosion potential due to water flowing from the land side.
- Salt pollution risks to overhead electrode line.
- Earth or rock slide risks.
- Any other geological hazard.
- Impact and mitigation of ice around electrode elements.
- Impact of pack ice on ocean side of breakwater or support structure.
- Geotechnical data required for breakwater or support structure design.

Detailed Design of Electrode

- Provide preliminary drawings of breakwater, support structure, electrode, and interconnection to electrode line.
- Provide preliminary design of electrode line.

Preliminary Cost Estimates

- Develop preliminary cost estimates of the shoreline pond electrode
- Develop preliminary cost estimates of the electrode line.

Review of Land Ownership

- Identify any land ownership issues for the electrode site.
- Identity potential right of way for the electrode line.

Identification of any Potential Environmental Issues

- Identify any potential environmental issues related to the shoreline pond electrode that may be raised during the regulatory process and prepare responses to those issues.

Identification of any Potential Issues Associated with the Long Electrode Line

- Ground fault clearing on long electrode line.
- Fault detection on long electrode line.

14.2 Island Electrode Site

The shoreline pond electrode at Dowden's Point has been shown to be a viable alternative. Since there is significant infrastructure near the site, a more detailed evaluation is required to provide a higher confidence level on the electrical simulation results and electrical interference impact assessment.

Collect Additional Data to Improve GPR Electrical Modeling Scenarios

- Detailed geological and geophysical site investigation to improve land soil model.
- Review of sea water resistivities considering the fresh water inlets in the area and seasonal resistivity variation.
- Collect and compile resistivity data for small ponds adjacent to the shoreline.
- Compile bathymetric data.
- Assess the effect of the tide on the water level in the proposed shoreline pond.

Collect Additional Data for Assessment of for Electrical Interference on Infrastructure

- Transmission line TL217 and TL242 foundation steel, guy wire anchor and grounding system details.
- Ground grid impedances for the stations.
- Distribution system details including distribution transformer ratings, pole grounding details and area map indicating route and distribution transformer locations.
- Other infrastructure including residential infrastructure in close proximity to the electrode.

Detailed Evaluation and Impact Assessment

- Qualify the electrode operation duty.
- Refine electrode model and reaffirm simulation results based on additional data.
- Assess the impact on the infrastructure based on additional information and new simulation results.
- Develop potential mitigation as required.

Literature Review of Other Consequences of Electrode

- Identify the risks associated with other impacts from electrode operation (e.g. production of chlorine gas, compass deviation, corrosion of ships, etc.).

Civil and Mechanical Requirements for Design and Construction of Breakwater and Electrode

- Precipitation and snow melt run-off water issues for the cove.
- Erosion potential due to water flowing from the land side.
- Shoreline erosion.
- Impact and mitigation of ice around electrode elements.

- Impact of pack ice on ocean side of breakwater or support structure.
- Tidal effects.
- Geotechnical data required for breakwater or support structure design.

Detailed Design of Electrode

- Provide preliminary drawings of breakwater, support structure, electrode, and interconnection to electrode line.
- Provide preliminary design of electrode line.

Preliminary Cost Estimates

- Develop preliminary cost estimates of the shoreline pond electrode.
- Develop preliminary cost estimates of the electrode line.

Review of Land Ownership

- Identify any land ownership issues for the electrode site.
- Identity potential right of way for the electrode line.

Identification of Potential Environmental Issues

- Identify any potential environmental issues related to the shoreline pond electrode that may be raised during the regulatory process and prepare responses to those issues.

15. References

1. Hatch Ltd., "DC1110 – Electrode Review – Gull Island & Soldiers Pond", March 2008.
2. CIGRÉ Working Group 14.21 – TF2, "General Guidelines for the Design of Ground Electrodes for HVDC Links", July 1998.
3. EPRI EL-2020, Project 1467-1, "HVDC Ground Electrode Design", August 1981.
4. Kalmijn, A.J., "Electro-perception in Sharks and Rays", Nature 212, 1966.
5. Balayev, L.A, N.N Fursa, "The Behaviour of Ecologically Different Fish in Electric Fields, Threshold of Anode Reaction and Tetanus", 1982.
6. Environment Canada, National Climate Data and Information Archive, [website: www.climate.weatheroffice.gc.ca]
7. Dalziel, C.F., "The Threshold of Perception Currents", IEEE Paper 54-209, No. 13, June 1954.
8. Kimbark, E.W., "Direct Current Transmission, Vol. 1", Wiley Interscience, 1971.
9. AMEC, "Site Investigations Dowden's Point NL", December 2009.
10. EPRI, TR-100450, "Proceedings: Geomagnetically Induced Current Conference", June 1992.
11. Ontario Electrical Safety Code, 23rd Edition, August 2002.
12. National Electrical Safety Code, 2007 Edition.

Appendix A

Labrador

Surficial Geology Map

Figure A-1: Surficial Geology Map

HATCH™

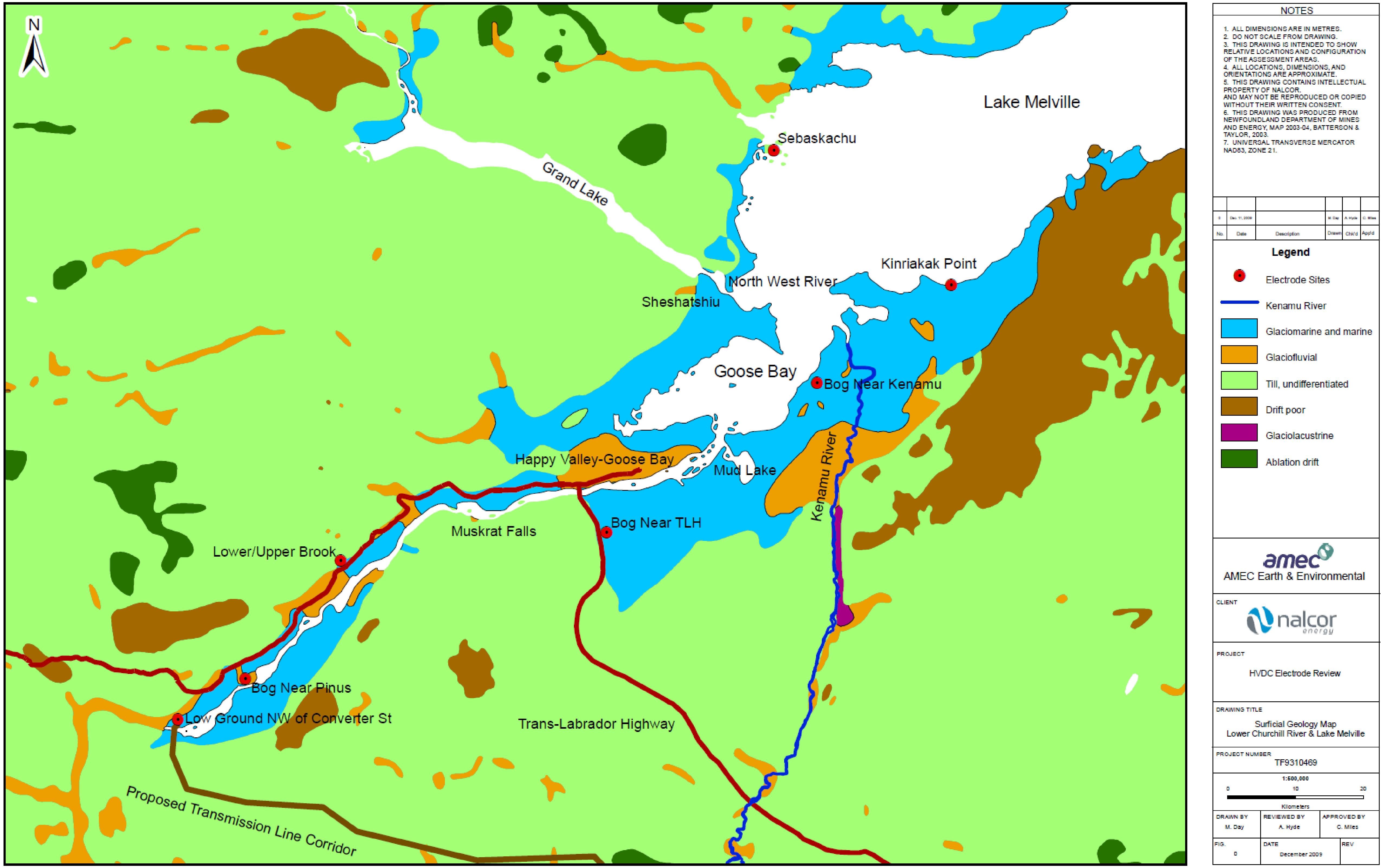


Figure A-1: Surficial Geology Map – Surrounding Area of Potential Land Electrodes

Appendix B

Labrador

Land Electrode

GPR Contour Plots

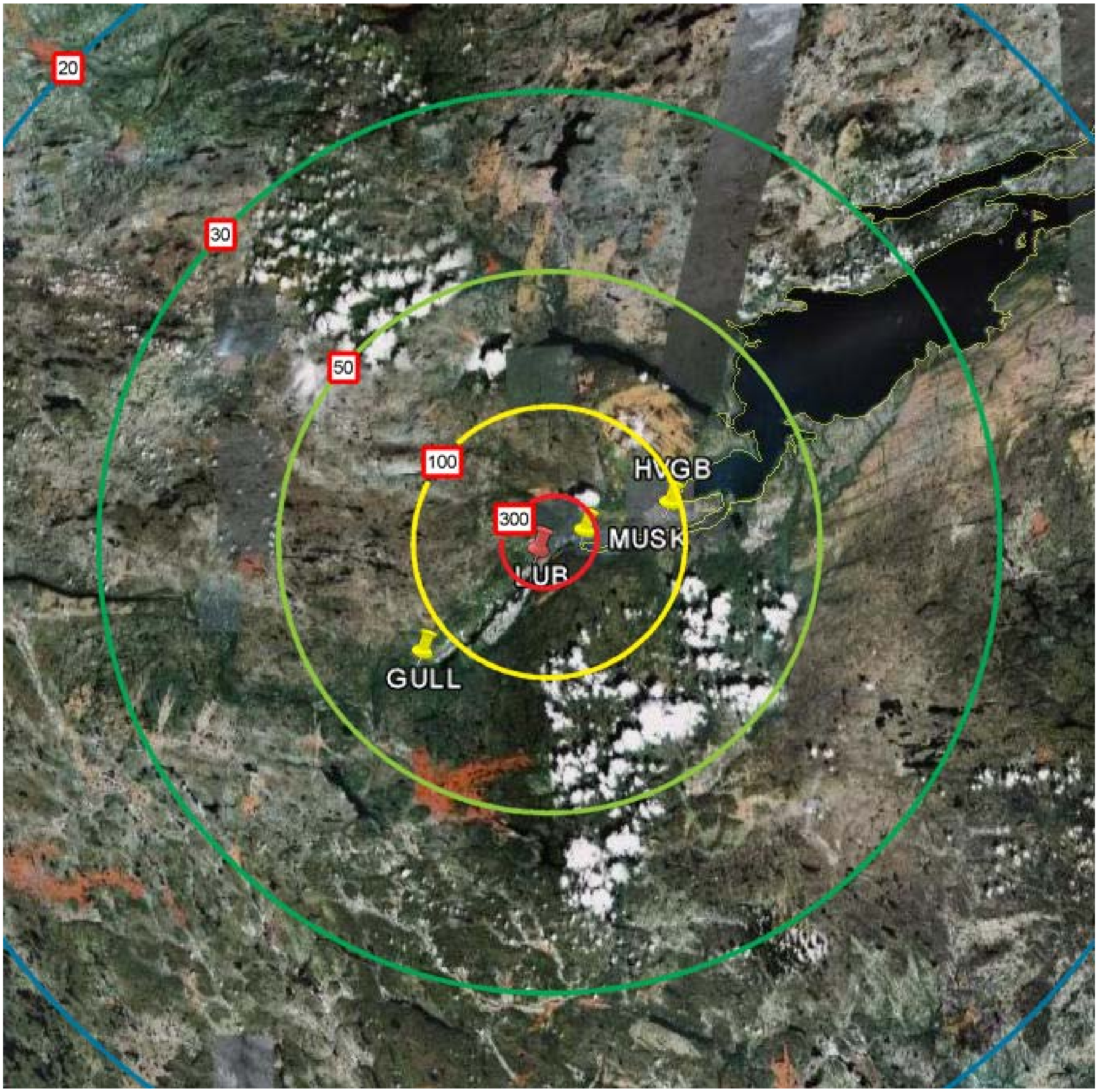


Figure B-1: GPR Contours – LUB, Scenario A

GPR at center of electrode = 1035.14 V

*Note: The position of the GPR contours is limited in accuracy.

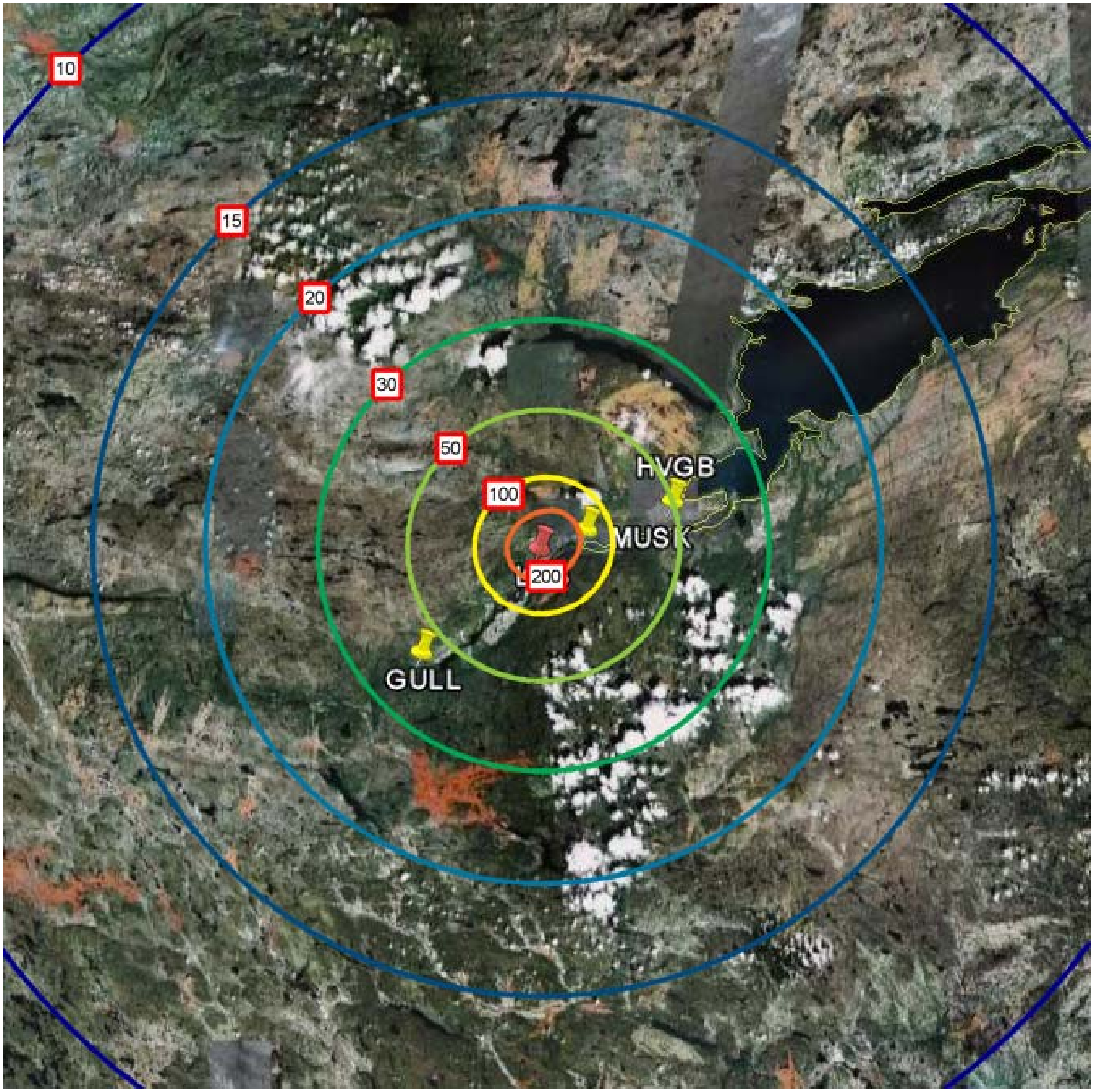


Figure B-2: GPR Contours – LUB, Scenario E

GPR at center of electrode = 696.55 V

*Note: The position of the GPR contours is limited in accuracy.

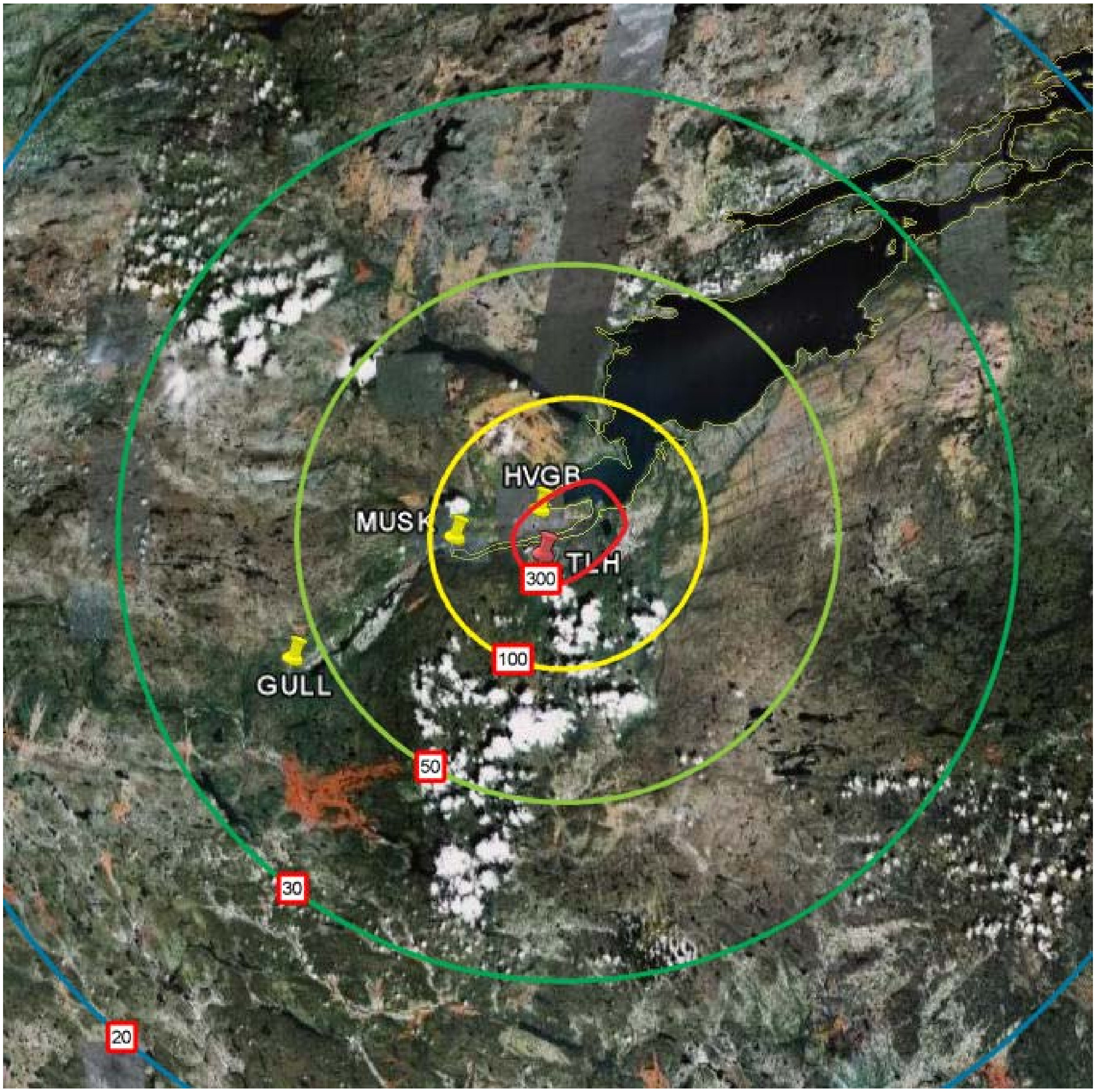


Figure B-3: GPR Contours – TLH, Scenario A

GPR at center of electrode = 708.01 V

*Note: The position of the GPR contours is limited in accuracy.

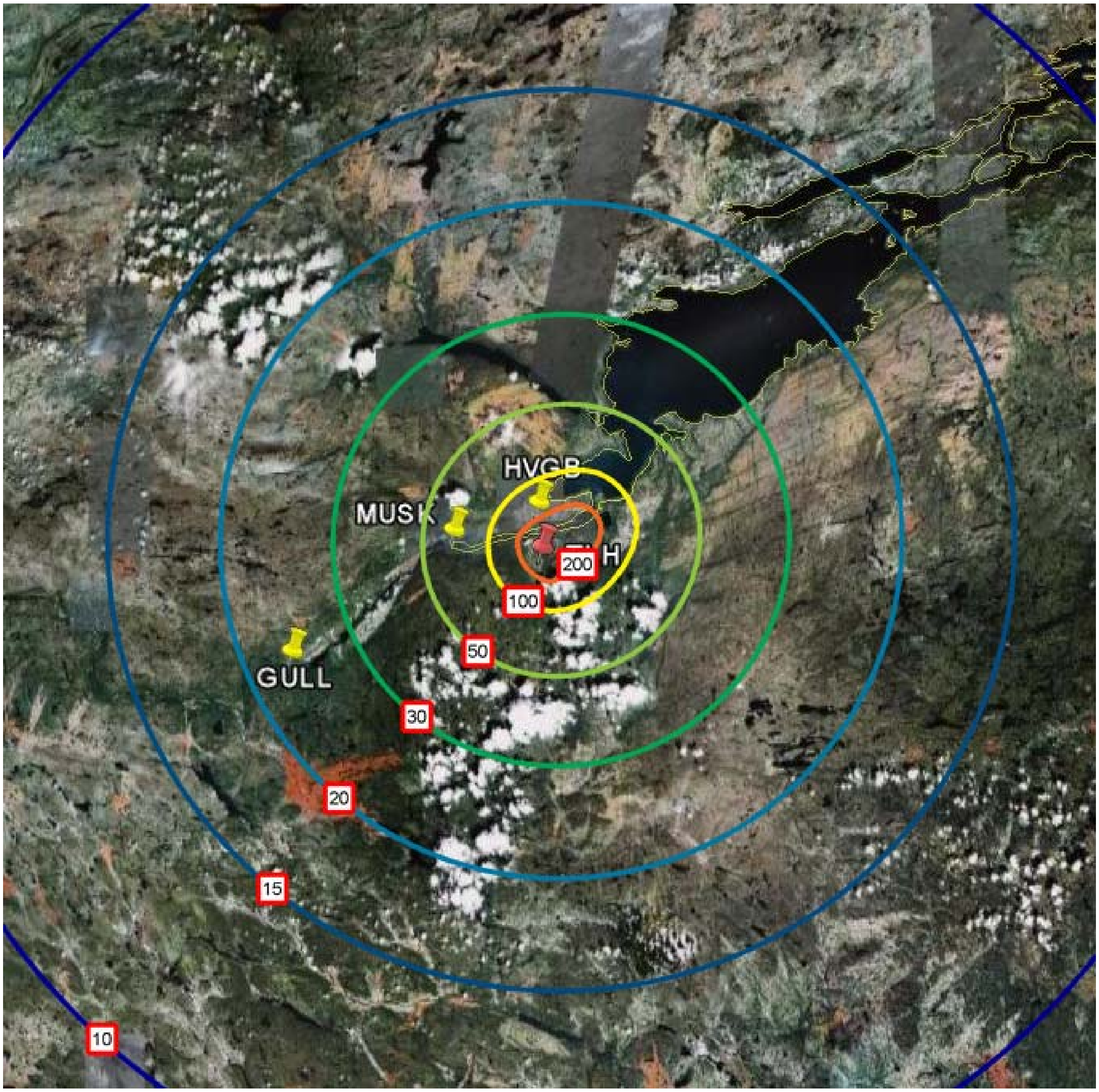


Figure B-4: GPR Contours – TLH, Scenario E

GPR at center of electrode = 539.49 V

*Note: The position of the GPR contours is limited in accuracy.

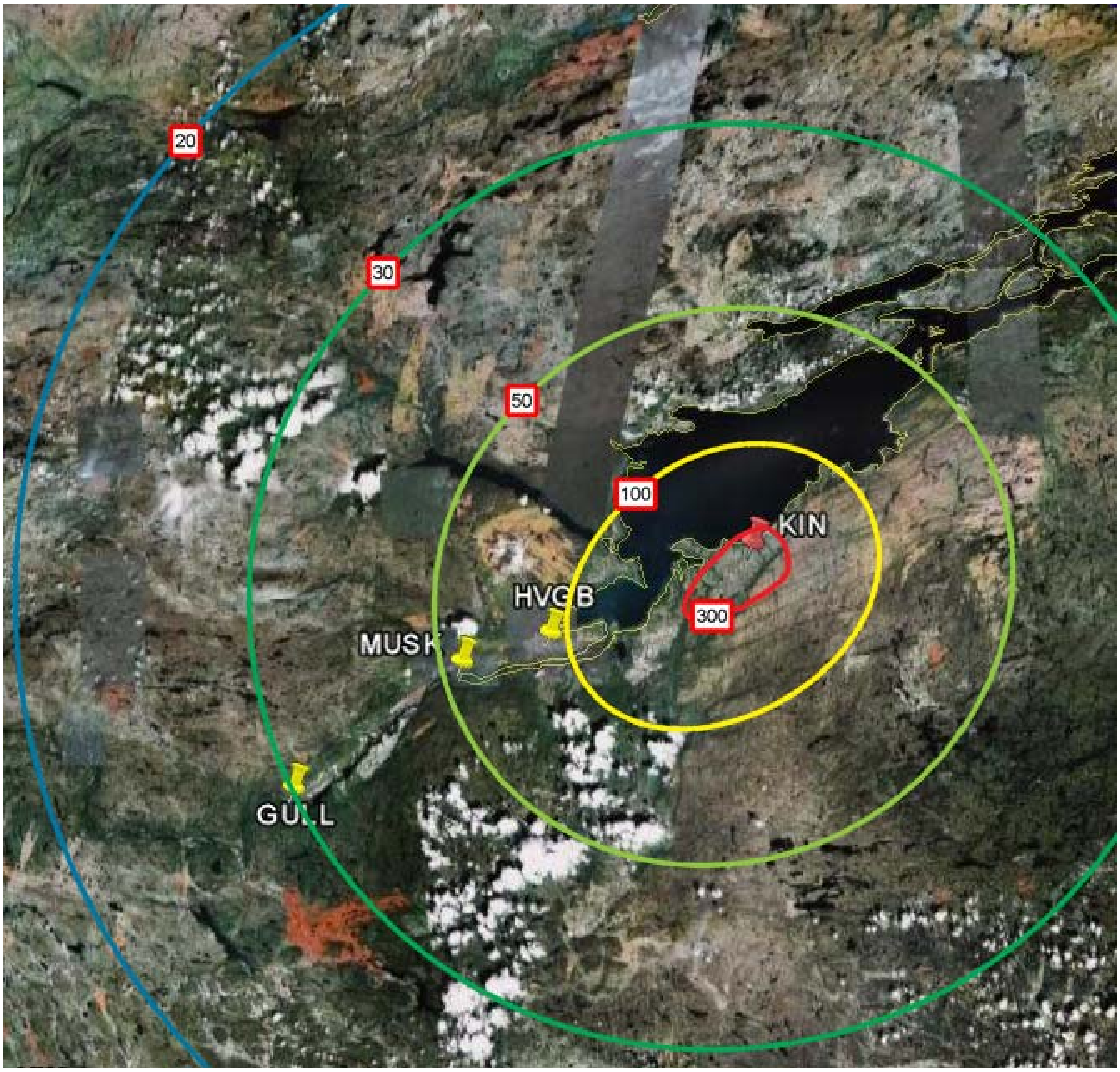


Figure B-5: GPR Contours – KIN, Scenario A

GPR at center of electrode = 512.60 V

*Note: The position of the GPR contours is limited in accuracy.

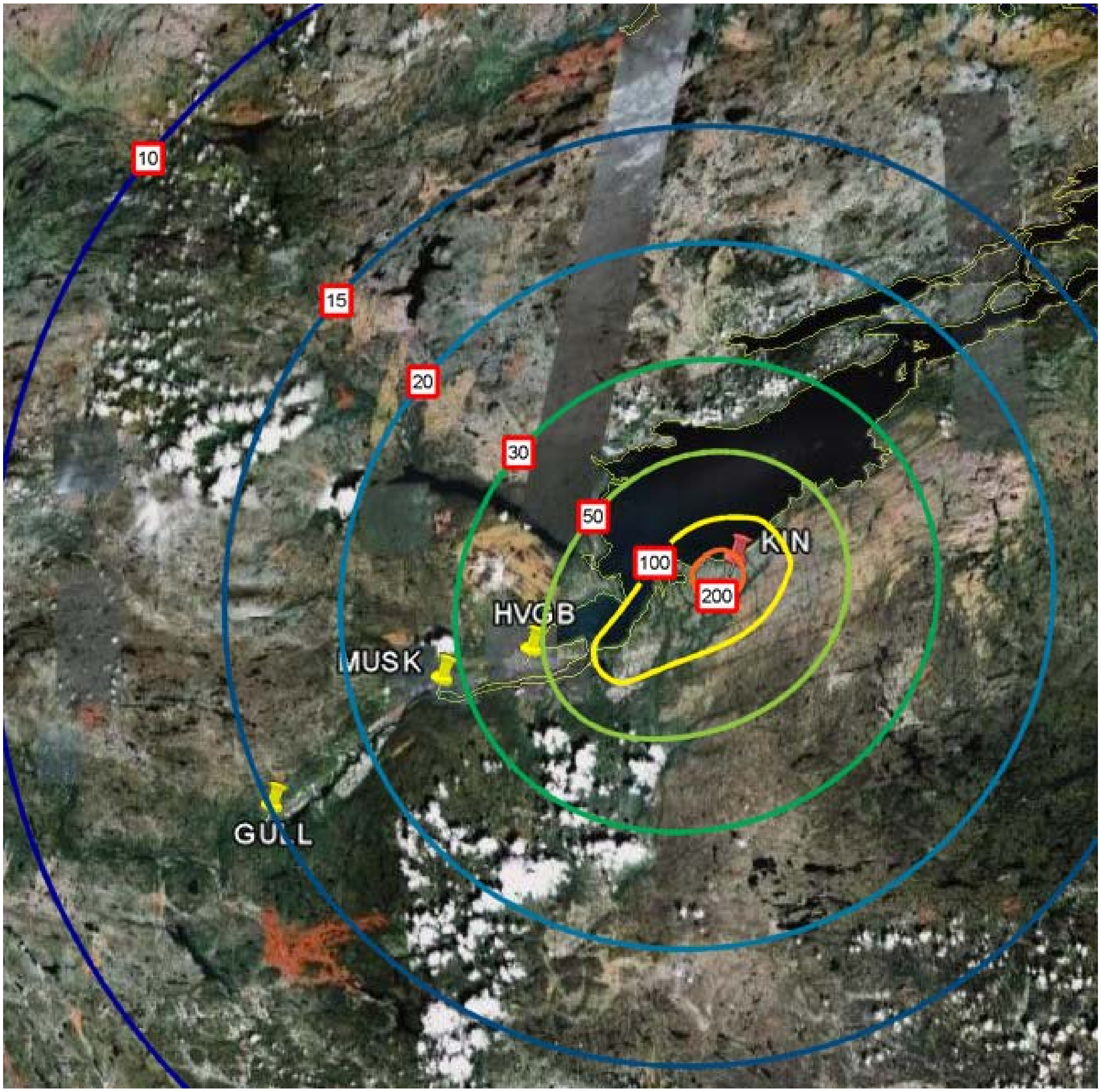


Figure B-6: GPR Contours – KIN, Scenario E

GPR at center of electrode = 443.10 V

*Note: The position of the GPR contours is limited in accuracy.

Appendix C

Shoreline Pond Electrode Near Dowden's Point

Location and Design

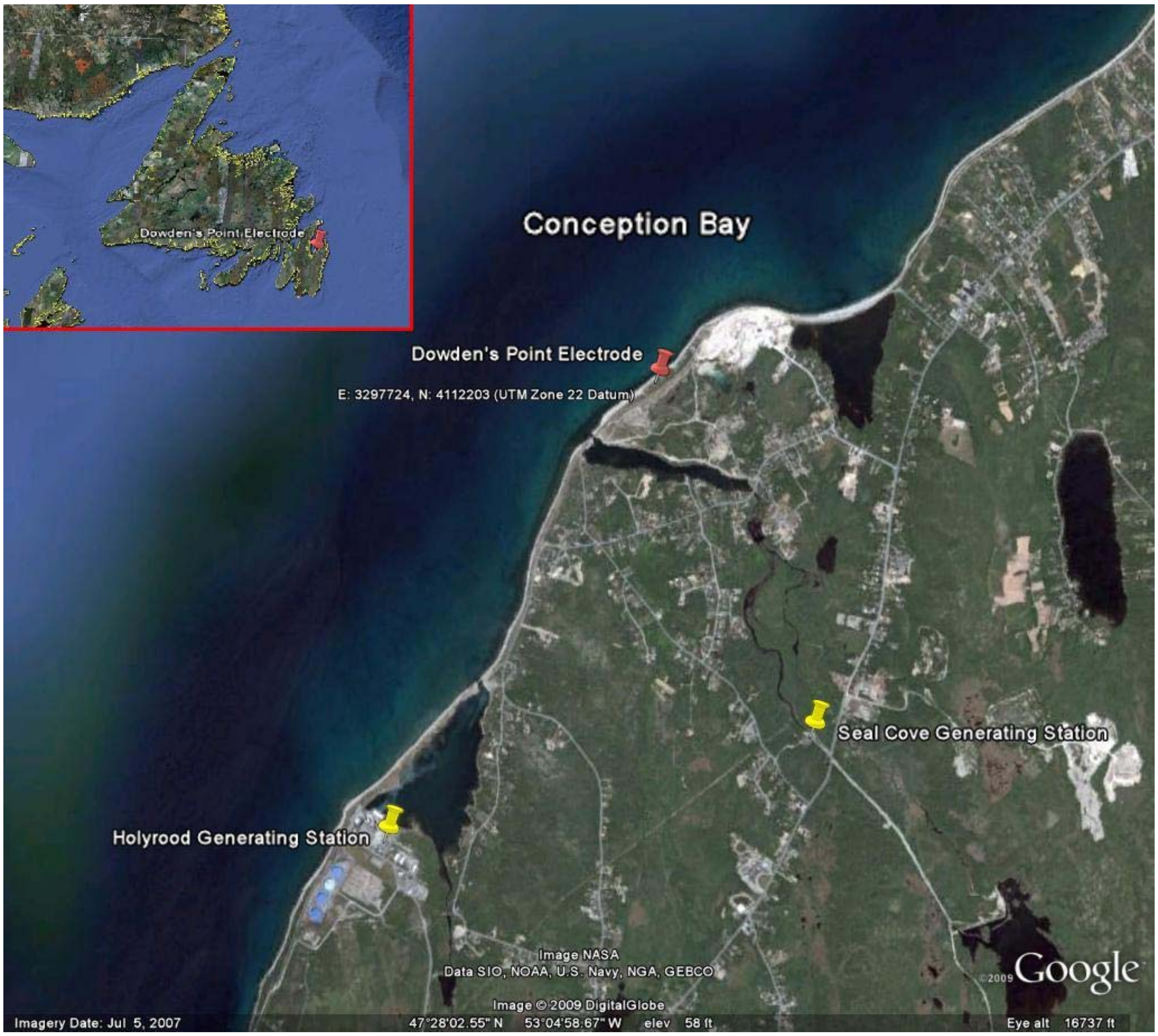
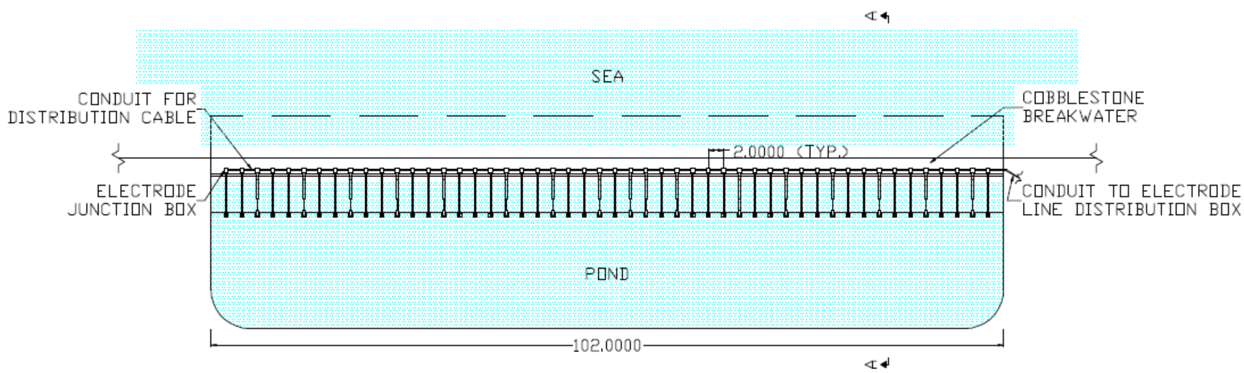


Figure C-1: Dowden's Point Electrode Location



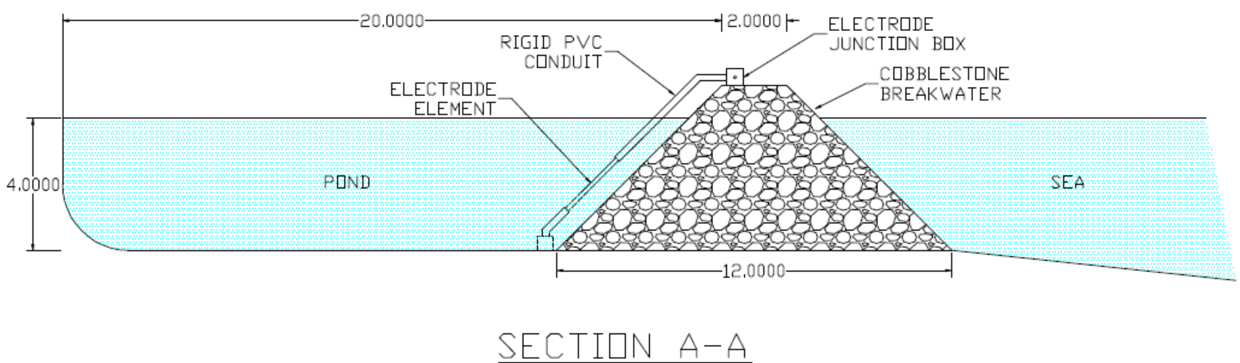


Figure C-2: HVdc Shoreline Pond Electrode Plan and Section

HATCH™

Table C-1: Electrode Design Basis Calculations

Anode Element Resistance and Current Density

References:

Anotec element 4884H: 122mm diameter and 2130mm long

IEEE 80, Section 14.6 "Concrete-Encased Electrodes"

Anode Resistance					***Remarks***
Resistivity of the surrounding volume	ρ	=	0.2	Ωm	Salt water
Length of the anode	L	=	2.13	m	From Anotec
Diameter of the anode	d	=	0.122	m	From Anotec
Resistance of anode in uniform volume	$R_{anode} = \rho / 2\pi L\ [\ LN(8L/d) - 1]$	=	0.05887	Ω	ref. IEEE 80, Equation 59
Current Density					
Electrode current	I_{tot}	=	1340	A	
Current per anode	I_{anode}	=	30	A	From Anotec
Number of anode elements	$N_{anode} = I_{tot}/I_{anode}$	=	44.667		
		=	50		
Anode element surface area	A_{anode}	=	0.82	m^2	From Anotec
Surface area of anodes	A_{tot}	=	41	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	32.683	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	6.537	V/m	
Voltage gradient required at breakwater	$E_{breakwater}$	=	1.25	V/m	Assumed
Currrent density required at breakwater	$J_{breakwater} = J_{tot}{*}E_{breakwater}/E_{tot}$	=	6.25	A/m^2	
Area of breakerwater	$A_{breakwater} = I_{tot}/J_{breakwater}$	=	214.400	m^2	

A 100mx20m pond of depth 4m will provide a safe and conservative design.

WorkingTogether SAFELY

Appendix D

Island

Simulation Results

Shoreline Pond Electrode Model and GPR Contour Plots

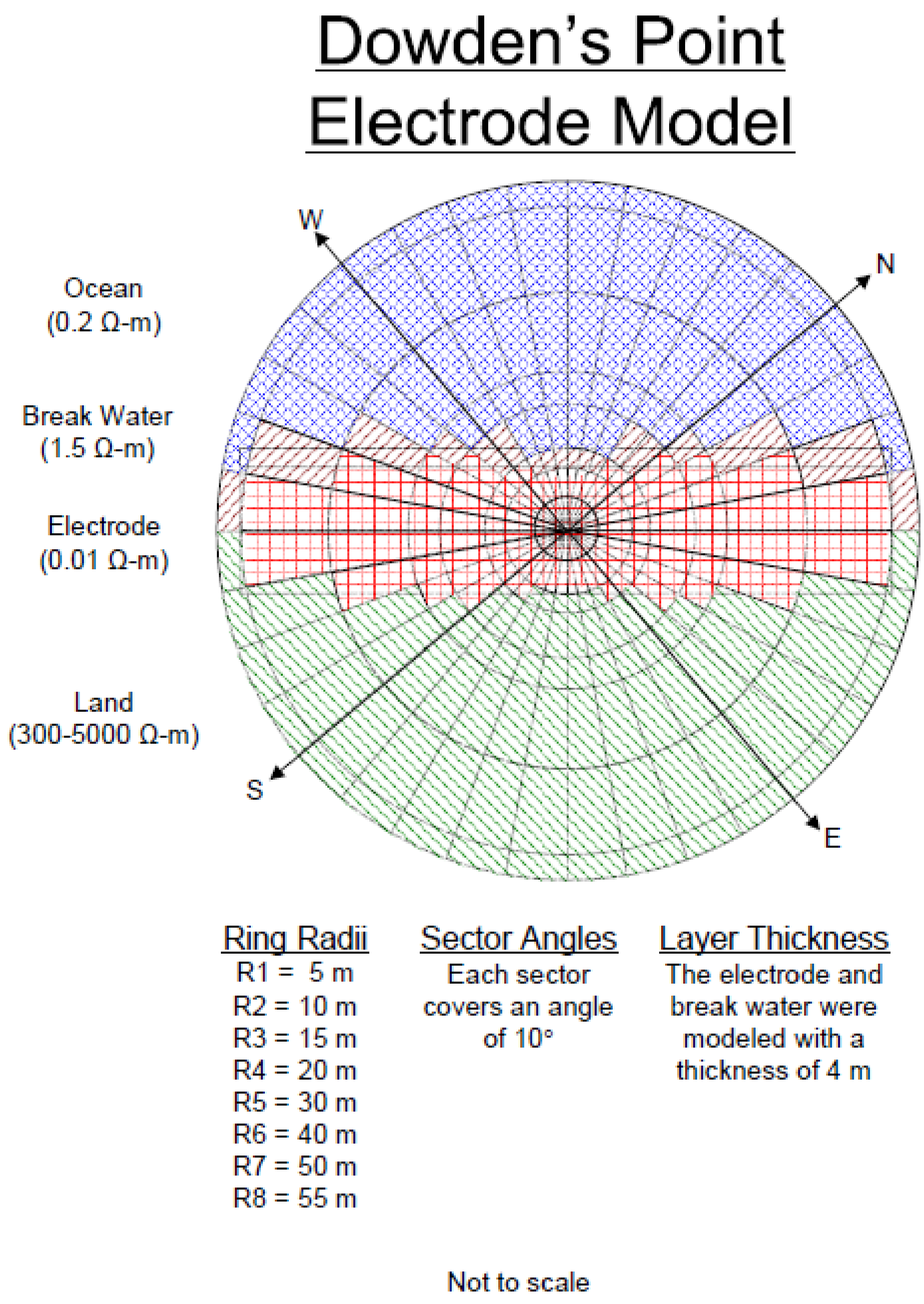


Figure D-1: Shoreline Pond Electrode Soil Model

The soil model is based on modeling Scenario #2 for soil inland and under the sea, bathymetric data for sea depths around Dowden's Point and rough estimates of the sea depths farther away.

Dowden's Point Electrode Equipotential Contours (to 10 km)

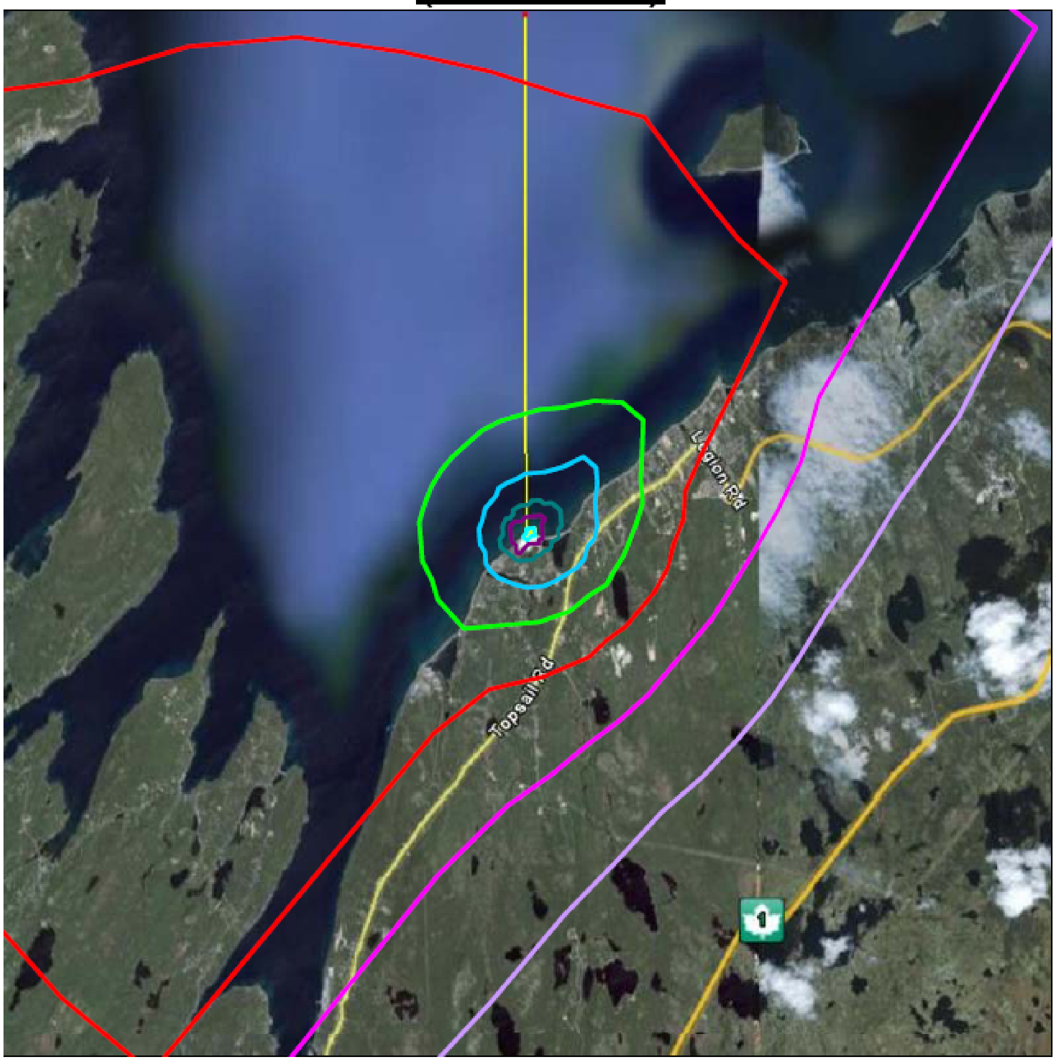
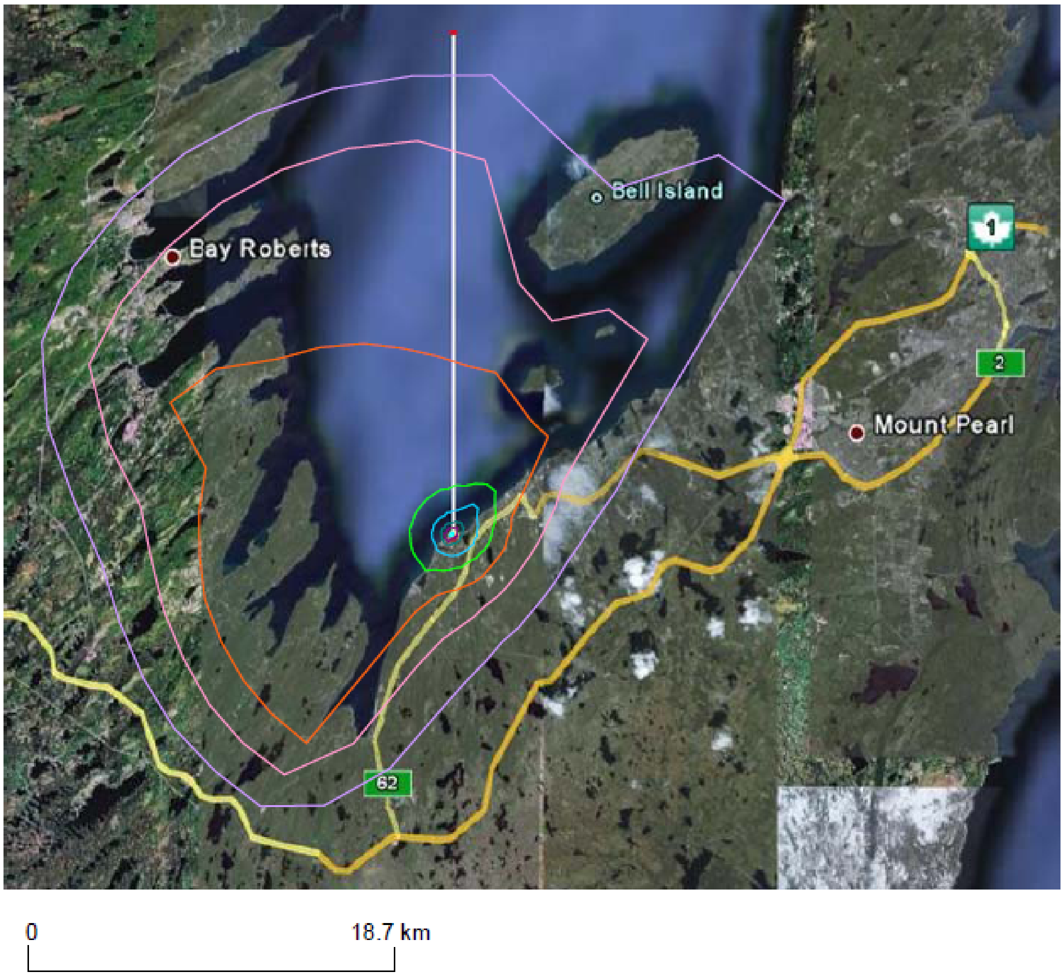


Figure D-2: GPR Contours (10 km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

Dowden's Point Electrode Equipotential Contours (to 25 km)



Ground Potential Rise [V]

— 40 — 30 — 20 — 10 — 8 — 6 — 5 — 4 — 3 — 2

Figure D-3: GPR Contours (25 km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

Dowden's Point Electrode Equipotential Contours (to 120 km)

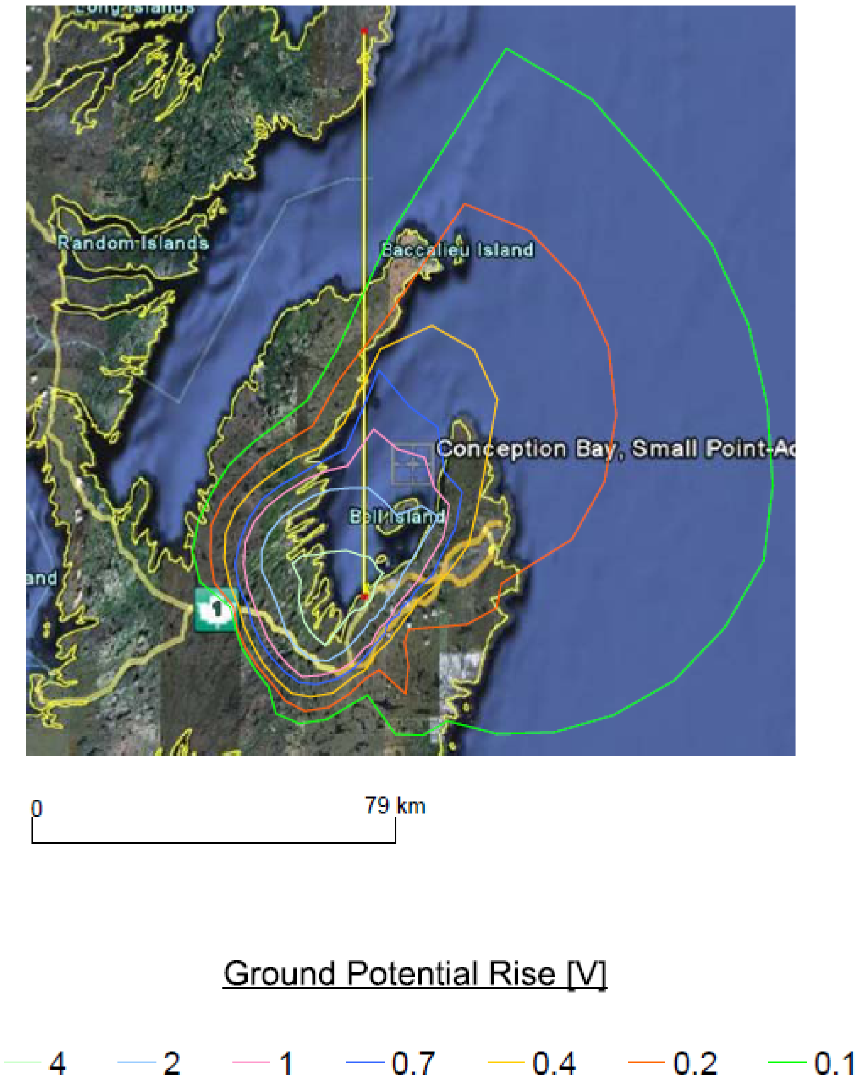


Figure D-4: GPR Contours (120 km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

Appendix E

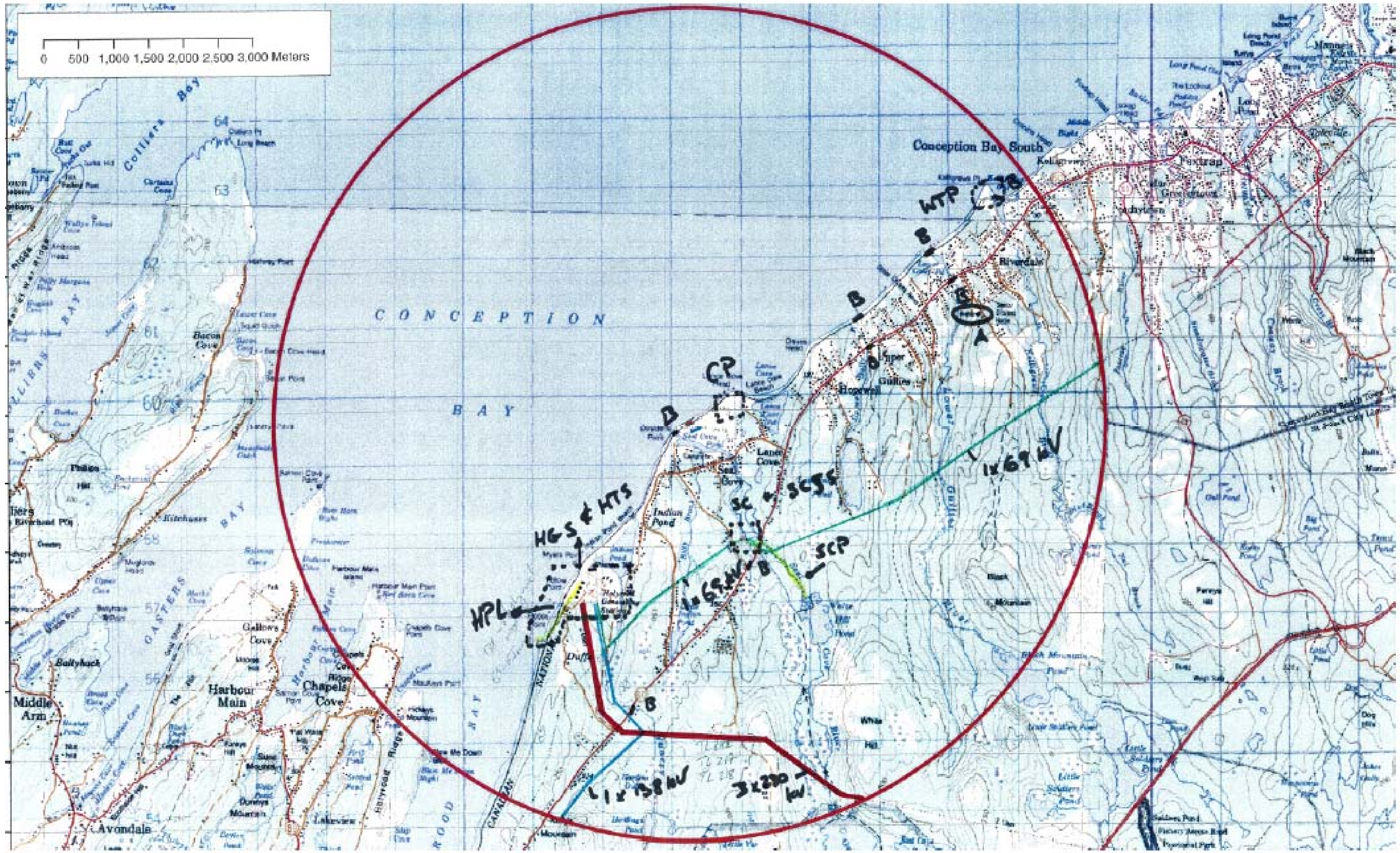
Known Infrastructure Near Dowden's Point

Shoreline Pond Electrode Location

Table E-1: Existing Infrastructure in the Vicinity of the Dowden's Point HVdc Electrode

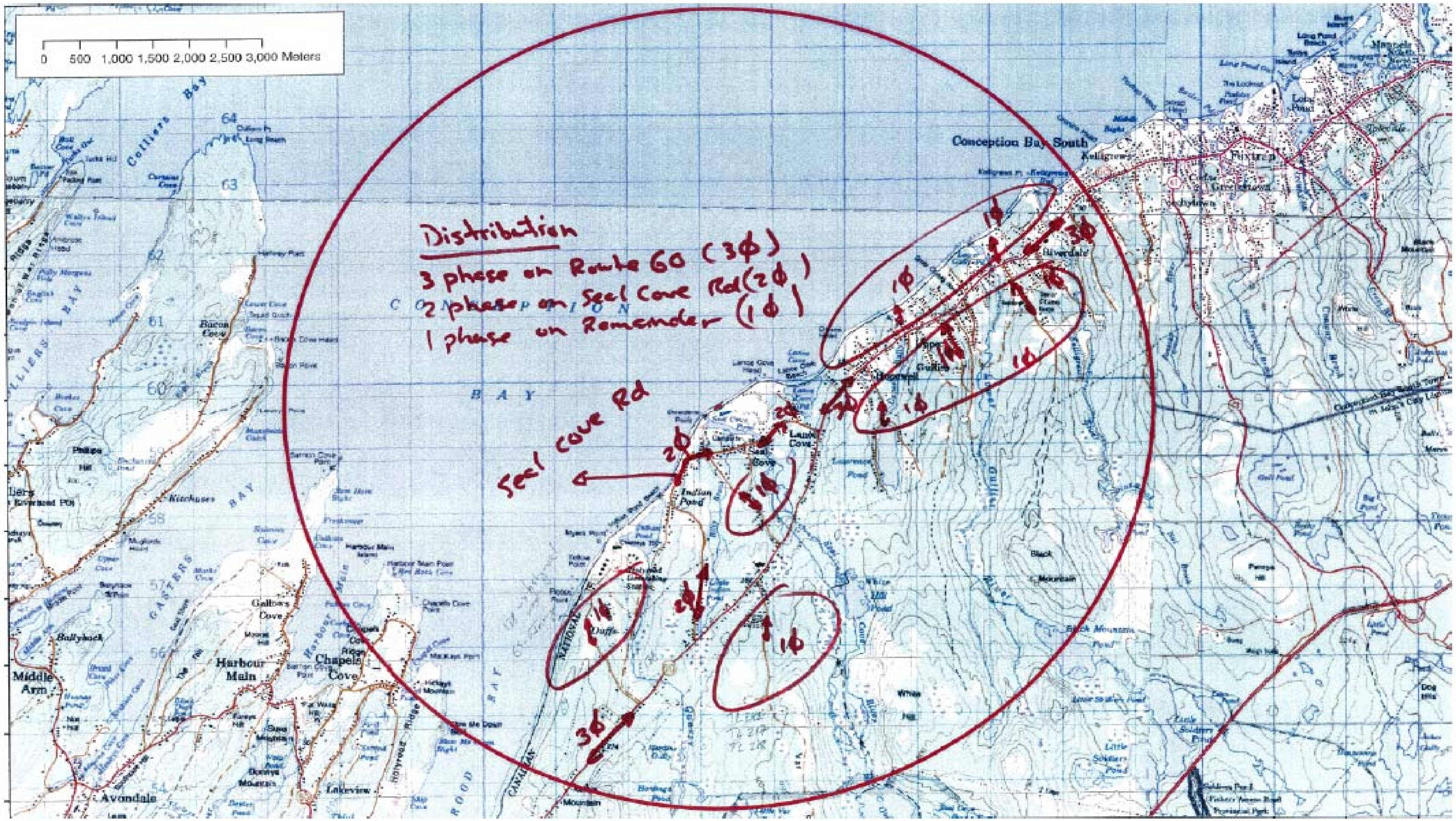
Distances estimated from response to infrastructure data request prepared by John Walsh, received July 28, 2009.

Identifier	Description	Min Distance from Electrode (m)	Notes
A	Sports Arena	4100	Steel building
B1	Bridge	500	
B2	Bridge	2600	
B3	Bridge	2600	
B4	Bridge	4000	
B5	Bridge	4000	
B6	Bridge	4400	
B7	Bridge	2200	
CP	Concrete mix plant	500	
HGS	Holyrood generating station	2600	3 thermal units, pipeline connection & jetty for refuelling, gas turbine
HTS	Holyrood transmission station	2600	3x230 kV lines, 1x138 kV line, 1x69 kV lines, 2x69 kV:230 kV trafos, 3x18 kV:230 kV trafos, etc.
HPL	Holyrood pipeline	2600	1.29 km above ground pipeline connecting storage tanks to tanker jetty for fuel transfer
SC	Seal Cove generating station	2000	Hydro station
SCSS	Seal cove substation	2000	2x69 kV lines, steps down to 12.5 kV for distribution
SCP	Seal Cove Penstock	2000	1.2 km long steel penstock, 2 m in diameter
WTP	Wastewater treatment plant	5200	Connected to sea via outfall pipe
	Water/Sewer system		Cast iron & PVC used throughout area to connect to town of CBS, some artesian wells to southern extent of route 60
	230 kV lines TL217, TL218 & TL242	2600	Approximate length within zone for each line is 5.7 km, generally move away from electrode
	138 kV line 39L	2600	Approximate length within zone 3.7 km, generally moves away from electrode
	69 kV line 38L (Holyrood to Seal Cove)	2000	Approximate length 4 km from Holyrood to Seal Cove
	69 kV line 52L (Kelligrews to Seal Cove)	2000	Approximate length within zone of 6 km, generally moves away from electrode
	12.5 kV, 3 phase distribution	1200	Approximate length within zone is 8.7 km, runs along route 60
	12.5 kV, 2 phase distribution	700	Approximate length within zone is 5.25 km, runs along Seal Cove Road
	12.5 kV, 1 phase distribution	<500	Approximate length within zone is 36 km



MAP – 1

Figure E-1: HV Transmission/Generation Infrastructure



MAP – 2

Figure E-2: 12.47 kV Distribution Infrastructure

HATCH™

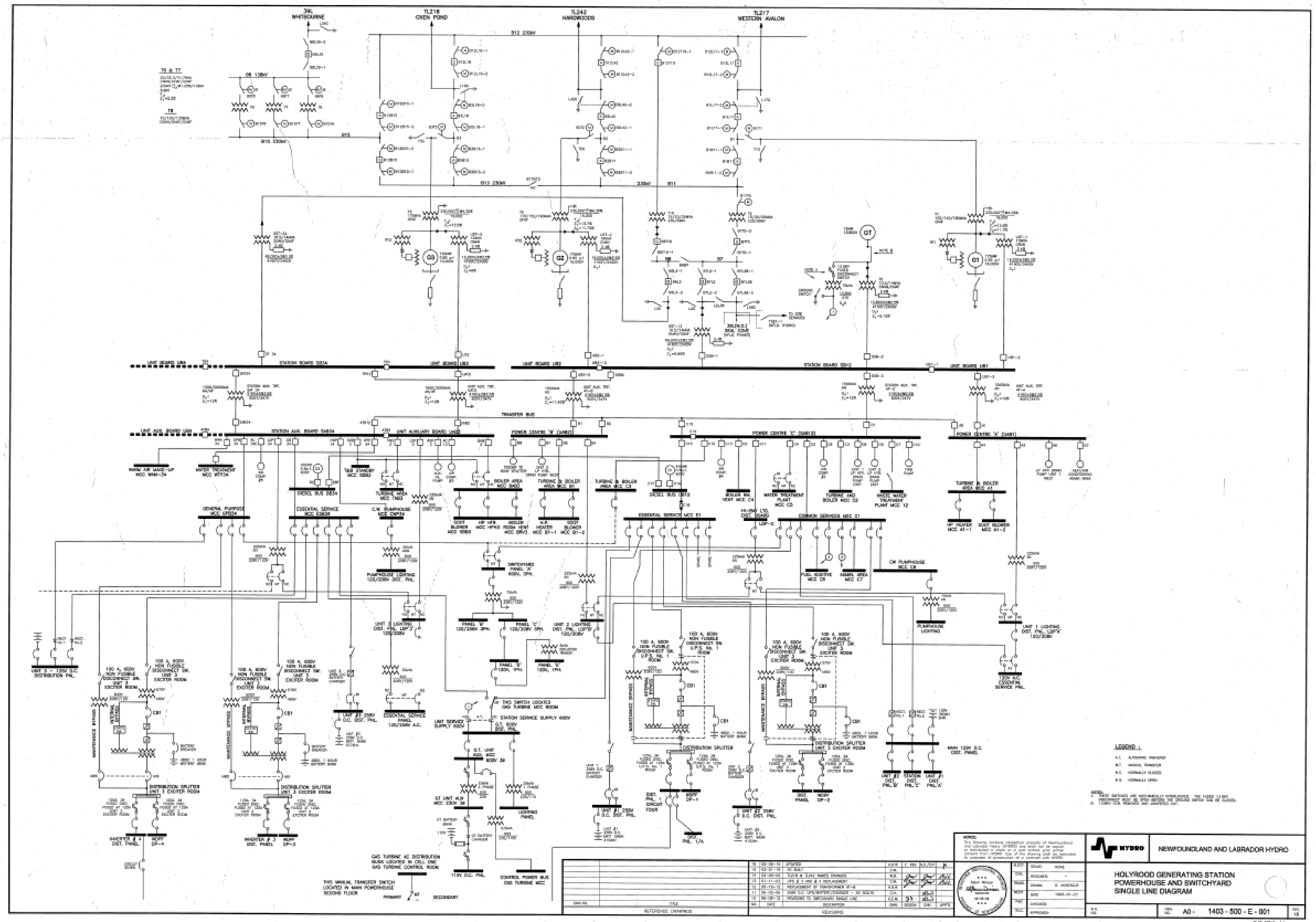


Figure E-3: Holyrood Generating and Transmission Station Single Line Diagram

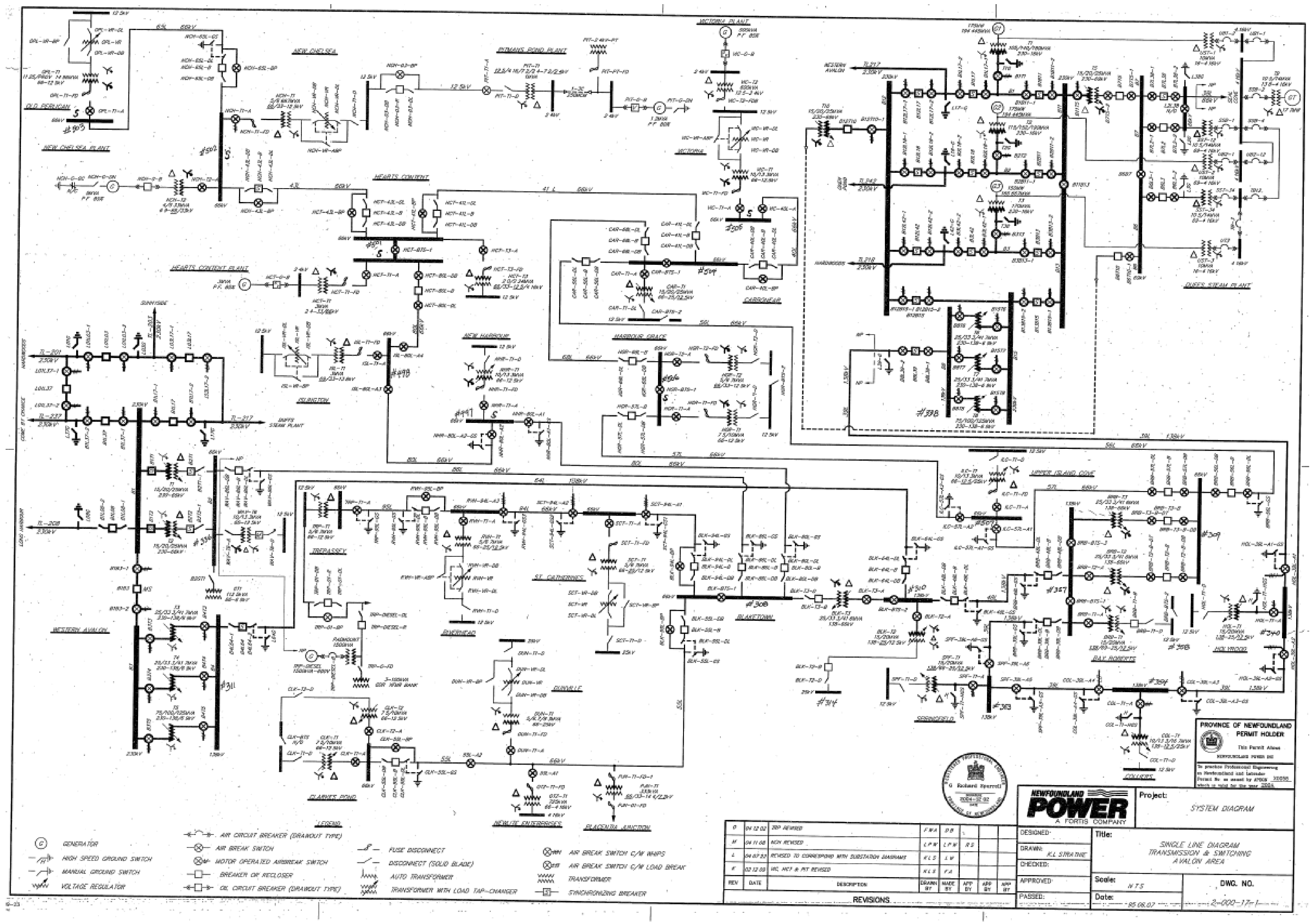


Figure E-4: Seal Cove Generating and Transmission Station Single Line Diagram

Table E-2: 230 kV Transmission Line TL 217 Data

General:	
Transmission Line Name:	TL 217
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Western Avalon Station
Tower/Span:	
Type of Tower:	Steel Lattice
Type of Foundation:	Steel Grillage
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	250 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	76.7 km
Conductors	
Phase conductor number/size/type:	804 kcmil 23/19 AACSR/TW
Skywire number/size/type:	2 x 9/16" Steel Wire (5/8" EHS Steel Wire assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station only)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohm
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-3: 230 kV Transmission Line TL 218 Data

General:	
Transmission Line Name:	TL 218
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Oxen Pond Station
Tower/Span:	
Type of Tower:	Wood Pole
Type of Foundation:	Wood Pole
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	200 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	37.3 km
Conductors	
Phase conductor number/size/type:	795 ACSR 26/7 "Drake" 37 Strand AASC Arvidal
Skywire number/size/type:	2 x 7/16" Steel Wire (5/8" EHS Steel Wire Assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station only)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-4: 230 kV Transmission Line TL 242 Data

General:	
Transmission Line Name:	TL 242
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Hardwoods Station
Tower/Span:	
Type of Tower:	Steel Lattice
Type of Foundation:	Steel Grillage
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	220 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	27.2 km
Conductors	
Phase conductor number/size/type:	804 kcmil 23/19 AACSR/TW
Skywire number/size/type:	2 x 9/16" Steel Wire (5/8" EHS Steel Wire Assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-5: 138 kV Transmission Line 39L data

General:	
Transmission Line Name:	39L
Voltage Rating:	138 kV
Terminal Stations:	Holyrood Terminal Station
Tower/Span:	
Type of Tower:	Wooden H-Frame
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase
Approximate Span:	100-200 m
Transmission line plan drawing(s)	
Length of Transmission Line	41.89 km (to Bay Roberts Station)
Conductors	
Phase conductor number/size/type:	397.5 MCM ACSR
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	No
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-6: 69 kV Transmission Line 52L Data

General:	
Transmission Line Name:	52L
Voltage Rating:	69 kV
Terminal Stations:	Kelligrews to Seal Cove Generation Station
Remote end Terminal Station	Single line diagram including transformer data is known.
Tower/Span:	
Type of Tower:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase no OHGW
Approximate Span:	70-90 m
Transmission line plan drawing(s)	
Transmission Line Length	8.22 km
Conductors	
Phase conductor number/size/type:	477 MCM ASC
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	None
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-7: 69 kV Transmission Line 38L Data

General:	
Transmission Line Name:	38L
Voltage Rating:	69 kV
Terminal Stations:	Seal Cove to Holyrood
Tower/Span:	
Type of Tower:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase no OHGW
Approximate Span:	70-90 m
Transmission line plan drawing(s)	
Transmission Line Length	3.54 km
Conductors	
Phase conductor number/size/type:	715.5 MCM ASC, 397.5 MCM ACSR
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	None
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table E-8: 12.47 kV Distribution System Data

General:	
Distribution Line Name:	Two main feeders from Seal Cove distribution Station
Voltage Rating:	12.47 kV
Terminal distribution Station:	Seal Cove Distribution Station
Pole/Span:	
Type of pole:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration:	3 Phase, 2 phase and Single phase
Approximate Span:	60 m-70 m
Distribution system area map	Not Available
Conductors/Distribution Transformer	
Phase conductor size/type:	2/0 ACSR
Neutral Size:	1/0 ACSR
Distribution transformer (single phase or three phase Y grounded)	
Typical distribution transformer sizes	25 kVA (assumed five per kilometre)
Grounding/Continuity	
Neutral is continuous (yes/no):	Yes
Grounding per CSA standards, four grounds per 1000 m run and at transformers (yes/no)	Yes
Pole Grounding Impedance (Pole ground rod in parallel with residential ground rod(s))	25 Ohms
Residential Connections	
Provide description and sketch of single phase distribution transformers and house connections	Typical 120/240 connection with mid point grounding
Confirm hose ground type (ground rods, ground plates, or cold water system)	Ground Rod
Provide estimate of typical ground resistance	Considered in parallel with pole ground rod.

*Assumptions highlighted.

Table E-9: Holyrood Generating Station Data

General	
Description of Structure:	Holyrood Thermal Generation Station
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	Yes via pipeline and Jetty for refuelling (see below)
Approximate size of structure (length m x width m or diameter m)	Approx 600 m x 680 m on site including transmission station
Single Line Diagram	Available
Conductive Connection	
Fuel transfer pipeline	Yes

*Assumptions highlighted.

Table E-10: Holyrood Transmission Station Data

General:	
Voltage Rating	230 kV, 138 kV, 69 kV
Single line diagram showing transformers, lines and feeders	Provided
Grounding and Conductive Connections	
Station ground electrode Impedance:	0.5 Ohms
Transformer winding connections of 230/69 kV transformers T5 and T10	Delta/Wye-grounded
Transformer winding connections of 230/138 kV auto transformers T6, T7 and T8	Wye-grounded/Wye-grounded
230 kV T/L Skywires	Yes
Remote end 230 kV station through transformer windings	Yes
138 kV T/L Skywires	No
Remote end 138 kV station	No
69 kV T/L Skywires	No
Remote end 69 kV station	
Grounding connections to generating station	Yes

*Assumptions highlighted.

Table E-11: Seal Cove Generation Station Data

General	
Description of Structure:	Seal Cove Hydroelectric Generation Station
Single Line Diagram	Provided
Approximate size of structure (length m x width m or diameter m)	Approx 80 m x 70 m on site (building and substation) Penstock connection
Conductive Connections and Grounding	
Ground grid impedance	0.5 Ohms
Are structure members in contact with sea body of water?	No
Remote metallic connection through penstock	Yes
Connection to Newfoundland Hydro Substation	Yes
Connection to remote station through 69 kV circuit	

*Assumptions highlighted.

Table E-12: Newfoundland Power Substation Data

General:	
Voltage Rating:	69 kV, 12.5 kV
Single line diagram	
Grounding and Conductive Connections	
Station ground electrode impedance:	0.5 Ohms
Distribution feeder neutral connections to station ground/ neutral size	Yes, 2/0 ACSR distribution neutral
Connection to utility distribution transformers via distribution circuit conductors/ distribution feeder conduction sizes	Yes, 4/0 ACSR for distribution neutral
Connection to remote station via 69 kV Line Conductor/Conductor size	Yes

*Assumptions highlighted.

Table E-13: Pipeline for Holyrood Fuel Transfer Data

Metallic Pipeline Name:	
Type of steel:	Carbon steel ASTM A53/D106Grb Type
Diameter of pipe (mm):	18” mainline; 16” branch lines to tanks
Wall thickness (mm):	3/8” (on 18” diameter) standard wall
Length (km):	1.29 km
Type of insulation/coating:	No coating; pre-formed mineral fibre insulation
Leakage resistance of coating (Ohms/m^2):	N/A
Longitudinal resistance (Ohms/m^2):	N/A
Cathodic protection scheme (impressed current or sacrificial anode) and details	No
Confirm hose ground type (ground rods, ground plates, or cold water system)	GFI protection on heat tracing
Provide estimate of typical ground resistance	

*Assumptions highlighted.

Table E-14: Penstock for Seal Cove Station Data

Metallic Pipeline Name:	Penstock
Type of steel:	
Diameter of pipe (mm):	
Wall thickness (mm):	
Length (km):	1.2 km
Type of insulation/coating:	No coating or insulation
Leakage resistance of coating (Ohms/m^2):	
Longitudinal resistance (Ohms/m^2):	
Cathodic protection scheme (impressed current or sacrificial anode) and details	No
Confirm hose ground type (ground rods, ground plates, or cold water system)	
Provide estimate of typical ground resistance	

*Assumptions highlighted.

Table E-15: Concrete Mix Plant Data

Structure Name:	
Description of Structure:	Concrete Mix Plant
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	Approx 300 m x 300 m area. Contains building (small batch plant), lay down areas, and yard for equipment and trucks.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table E-16: Wastewater Treatment Plant Data

Structure Name:	
Description of Structure:	Wastewater Treatment Plant
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	Yes Via outfall pipe, unsure if pipe is metal or PVC
Approximate size of structure (length m x width m or diameter m)	Approx size of 160 m x 70 m in area. Contains two buildings.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table E-17: Sports Arena Data

Structure Name:	
Description of Structure:	Arena, steel building
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	Approx size of 100 m x 90 m in area. Contains one building.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table E-18: Various Bridges

Structure Name:	
Description of Structure:	Bridges
Is structure connected to the power system grounding system? If yes provide connection details	
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	<100
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table E-19: Water and Sewer Infrastructure for the Town of Conception Bay South

Structure Name:	
Description of Structure:	Water and Sewer Pipes
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Appendix F

230 kV Skywire Impact Assessment

Model, Data and Results

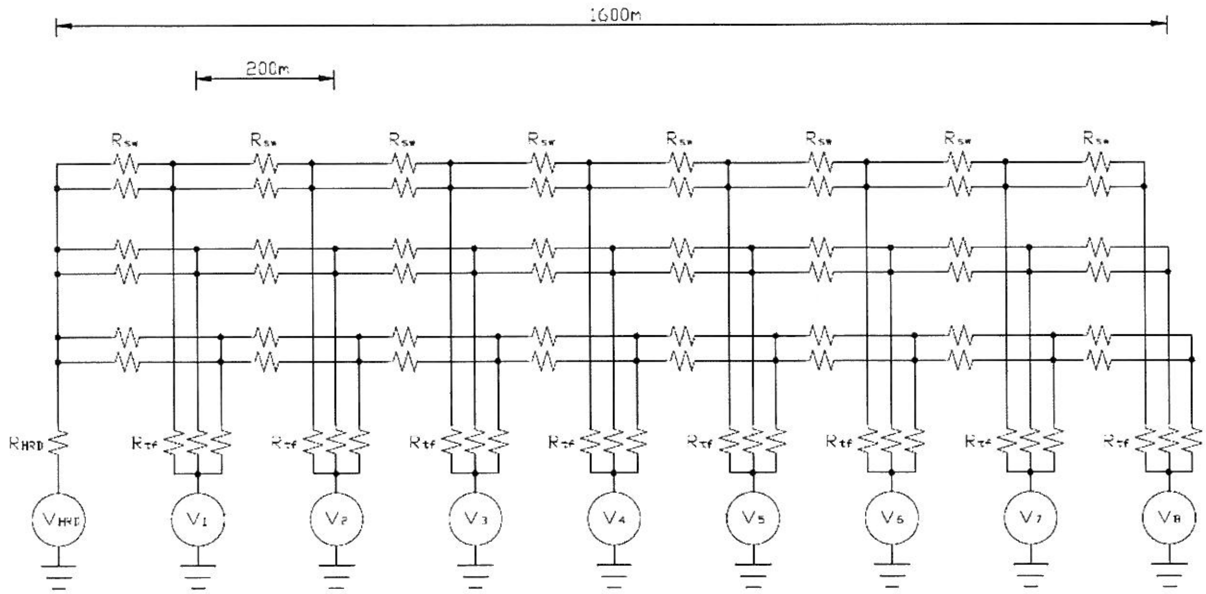


Figure F-1: Skywire Model

Table F-1: Skywire Network Data

Station Grounding Grids						**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5			Assumed
Tower Footing Resistance						
Tower Footing Resistance	R_{tf}	Ω	15			Assumed
Skywire Resistance						
Line Designation			**TL217 (HRD-WAV)**	**TL218 (HRD-OPD)**	**TL242 (HRD-HWD)**	
Length of Skywire	l_{tot}	m	1600	1600	1600	
Span of Skywire	l	m	200	200	200	See Note 2
Number of Towers	$N_{towers}=l_{tot}/l$		8	8	8	
DC Resistance (@ 20°C)	R_{cond}	Ω/km	1.405	1.405	1.405	See Note 1
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.281	0.281	0.281	

Notes:

1. All skywires assumed to be steel wire 5/8" (R_{dc} = 2.261Ω/mile, from CDEGS)
   Actual skywires are 9/16" steel (TL217 & TL242) and 7/16" steel (TL218)
2. Span of all skywires assumed to be 200 m (i.e., 1600/200 = 8 segments from Holyrood)
   Actual spans are 250 m (TL217), 200 m (TL218) and 220 m (TL242)

Table F-2: Skywire Network Simulation Results

Tower Designation	GPR (V)	Calculated dc Stray Current, I_{dc} (A)	Permissible Current through Steel Foundation (A)	Permissible Current through Steel Guywire Anchors (A)	Permissible Current through Copper Bonded Rods (A)
Holyrood Terminal Station	4.500	0.1853			
1st Tower from Holyrood	4.400	0.0008	0.3858	0.1144	0.4276
2nd Tower from Holyrood	4.300	-0.0058	0.3858	0.1144	0.4276
3rd Tower from Holyrood	4.200	-0.0124	0.3858	0.1144	0.4276
4th Tower from Holyrood	4.100	-0.0192	0.3858	0.1144	0.4276
5th Tower from Holyrood	4.000	-0.0260	0.3858	0.1144	0.4276
6th Tower from Holyrood	3.900	-0.0331	0.3858	0.1144	0.4276
7th Tower from Holyrood	3.800	-0.0404	0.3858	0.1144	0.4276
8th Tower from Holyrood	3.700	-0.0481	0.3858	0.1144	0.4276

Notes

1. The current division between the steel foundation, guywire anchors and copper rods will depend on the surface area in contact with the earth for each element. A current equal to 100% of the total current through the tower is considered for each element as a conservative approach.
2. The polarity of the calculated currents indicate direction of flow during anodic operation:
   +ve, from ground into tower; -ve from tower into ground.
3. The network was analyzed as a resistive network in the CDEGS software.

Appendix G

Equipment Impact Assessment

230 kV, 138 kV, 69 kV

Models, Data and Results

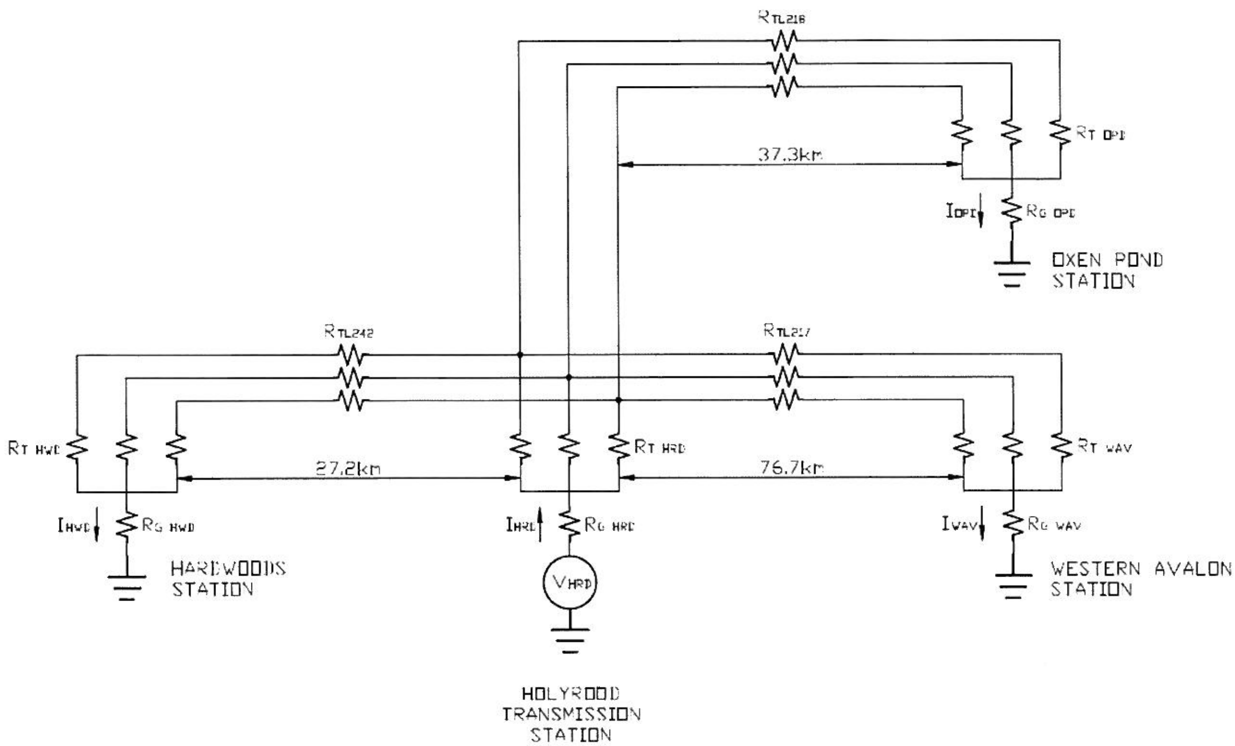


Figure G-1: 230 kV Transmission Network Model

HATCH™

Table G-1: 230 kV Transmission Network Data

230 kV Transformer Data
Holyrood Terminal Station

Transformer Designation			HRD_T1	HRD_T2	HRD_T3	HRD_T6	HRD_T7	HRD_T8	Remarks
Transformer Type			Two Winding	Two Winding	Two Winding	Auto	Auto	Auto	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	105.000	**115.000**	101.998	**25.000**	**25.000**	**75.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	140.000	152.000	127.532	33.300	33.300	100.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	**180.000**	190.000	**170.000**	41.700	41.700	125.000	
High Voltage	V_H	kV	230.000	230.000	230.000	230.000	230.000	230.000	
Low Voltage	V_L	kV	16.000	16.000	16.000	138.000	138.000	138.000	
Tertiary Voltage	V_T	kV	N/A	N/A	N/A	6.900	6.900	6.900	
Load Loss at Base MVA	kW_{loss}	kW	422.770	252.050	662.600	62.430	65.800	91.660	Nalcor Input (Transformer databook sheets)
Rated 230 kV Current at Base MVA	I_{rated}	A	451.853	288.684	426.750	62.757	62.757	188.272	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500	0.300	0.300	0.300	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	1.355	1.443	1.280	0.188	0.188	0.565	Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.452	0.481	0.427	0.063	0.063	0.188	
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.678	0.722	0.640	0.094	0.094	0.282	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10{*}MVA_{rated})$	%	0.235	0.219	0.390	0.250	0.263	0.122	
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	293.889	460.000	311.176	2,116.000	2,116.000	705.333	
DC Resistance	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	0.690	1.008	1.213	5.284	5.569	0.862	
230 kV Winding Resistance	R_{dc230}	Ω	0.687	1.003	1.207	5.284	5.569	0.862	See Notes 3 and 4

Equivalent Resistance of 230 kV Windings	$R_{HRD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.208

230 kV Transformer Data
Western Avalon

Transformer Designation			WAV_T1	WAV_T2	WAV_T3	WAV_T4	WAV_T5		Remarks
Transformer Type			Two Winding	Two Winding	Auto	Auto	Auto		
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta		
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**	**15.000**	**25.000**	**25.000**	**75.000**		Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000	20.000	33.000	33.000	100.000		
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	25.000	25.000	33.300	33.300	125.000		
High Voltage	V_H	kV	230.000	230.000	230.000	230.000	230.000		
Low Voltage	V_L	kV	66.000	66.000	138.000	138.000	138.000		
Tertiary Voltage	V_T	kV	N/A	N/A	6.900	6.900	6.900		
Load Loss at Base MVA	kW_{loss}	kW	64.000	65.870	66.700	65.800	92.500		Nalcor Input (Transformer databook sheets)
Rated 230 kV Current at Base MVA	I_{rated}	A	37.654	37.654	62.757	62.757	188.272		
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.300	0.300	0.300		Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.188	0.188	0.188	0.188	0.565		Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.063	0.063	0.063	0.063	0.188		
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.094	0.094	0.282		
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10{*}MVA_{rated})$	%	0.427	0.439	0.267	0.263	0.123		
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	3,526.667	3,526.667	2,116.000	2,116.000	705.333		
DC Resistance	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	15.047	15.487	5.645	5.569	0.870		
230 kV Winding Resistance	R_{dc230}	Ω	13.902	14.309	5.645	5.569	0.870		See Notes 3 and 4

Equivalent Resistance of 230 kV Windings	$R_{WAV}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}\|\|R_{T5}$	Ω	0.607

230 kV Transformer Data
Oxen Pond

Transformer Designation			**OPD_T1**	**OPD_T2**	**OPD_T3**				**Remarks**
Transformer Type			Two Winding	Two Winding	Two Winding				
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta				
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**40.000**	**75.000**	**75.000**				Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	53.300	100.000	100.000				
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	66.600	125.000	125.000				
High Voltage	V_H	kV	230.000	230.000	230.000				
Low Voltage	V_L	kV	66.000	66.000	66.000				
Tertiary Voltage	V_T	kV	N/A	N/A	N/A				
Load Loss at Base MVA	kW_{loss}	kW	103.900	98.559	176.100				Nalcor Input (Transformer databook sheets)
Rated 230 kV Current at Base MVA	I_{rated}	A	100.412	188.272	188.272				
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500				Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%}\cdot I_{rated}/100$	A	0.502	0.941	0.941				Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.167	0.314	0.314				
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}*1.5$	A	0.251	0.471	0.471				
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.260	0.131	0.235				
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,322.500	705.333	705.333				
DC Resistance	$R_{dc}=R_{tb}*R_{\%}/100$	Ω	3.435	0.927	1.656				
230 kV Winding Resistance	R_{dc230}	Ω	3.174	0.856	1.530				See Notes 3 and 4

Equivalent Resistance of 230 kV Windings	$R_{OPD}=R_{T1}\|\|R_{T2}\|\|R_{T3}$	Ω	0.468

230 kV Transformer Data
Hardwoods

Transformer Designation			**HWD_T1**	**HWD_T2**	**HWD_T3**	**HWD_T4**			**Remarks**
Transformer Type			Two Winding	Two Winding	Two Winding	Two Winding			
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Zig Zag			
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**40.000**	**40.000**	**40.000**	**75.000**			Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	53.300	53.300	53.300	100.000			
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	66.600	66.600	66.600	125.000			
High Voltage	V_H	kV	230.000	230.000	230.000	230.000			
Low Voltage	V_L	kV	66.000	66.000	66.000	66.000			
Tertiary Voltage	V_T	kV	N/A	N/A	N/A	N/A			
Load Loss at Base MVA	kW_{loss}	kW	126.380	116.100	131.770	174.470			Nalcor Input (Transformer databook sheets)
Rated 230 kV Current at Base MVA	I_{rated}	A	100.412	100.412	100.412	188.272			
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500	0.500			Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%}\cdot I_{rated}/100$	A	0.502	0.502	0.502	0.941			Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.167	0.167	0.167	0.314			
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}*1.5$	A	0.251	0.251	0.251	0.471			
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.316	0.290	0.329	0.233			
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,322.500	1,322.500	1,322.500	705.333			
DC Resistance	$R_{dc}=R_{tb}*R_{\%}/100$	Ω	4.178	3.839	4.357	1.641			
230 kV Winding Resistance	R_{dc230}	Ω	3.861	3.547	4.025	1.516			See Notes 3 and 4

Equivalent Resistance of 230 kV Windings	$R_{HWD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}$	Ω	0.690

HATCH™

Terminal Station Ground Grid Impedances

			Resistance						Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5						Assumed
Western Avalon Grounding Grid Resistance	$R_{G\ WAV}$	Ω	0.5						Assumed
Oxen Pond Grounding Grid Resistance	$R_{G\ OPD}$	Ω	0.5						Assumed
Hardwoods Grounding Grid Resistance	$R_{G\ HWD}$	Ω	0.5						Assumed

230 kV Transmission Lines

			TL217 (HRD-WAV)	TL218 (HRD-OPD)	TL242 (HRD-HWD)				Remarks
Length of Transmission Line	l	km	76.663	37.29	27.21				Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.01077	0.0036	0.00383				Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	5.69733	1.8780	2.02607				

Notes
1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio.
4. Resistances of Delta windings are ignored for auto transformers.
5. The 230 kV transfomer windings connected in Delta are not included in the tables.

Table G-2: 230 kV Transmission Network Simulation Results

230 kV Transformer Results
Holyrood Terminal Station

Transformer Designation			HRD_T1	HRD_T2	HRD_T3	HRD_T6	HRD_T7	HRD_T8
230 kV Winding Resistance	R_{dc230}	Ω	0.687	1.003	1.207	5.284	5.569	0.862
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.678	0.722	0.640	0.094	0.094	0.282
Calculated DC Current (1-phase)	I_{dc}	A	0.412	0.282	0.234	0.054	0.051	0.328

Stray DC Current at Holyrood	I_{HRD}	A	4.082
Stray DC Current at Holyrood (per phase)	I_{HRD} /3	A	1.361
Equivalent Resistance of 230 kV Transformers	$R_{HRD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.208

230 kV Transformer Results
Western Avalon

Transformer Designation			WAV_T1	WAV_T2	WAV_T3	WAV_T4	WAV_T5	
230 kV Winding Resistance	R_{dc230}	Ω	13.902	14.309	5.645	5.569	0.870	
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.094	0.094	0.282	
Calculated DC Current (1-phase)	I_{dc}	A	0.012	0.012	0.030	0.030	0.194	

Stray DC Current at Western Avalon	I_{WAV}	A	0.836
Stray DC Current at Western Avalon (per phase)	I_{WAV} /3	A	0.279
Equivalent Resistance of 230 kV Transformers	$R_{WAV}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}\|\|R_{T5}$	Ω	0.607

230 kV Transformer Results
Oxen Pond

Transformer Designation			OPD_T1	OPD_T2	OPD_T3			
230 kV Winding Resistance	R_{dc230}	Ω	3.174	0.856	1.530			
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.471	0.471			
Calculated DC Current (1-phase)	I_{dc}	A	0.083	0.309	0.173			

Stray DC Current at Oxen Pond	I_{OPD}	A	1.697
Stray DC Current at Oxen Pond (per phase)	I_{OPD} /3	A	0.566
Equivalent Resistance of 230 kV Transformers	$R_{OPD}=R_{T1}\|\|R_{T2}\|\|R_{T3}$	Ω	0.468

230 kV Transformer Results
Hardwoods

Transformer Designation			HWD_T1	HWD_T2	HWD_T3	HWD_T4		
230 kV Winding Resistance	R_{dc230}	Ω	3.861	3.547	4.025	1.516		
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.251	0.251	0.471		
Calculated DC Current (1-phase)	I_{dc}	A	0.092	0.100	0.088	0.235		

Stray DC Current at Hardwoods	I_{HWD}	A	1.548
Stray DC Current at Hardwoods (per phase)	I_{HWD} /3	A	0.516
Equivalent Resistance of 230 kV Transformers	$R_{HWD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}$	Ω	0.690

Notes:
1. The network was analyzed as a resistive network in the CDEGS software.

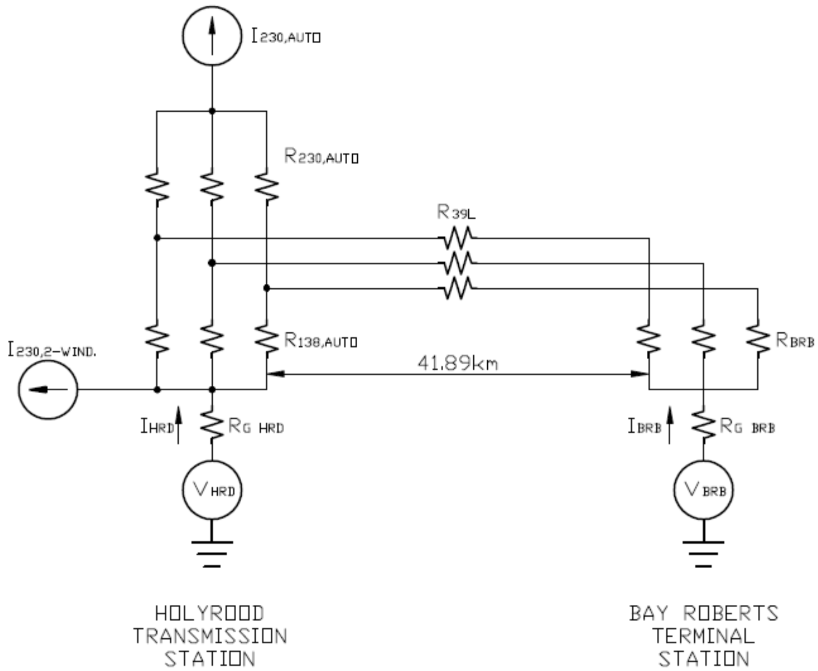


Figure G-2: 138 kV Transmission Network Model

HATCH™

Table G-3: 138 kV Transmission Network Data

138 kV Transformer Winding Data
Holyrood Terminal Station

Transformer Designation			**HRD_T6**	**HRD_T7**	**HRD_T8**	**Remarks**
Transformer Type			Auto	Auto	Auto	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**25.000**	**25.000**	**75.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	33.300	33.300	100.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	41.700	41.700	125.000	
High Voltage	V_H	kV	230.000	230.000	230.000	
Low Voltage	V_L	kV	138.000	138.000	138.000	
Tertiary Voltage	V_T	kV	6.900	6.900	6.900	
Load Loss at Base MVA	kW_{loss}	kW	62.430	65.800	91.660	Nalcor Input (Transformer databook sheets)
Rated 138 kV Current at Base MVA	I_{rated}	A	62.757	62.757	188.272	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.300	0.300	0.300	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.188	0.188	0.565	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.063	0.063	0.188	
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.282	230 kV excitation current citeria used
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.250	0.263	0.122	
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	2,116.000	2,116.000	705.333	
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}/100$	Ω	5.284	5.569	0.862	
138 kV Winding Resistance	R_{dc138}	Ω	2.114	2.228	0.345	See Notes 3 and 4

Equivalent Resistance of 138 kV Transformers	$R_{HRD}=R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.262

138 kV Transformer Winding Data
Bay Roberts

Transformer Designation			**BRB_T1**			**Remarks**
Transformer Type			Auto			
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Wye			
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**			Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000			
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A			
High Voltage	V_H	kV	138.000			Dual voltage transformer, 138 kV and 66 kV
Low Voltage	V_L	kV	12.500			Dual voltage transformer, 25 kV and 12.5 kV
Tertiary Voltage	V_T	kV	N/A			
Load Loss at Base MVA	kW_{loss}	kW	65.000			Typical value asumed.
Rated 138 kV Current at Base MVA	I_{rated}	A	62.757			
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500			Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.314			
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.105			
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.157			
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.433			
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,269.600			
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}/100$	Ω	5.502			
138 kV Winding Resistance	R_{dc138}	Ω	5.457			See Notes 3 and 4

Equivalent Resistance of 138 kV Transformers	$R_{BRB}=R_{T1}$	Ω	5.457

Station Grounding Grids

Description			**Resistance**			**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5			Assumed
Bay Roberts Grounding Grid Resistance	$R_{G\ BRB}$	Ω	0.5			Assumed

138 kV Transmission Line

			39L (HRD-BRB)			**Remarks**
Length of Transmission Line	l	km	41.89			Five sections, Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.0321148			Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	6.12			

Notes

1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio; for a 230/138 kV transformer split is 60% (mid tap and above) and 40% (from neutral to mid tap).
4. Resistances of Delta windings are ignored for auto transformers.
5. The 138 kV transfomer windings connected in Delta are not included in the tables.

Table G-4: 138 kV Transmission Network Simulation Results

138 kV Transformer Results
Holyrood Terminal Station

Transformer Designation			HRD_T6	HRD_T7	HRD_T8
138 kV Winding Resistance	R_{dc138}	Ω	2.114	2.228	0.345
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.282
Calculated DC Current (1-phase)	I_{dc}	A	0.048	0.046	0.295

Stray DC Current through T6, T7 and T8 Windings	I_{HRD}	A	1.167
Stray DC Current through T6, T7 and T8 (per phase)	I_{HRD} /3	A	0.389
Equivalent Resistance of 138 kV Transformers	$R_{HRD}=R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.262

138 kV Transformer Results
Bay Roberts

Transformer Designation			BRB_T1
138 kV Winding Resistance	R_{dc138}	Ω	3.861
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251
Calculated DC Current (1-phase)	I_{dc}	A	0.044

Stray DC Current at Bay Roberts	I_{BRB}	A	0.132
Stray DC Current at Bay Roberts (per phase)	I_{BRB} /3	A	0.044
Equivalent Resistance of 138 kV Transformers	$R_{BRB}=R_{T1}$	Ω	3.861

Notes:
1. The network was analyzed as a resistive network in the CDEGS software.

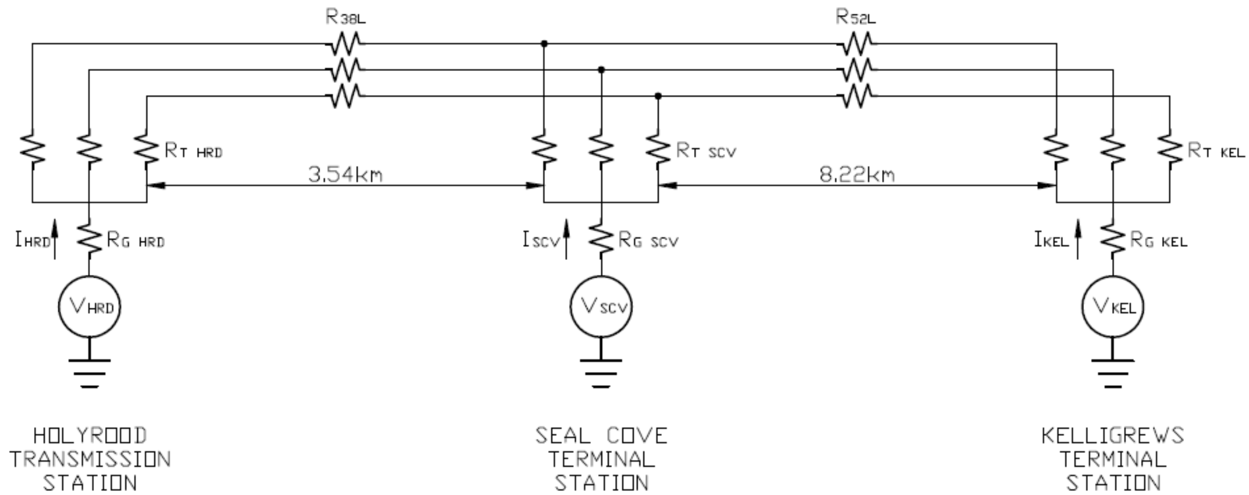


Figure G-3: 69 kV Transmission Network Model

HATCH™

Table G-5: 69 kV Transmission Network Data

69 kV Transformer Data
Holyrood Terminal Station

Transformer Designation			**HRD_T5**	**HRD_T10**	**Remarks**
Transformer Type			Two Winding	Two Winding	
Winding Connections (High/Low/Tertiary)			Delta/ Wye Gnd.	Delta/ Wye Gnd.	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**	**15.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000	20.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	25.000	25.000	
High Voltage	V_H	kV	230.000	230.000	
Low Voltage	V_L	kV	69.000	69.000	
Tertiary Voltage	V_T	kV	N/A	N/A	
Load Loss at Base MVA	kW_{loss}	kW	54.840	54.840	Nalcor Input (Transformer databook sheets)
Rated 69kV Current at Base MVA	I_{rated}	A	125.515	125.515	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.376	0.376	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.125	0.125	
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.188	0.188	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.366	0.366	
Transformer Base Impedance, 230kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	3,526.667	3,526.667	
DC Resistance from 69 kV	$R_{dc}=R_{tb}$ * $R_{\%}$/100	Ω	12.893	12.893	
69 kV Winding Resistance	R_{dc69}	Ω	1.065	1.065	See Notes 3 and 4

Equivalent Resistance of 69 kV Windings	$R_{HRD}=R_{T5}\|\|R_{T10}$	Ω	0.532

69 kV Transformer Data
Seal Cove

Transformer Designation			**SCV_T1**	**SCV_T2**	**Remarks**
Transformer Type			Two Winding	Two Winding	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**2.500**	**11.200**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	3.333	N/A	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A	N/A	
High Voltage	V_H	kV	69.000	69.000	
Low Voltage	V_L	kV	2.400	12.470	
Tertiary Voltage	V_T	kV	N/A	N/A	
Load Loss at Base MVA	kW_{loss}	kW	20.000	45.000	Typical values assumed
Rated 69kV Current at Base MVA	I_{rated}	A	20.919	93.718	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.063	0.281	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.021	0.094	
Permissible DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.031	0.141	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.800	0.402	
Transformer Base Impedance, 69 kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,904.400	425.089	
DC Resistance from 69 kV	$R_{dc}=R_{tb}$ * $R_{\%}$/100	Ω	15.235	1.708	
69 kV Winding Resistance	R_{dc69}	Ω	15.217	1.654	See Notes 3 and 4

Equivalent Resistance of 69 kV Windings	$R_{SCV}=R_{T1}\|\|R_{T2}$	Ω	1.492

HATCH™

69 kV Transformer Data
Kelligrews

Transformer Designation			KEL_T1		Remarks
Transformer Type			Two Winding		
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta		
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**11.250**		Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	14.950		
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A		
High Voltage	V_H	kV	69.000		
Low Voltage	V_L	kV	12.470		
Tertiary Voltage	V_T	kV	N/A		
Load Loss at Base MVA	kW_{loss}	kW	45.000		Calculated based on positive sequence resistance
Rated 69 kV Current at Base MVA	I_{rated}	A	94.136		
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500		Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}/100$	A	0.282		
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.094		
Permissible DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.141		
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.400		
Transformer Base Impedance, 69 kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	423.200		
DC Resistance from 69 kV	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	1.693		
69 kV Winding Resistance	R_{dc69}	Ω	1.639		See Notes 3 and 4

Equivalent Resistance of 69kV Windings	$R_{KEL}=R_{T1}$	Ω	1.639

Station Grounding Grids

			Resistance		Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5		Assumed
Seal Cove Grounding Grid Resistance	$R_{G\ SCV}$	Ω	0.5		Assumed
Kelligrews Grounding Grid Resistance	$R_{G\ KEL}$	Ω	0.5		

69kV Transmission Lines

			38L (HRD-SCV)	52L (SCV-KEL)	Remarks
Length of Transmission Line	l	km	3.54	8.22	Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.0078796	0.0230975	Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	0.3751478	1.0996720	

Notes
1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio.
4. Resistances of Delta windings are ignored for auto transformers.
5. The 69 kV transfomer windings connected in Delta are not included in the tables.

Table G-6: 69 kV Transmission Network Simulation Results

69 kV Transformer Results
Holyrood Terminal Station

Transformer Designation			HRD_T5	HRD_T10
69 kV Winding Resistance	R_{dc69}	Ω	1.065	1.065
Permissible DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.188	0.188
Calculated DC Current (1-phase)	I_{dc}	A	0.060	0.060

Stray DC Current at Holyrood	I_{HRD}	A	0.360
Stray DC Current at Holyrood (per phase)	$I_{HRD}/3$	A	0.120
Equivalent Resistance of 69 kV Transformers	$R_{HRD}=R_{T5}\|\|R_{T10}$	Ω	0.532

69 kV Transformer Results
Seal Cove

Transformer Designation			SCV_T1	SCV_T2
69 kV Winding Resistance	R_{dc69}	Ω	15.217	1.654
Permissible DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.031	0.141
Calculated DC Current (1-phase)	I_{dc}	A	0.007	0.064

Stray DC Current at Seal Cove	I_{SCV}	A	0.211
Stray DC Current at Seal Cove (per phase)	$I_{SCV}/3$	A	0.070
Equivalent Resistance of 69 kV Transformers	$R_{SCV}=R_{T1}\|\|R_{T2}$	Ω	1.492

69 kV Transformer Results
Kelligrews

Transformer Designation			KEL_T1
69kV Winding Resistance	R_{dc69}	Ω	1.639
Permissible DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.141
Calculated DC Current (1-phase)	I_{dc}	A	0.050

Stray DC Current at Kelligrews	I_{KEL}	A	0.149
Stray DC Current at Kelligrews (per phase)	$I_{KEL}/3$	A	0.050
Equivalent Resistance of 69 kV Transformers	$R_{KEL}=R_{T1}$	Ω	1.639

Notes:
1. The network was analyzed as a resistive network in the CDEGS software.

Appendix H

Distribution Neutrals Impact Assessment

12.47 kV

Model, Data and Results

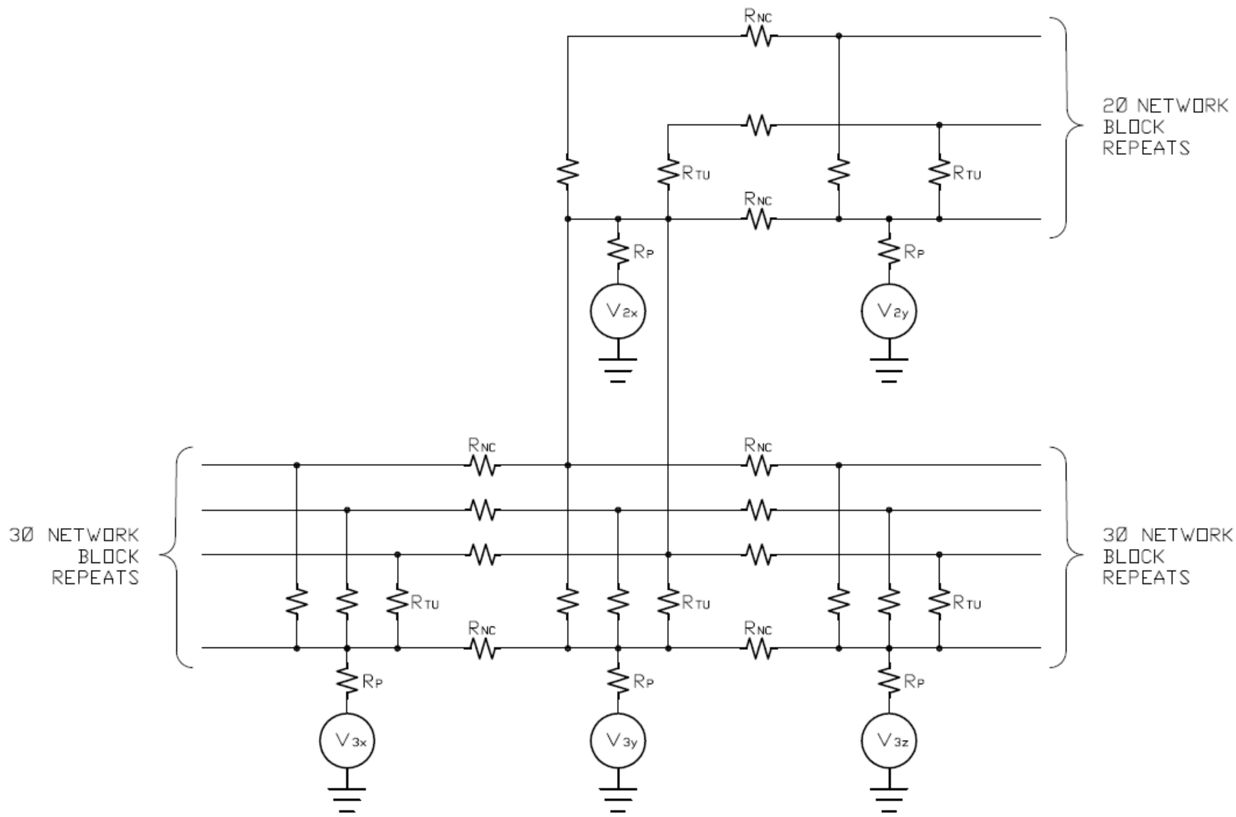


Figure H-1: 12.47 kV Distribution Network Model

HATCH™

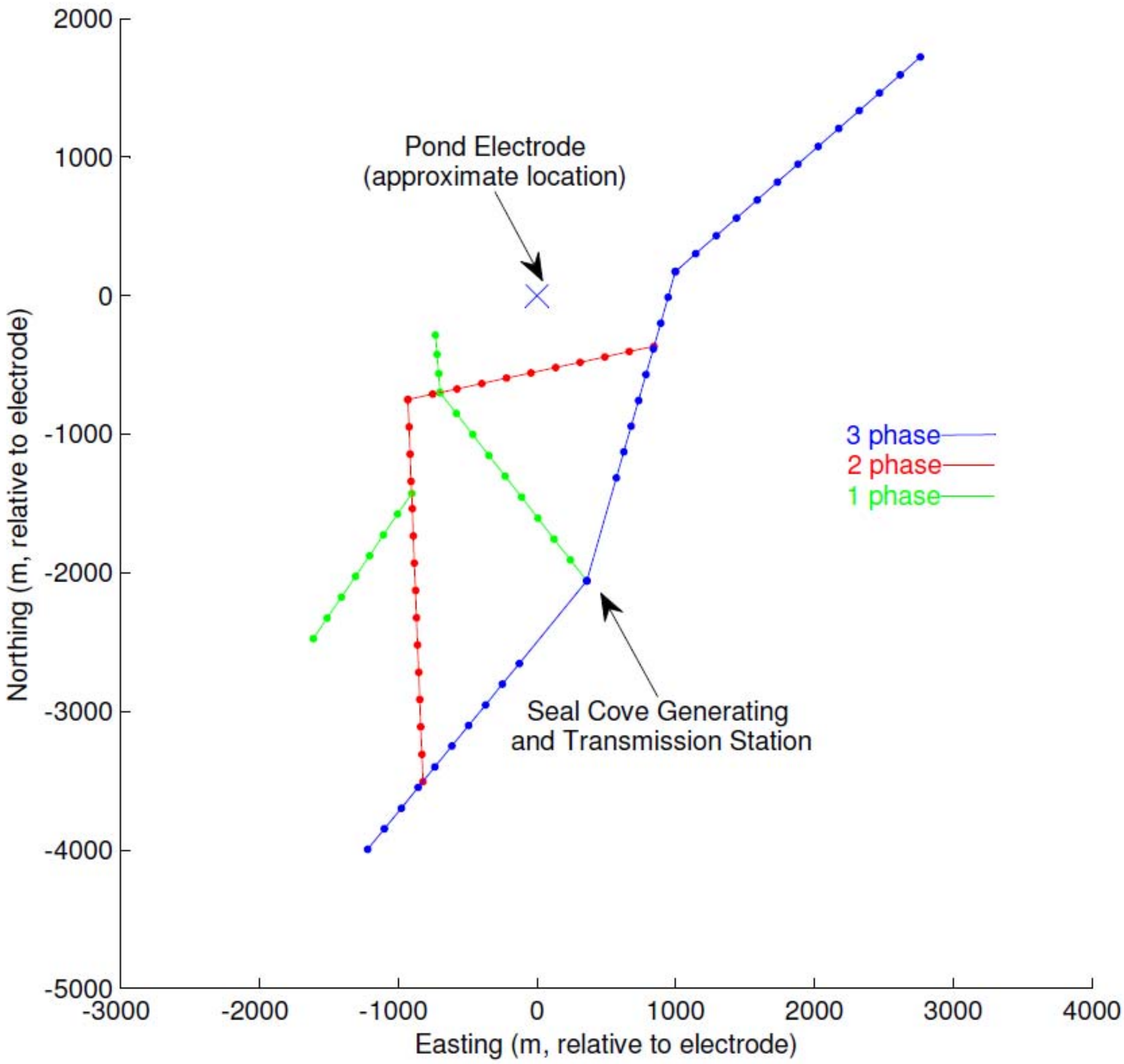


Figure H-2: Plan of 12.47 kV Distribution Network Model

Table H-1: 12.47 kV Distribution Network Data

Station Grounding Grids				**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5	(Assumed)
Pole Grounding Resistance				
Pole Grounding Resistance	R_P	Ω	15	(Assumed)
Distribution Transformers				
Utility Distribution Transformer	kVA_{TU}	kVA	25	(Assumed)
Utility Distribution Transformer Resistance	R_{TU}	Ω	186.6	
Seal Cove Station Distribution Transformer	MVA_{SCVdis}	MVA	5	(Assumed)
Seal Cove Station Distribution Transformer Resistance	R_{SCVdis}	Ω	0.187	
Line Resistances				
Span of Spacing of Distribution Transformers	l	m	200	
DC Resistance of Phase Conductor (2/0 ACSR)	R_{cond}	Ω/km	0.4255	
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.0851	
DC Resistance of Neutral Conductor (1/0 ACSR)	R_{cond}	Ω/km	0.5364	
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.10728	

Notes:
1. All utility transformers are assumed to be 1Ø.
2. Transformer spacing and pole grounding spacing is assumed the same for 1Ø, 2Ø and 3Ø circuits (200 m).
3. Zero 3Ø utility transformers are assumed for the first 600 m away from Seal Cove.

HATCH™

Table H-2: 12.47 kV Distribution Network Results

Pole Designation	GPR (V)	Calculated Current through Distribution Pole (A)	Permissible Current through Distribution Pole (A)	Calculated Current through Transfomer Windings (A)			Permissible Current through Transformer Windings (A)
				AØ	BØ	CØ	
Seal Cove	4.000	-0.8779	N/A	0.0657	0.0566	0.0670	0.7802
Closest Pole in 1Ø Line	6.250	0.0580	0.1144	N/A	0.0018	N/A	0.0232
Closest Pole in 2Ø Line	6.090	0.0491	0.1144	0.0020	N/A	0.0020	0.0232
Closest Pole in 3Ø Line	6.500	0.0627	0.1144	0.0023	0.0024	0.0023	0.0232

Notes
1. The polarity of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into pole; -ve from pole into ground.
2. The network was analyzed as a resistive network in the CDEGS software.

Appendix I

Permissible Material Loss

Data and Calculations

Table I-1: Corrosion Data and Calculations for Permissible Material Loss and dc Stray Currents

Table I-1: Corrosion Data and Calculations for Permissible Material Loss and dc Stray Currents

Steel Foundation				***Remarks***
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	1	%	Assumed
Total Weight	m_{tot}	600000	g	Assumed
Electrode Duty (as Anode)	Ah_{duty}	20000000	A.h	
	=	2100.457	A.yr	
Ah to cause one molar mass loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Iron	$m_{Fe,mol}$	27.925	g	Molar mass divided by valence number
Allowable material Loss	$m_{loss}=m_{tot}*m_{\%}$	6000.000	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	5758.681	A.h	
Permissible Current through Steel Foundation	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.386	A	
Steel Guywire Anchors (two assumed)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	10	%	Assumed
Guywire Anchor Diameter	d	0.022	m	Assumed
Guywire Anchor Length	l	6	m	Assumed, Two anchors each 3 m long
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	17790.211	g	
Electrode Duty (as Anode)	Ah_{duty}	20000000	A.h	
	=	2100.457	A.yr	
Ah to cause one molar mass loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Iron	$m_{Fe,mol}$	27.925	g	Molar mass divided by valence number
Allowable material Loss	$m_{loss}=m_{tot}*m_{\%}$	1779.021	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	1707.469	A.h	
Permissible Current through Anchors	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.114	A	
Steel Grounding Rods (two assumed)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	50	%	Assumed
Grounding Rod Diameter	d	0.019	m	Assumed
Grounding Rod Length	l	6	m	Assumed, Two rods each 3 m long
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	13269.145	g	
Electrode Duty (as Anode)	Ah_{duty}	20000000	A.h	
	=	2100.457	A.yr	
Ah to cause one Molar Mass Loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Iron	$m_{Fe,mol}$	27.925	g	Molar mass divided by valence number
Allowable Material Loss	$m_{loss}=m_{tot}*m_{\%}$	6634.572	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	6367.731	A.h	
Permissible Current through Rods	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.427	A	

Appendix J

Project Memo

Summary of Electrode Review Panel Working Session Meetings

St. John's, June 11-12, 2009

HATCH™

Project Memo

June 25, 2009

TO: Raj Kaushik

FROM: Pete Kuffel

cc: Steve Bonnell
Don Gordon
Calvin Miles
Hugh Miller
Jennifer Strong
Terry Treasure
Kyle Tucker

Nalcor Energy – Lower Churchill Project
WTO DC1250

Summary of Electrode Review Panel Working Session Meetings, St. John's, June 11-12, 2009

Introduction

As part of WTO DC1250 to review the technical viability of land and shore electrodes for the Gull Island and Soldier's Pond converter stations, a panel of experts was assembled consisting of: Don Gordon, Terry Treasure, Calvin Miles, Hugh Miller and Peter Kuffel. As part of their ongoing work, the panel held working session meetings in St. John's on June 11 & 12, 2009. This memo provides a summary of the working session meetings and the next steps to be undertaken to move the electrode review process forward.

Attendance

The following were in attendance:

Name	Affiliation	Email Address
Raj Kaushik	NE-LCP	rkaushik@nalcorenergy.com
Pete Kuffel	Hatch	pkuffel@hatch.ca
Bob Barnes	NE-LCP	bbarnes@nalcorenergy.com
Jennifer Strong	NE-LCP	jstrong@nalcorenergy.com
Kyle Tucker	NE-LCP	ktucker@nalcorenergy.com
Hugh Miller	AMEC	millergeo@nl.rogers.com
Calvin Miles	AMEC	calvin.miles@amec.com
Steve Bonnell	NE-LCP	sbonnell@nalcorenergy.com
Terry Treasure	Hatch	treasure@telus.net
Don Gordon	Teshmont	dgordon@teshmont.com
Robert Woolgar (part time)	Hatch	
Cliff Rowe (part time)	NE-LCP	

Summary of Working Session Meetings

The meetings took the form of an open forum with some presentations along with ongoing discussions. Key points raised include:

- NE-LCP indicated that sea electrodes were the least desirable type in terms of environmental impact. The footprint of the sea electrode will be a key issue; all things being equal, a large footprint land electrode would likely pose less of an environmental challenge than an off-shore footprint.
- The current schedule has the EIS for the transmission (including the ground electrodes) being prepared in the fall and winter, with a submission in the spring of 2010.
- The principal objectives of electrode review were identified as follows:
  - Review the viability of alternate electrode types (land and shore) and potential locations for the Gull Island and Soldiers Pond electrodes.
  - If either is found to be viable, review and identify steps required and the process to be undertaken by NE-LCP to:
    - fully assess the potential options;
    - provide a basis for comparison to the currently identified preferable electrodes; and
    - determine preferred electrode types and locations on the basis of technical, economic and environmental considerations.
- The goals of the working session were identified as follows:
  - Clarify requirements of NE-LCP.
  - Clarify applicable regulatory and environmental requirements.
  - Identify requirements to determine viability for each of the land and shore electrodes.
  - Identify type and potential sources of existing data.
  - Identify preliminary search regions.
  - Identify criteria that can be applied in order to determine viability.
  - Develop scope of work for preliminary field investigations to collect data to confirm viability of potential sites.
  - Develop framework for technical, economical and environmental analysis of viable sites.
  - Develop a framework for the final report.
- Previous work related to electrode selection and the currently identified potential locations for the electrodes were discussed. It was agreed that additional work was required to investigate potential alternate electrode locations and to substantiate the final proposed electrode types and locations.

- The nominal current carrying requirements of the electrodes are as follows:

	Gull Island	Soldiers Pond	Salisbury
Nominal Current (A)	1780	890	890
Maximum Continuous Current (A)	2320	1340	980
Maximum 10 Minute Overload (A)	2760	1780	980

- The potential for iceberg damage to the cables in the Strait of Belle Isle and the resultant loss of a pole for an extended period of time until the cable damage could be repaired (estimated to be up to one year) represents a critical design requirement. Under conditions of extended monopolar outage with electrode return, the electrodes must be capable of carrying the maximum continuous current.
- Potential advantages and disadvantages of sea/shore and land electrodes were discussed and, in particular, the application of each type for the Labrador and Island electrodes. Based on the discussions of potential environmental impacts, it was decided that if a suitable location could be found, a land electrode would be the preferred type, followed by a shore electrode, then followed by a sea electrode.
- Some basic requirements for land and shore electrodes were identified to be used when considering potential sites as follows:
  - Land electrode:
    - Nominal resistivity of 100Ωm or less is desirable.
    - Low resistivity layer thickness of 20m or more is desirable.
    - Step potential = 5 + 0.03ρ, where ρ is the resistivity of the earth.
    - With ρ = 100Ωm, step potential = 8V
  - Shore/sea electrode:
    - The electric field at the public access point should be a maximum of 1.25V/m.
- A discussion of known geological conditions in Labrador and on the Island was held.
- The shore electrode at the Haenam terminal of the Cheju Island HVdc system was discussed. Pictures of the electrode structure indicate a fairly simple structure. The breakwater for the site is estimated to be 50 m long, and the minimum depth of the pond is 2.5 m.
- The shore and beach electrodes of the Vancouver Island HVdc system were discussed including their location and construction.
- A number of potential sites for land and shore electrodes in Labrador and on the Island were identified and discussed. These are discussed in greater detail below.

- Next steps to follow up on these potential sites were identified. These are discussed in greater detail below.
- At the conclusion, a summary of the working session was presented to NE-LCP.

Potential Sites Identified

Based on the known geological conditions in Labrador and on the Island, a number of potential electrode sites were identified. The known or estimated resistivity at each site along with other factors to be considered in the evaluation was assembled and is summarized in Table 1 and Table 2 and the sites were ranked in order of preference. Figure 1 contains a map indicating the potential locations identified.

Labrador

The currently known geological data for Labrador indicates there is a low resistivity silt/clay layer located in the area between the proposed Gull Island and Muskrat Falls generating stations which may be suitable for a land electrode. If a suitable site could be found in this region, it would have the advantage that the electrode line would be short and follow an existing right of way. In addition, a low resistivity bog area was identified south of the Trans-Labrador Highway south of the new bridge which may be suitable for a land electrode. If none of these sites were suitable, it was suggested that a shore electrode on Lake Melville may be preferable to the currently recommended sea electrode in Lake Melville.

Island

The currently known geological data for the Island indicates that identification of a suitable location for a land electrode would be very unlikely; therefore discussion concentrated on locating potential sites for a shore electrode. The most likely site for a land electrode was identified at the St. John’s shale which is located 10 km from the Soldier's Pond Converter site on the other side of the peninsula and away from Holyrood; however, the resistivity is believed to be too high for it to be a viable option. An item of concern related to locating a suitable site for a shore electrode is the proximity of existing housing and infrastructure located close the shore.

A potential site for a shore electrode was identified at Dowden’s Point (near Seal Cove). The site was previously used in the cement industry and is a brownfield site located adjacent to the shore. The potential exists to create a pond connected to the sea where the electrode could be located. The site is located close to the converter station and would result in a short electrode line. The main concern for the site is the proximity of the site to existing housing and the associated infrastructure, along with the proximity to the Holyrood generating station and the potential converter station.

nalcor energy

Potential Electrodes Sites

Figure 1: Potential Electrode Site Locations

HATCH™

Table 1: Potential Sites Identified in Labrador

Rank	Site	Estimated Resistivity Shallow (ohm*m)	Deep (ohm*m)	Land Area Available (km²)	Land Ownership	Distance From Substation (km)	Nearest Infrastructure (km)	Electrode Line New ROW/total length (km)	Environmental Considerations	Technical Issues	Questions
1	Bog near Pinus River	50	5000	1.5	Crown	10	10	2/12	Bog		
2	Lower/Upper Brook between Gull Island and Muskrat Falls Sites	50	5000 (Fault)	60	Crown	30	30	0/30	Bog, forest	Proximity to reservoir	Electro-osmosis
3	Bog near TLH south of new bridge	50	5000	infinite	Crown	40	15	60/120	Bog		
4	Bog near Kennamu (?)	50	5000	infinite	Crown	60	15	60/120	Bog		
5	Shoreline near Kinnu (?) or Sebiskachu(?)	2	5000	infinite	Crown	60	?	90/150	Bog, shoreline	Freezing, access	
X	Low ground NW of converter station	50	5000	16	Crown	4 - 5	4 - 5	0/4-5	Bog, forest	Proximity to converter station	

Table 2: Potential Sites Identified on the Island

		Estimated Resistivity		Land		Distance from	Nearest	Electrode Line			
Rank	Site	Shallow (ohm*m)	Deep (ohm*m)	Area Available (ha)	Land Ownership	Substation (km)	Infrastructure (km)	New ROW/total length (km)	Environmental Considerations	Technical Issues	Questions
1	Dowden's Point (Mac Mix Pit)	2	2000	3	Private	3	0.5	short	Brownfield	Proximity to houses and possible infrastructure, freezing	Existing infrastructure
2	Indian Pond	2	2000	10	Crown	0.30	0.3	short	Fish, ocean	Proximity to Holyrood, converter stations, & other infrastructure, freezing	Existing infrastructure
3	Chapel Cove	2	5000	2	Private, crown	3	0.05	long	Fish, ocean	Proximity to houses and possible infrastructure	Existing infrastructure
X	Soldiers Pond	500?	5000	infinite	Crown	10	1	medium	Forest	Proximity to infrastructure, high shallow earth resistivity,	
X	Area south of Holyrood GS	50?	2000?	1-2	Hydro, crown	< 1	0.2	short	Cleared	Proximity to Holyrood, converter stations, & other infrastructure	
X	St. John's shale	500	2000	infinite	Crown	5	5	medium	Forest	Proximity to Holyrood, converter stations, & other infrastructure, high shallow earth resistivity	

Next Steps

In order to proceed with a preliminary evaluation of the potential sites identified and the development of field programs to fully investigate the sites the following action plans were identified.

Labrador

As undertaking field work in Labrador would take some time, it was decided that preliminary electric field calculations should be undertaken based on the currently known and estimated earth resistivity data. The findings of these calculations would then be used in confirming initial rankings of the sites and the development of a field program for Labrador. At this time it is anticipated that the field program in Labrador will have two phases, a preliminary field program to gather sufficient data to confirm the preliminary electric field calculations and a more detailed program for the most likely candidate site(s).

The next steps identified for Labrador were as follows:

- Assemble/review existing data – *Nalcor/CM*
- Identify electric field modeling data requirements – *PK/DG/TT*
- Prepare electric field model data – *HM*
- Perform preliminary electric field simulations – *PK/TT/DG(/Teshmont)*
    - Bog near Pinus River site
    - Lower/Upper Brook site
    - Bog near TLH south of new bridge
- Confirmation of initial rankings – *all*
- Ranking of potential sites – *all*
    - Technical considerations
    - Economic considerations
    - Environmental considerations
- Develop site field program – *all*
    - Preliminary
    - Detailed

Island

As the Dowden's Point site would provide a number of advantages over other potential sites on the Island and performing preliminary field investigations is relatively easy it was recommended that a field program be undertaken at the site as soon as possible. The findings from the site investigations study will be used in preliminary electric filed simulations. In the event that the electric field calculations show that the Dowden's Point and Indian Pond sites are not viable, an exclusion zone which would be required around any potential electrode site will be identified in order to assist with locating alternate sites.

The next steps identified for the Island were as follows:

- Assemble/review existing data – *Nalcor/CM*
- Review Dowden's Point site – *Nalcor*
    - Land ownership/usage.
    - Indentify the type and location of the existing surrounding infrastructure (power system, grounding principles, buried metallic objects, water and sewer pipe types, etc.).
    - Identify any other issues.
- Estimate voltage contours for electrode located on the shore line at Dowden's Point using estimated data – *DG(/Teshmont)*
- Site investigations at Dowden's Point – *CM/HM*
    - Resistivity measurements
    - Bore hole drilling
    - Water sample and testing
    - Other?
- Identify electric field modeling data requirements – *PK/DG/TT*
- Prepare electric field model data – *HM*
- Perform preliminary electric field simulations – *PK/TT/DG(/Teshmont)*
    - Dowden's Point site
    - Indian Pond site
    - Identification of "exclusion zone"
- Confirmation of initial rankings – *all*
- Ranking of potential sites – *all*
    - Technical considerations
    - Economic considerations
    - Environmental considerations
- Develop detailed site field program – *all*

Schedule

The draft schedule was reviewed and revised to reflect the outcomes of the working session meeting.

PK:nl

Appendix K

Project Memo

Labrador Ground Electrode Study

Project Memo

September 29, 2009

TO: Jennifer Strong

FROM: Pete Kuffel, Rauf Ahmed, Ben McLeod

cc: Raj Kaushik
Don Gordon
Terry Treasure
Calvin Miles
Hugh Miller

Nalcor Energy – Lower Churchill Project WTO DC1250

Labrador Ground Electrode Study

Introduction

This document presents the electrical field simulation and design calculation results of the HVDC ground electrode for the Gull Island converter station at the potential sites in Labrador identified during the Electrode Review Panel Working Session meetings held in St. John's on June 11-12, 2009. The purpose of the simulations was to investigate the viability of the potential sites based on anticipated geological conditions. The simulations were performed using the CDEGS grounding analysis software. Ground potential rise (GPR) values were calculated at the electrode site and various locations of interest, including the Gull Island converter station, Gull Island generating station, Muskrat Falls generating station, and the town of Happy Valley-Goose Bay.

Electrode Design

Temperature rise at the electrode element and soil interface, step potential, and available space are the main parameters which determine the type and size of an electrode. The availability of space was not a constraint rather surficial geology (width of low resistivity top layer of soil) was a limiting factor. The design objective of temperature rise and step potential can be met with various electrode shapes and designs. A ring type electrode was selected, being a proven design and easy to analyze.

The soil adjacent to the electrode bed coke is important for thermal stability of the electrode and is considered in the design of the electrode. Electrodes of diameter 1000m, 1500m and 2000m were analyzed; Table 1 shows the design calculation results for these ring electrodes in 50 Ohm-m and 100 Ohm-m surficial soil based on the formulas presented in [1] and [2].

HATCH™

Table 1 Preliminary Electrode Designs Considered

Parameter Description		Ring Electrode Options					
		1000A	1000B	1500A	1500B	2000A	2000B
Diameter of Ring Electrode (m)	D =	1000	1000	1500	1500	2000	2000
Coke bed side (m)	s =	0.5	0.5	0.5	0.5	0.5	0.5
Avg Resistivity (ohm*m)	ρ =	50.0	100.0	50.0	100.0	50.0	100.0
Electrode Perimeter (m)	P =	3142	3142	4712	4712	6283	6283
Depth of electrode (m)	h =	2.5	2.5	2.5	2.5	2.5	2.5
Electrode Resistance in uniform soil (ohms)	Re =	0.041	0.082	0.029	0.057	0.022	0.044
Electrode Ground Potential Rise GPR (V)	Ve =	94	188	66	132	51	102
Irated (A)	I =	2300	2300	2300	2300	2300	2300
Current Density (A/m^2)	Id =	0.37	0.37	0.24	0.24	0.18	0.18
Soil Conductivity (W/m^oC)	λ =	0.833	0.833	0.833	0.833	0.833	0.833
Heat Capacity (MJ/m^3C)	γ =	2.200	2.200	2.200	2.200	2.200	2.200
Max. Temperature Rise (C)	θmax =	105.89	211.78	51.91	103.83	31.22	62.44
Time Constant (days)	T =	402.43	402.43	443.93	443.93	474.61	474.61
Time to 60 Degrees C Rise(days)	t_{60} =	337	134	N/A	383	N/A	1539

Electrode GPR (Ve) in uniform infinite soil model to remote earth is

$$Ve = \sqrt{(2\lambda\rho\theta)}$$

Where:

λ = Heat conductivity of the soil (W/mC)

θ = Design temperature rise of electrode above earth ambient temperature (C), 60^oC considered in the calculations for a conservative design. The yearly average at Happy Valley Goose Bay is approximately 0^oC that will be average temperature of soil at a depth of 2.5m. A higher design temperature rise can be justified.

ρ = Resistivity of soil (Ωm)

Electrode resistance to remote ground (Re) in infinite uniform soil resistivity

$$Re = (\rho/(\pi^2 * D)) * \ Ln\ (4D/b)$$

Where:

ρ = soil resistivity (Ωm)

D = diameter of the electrode ring (m)

$b = \sqrt{dh}$

d = equivalent diameter of the electrode (m) = $4*s/\pi$

s = length of side of square cross section of electrode (m)

h = depth of burial (m)

Maximum Temperature (θmax)

$$\theta max = Ve^2/2\lambda\rho$$

Time to 60°C Temperature Rise (t_{60})

$$t_{60} = T \, Ln\,(1\text{-}60/\,\theta max)$$

The values calculated in Table 1 assume an infinite uniform soil body which is a valid assumption for the calculation of maximum temperature rise since this depends on the soil adjacent to the electrode elements. This assumption however does not hold true for the GPR distribution and electrode impedance which depend on local as well as remote geological conditions. The actual electrode GPR and electrode impedance will be higher than the values calculated values in Table 1.

Based on the results of maximum temperature rise and the soil data, an electrode with a diameter of 2000m was selected for the study. It should be noted that beyond the electrode site, the GPR values will depend on the geology of the site and not the actual design of the electrode.

Description of Simulation Model

The simulation model is comprised of three major parts:

- the soil model,
- the electrode conductor model and
- the observation profiles and points.

Soil Model

Soil modeling data (including resistivities and thicknesses of geological units) based on currently known information [3] was prepared. A number of scenarios were evaluated in order to undertake a sensitivity analysis for variations in soil data.

Three different geological bodies were included in the soil model; surficial sediments, Double Mer formation sediments, and granitoid rock. The high-resistivity (~10,000Ωm) granitoid rock is abundant in the area and is considered the native soil (i.e. extending *ad infinitum*) in the model. The surficial body is of low resistivity (~50Ωm) and the Double Mer body is of medium resistivity (~2000Ωm). The surficial and Double Mer bodies were modelled as rectangular finite volumes of uniform thickness with coinciding boundaries; the surface area of rectangular soil volumes was selected based on the surficial sediment expanse at the electrode location.

The conductive body of lake Melville was not considered in the model.

Figure 1 shows the expected surficial sediment boundaries the finite rectangular areas considered in the model.

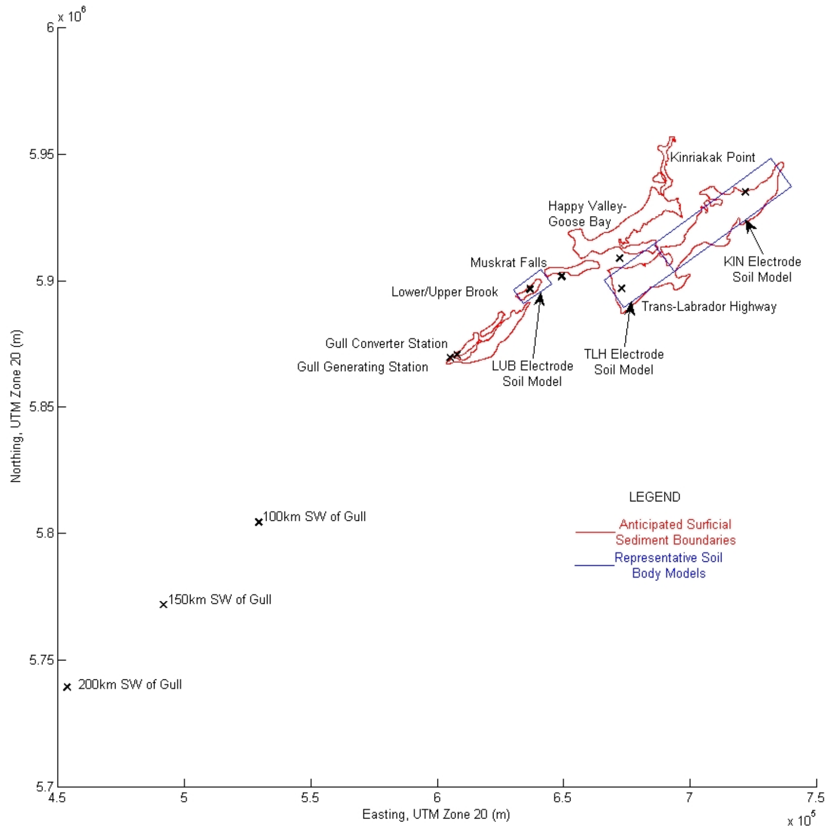


Figure 1 Anticipated Surficial Sediments and Representative Models

Electrode Conductor Model

The electrode itself was modelled as a piecewise linear ring consisting of 78 conductor sections surrounded by a conductive coke bed layer and 78 coke bed sections to connect the conductor sections. Insulated cables are considered to connect the electrode sections and distribution junction box at the centre of the electrode. Figure 2 shows conductor network used for simulations. The number of conductor sections were selected to have good match with calculated electrode resistance in uniform soil model.

The electrode was energized for anodic operation for current dissipation to the remote earth. A return electrode (other end of the HVdc link) was not considered since this will have minor impact on the voltage distribution in the zone of interest as the separation between the HVdc terminals is large compared to the zone of interest.

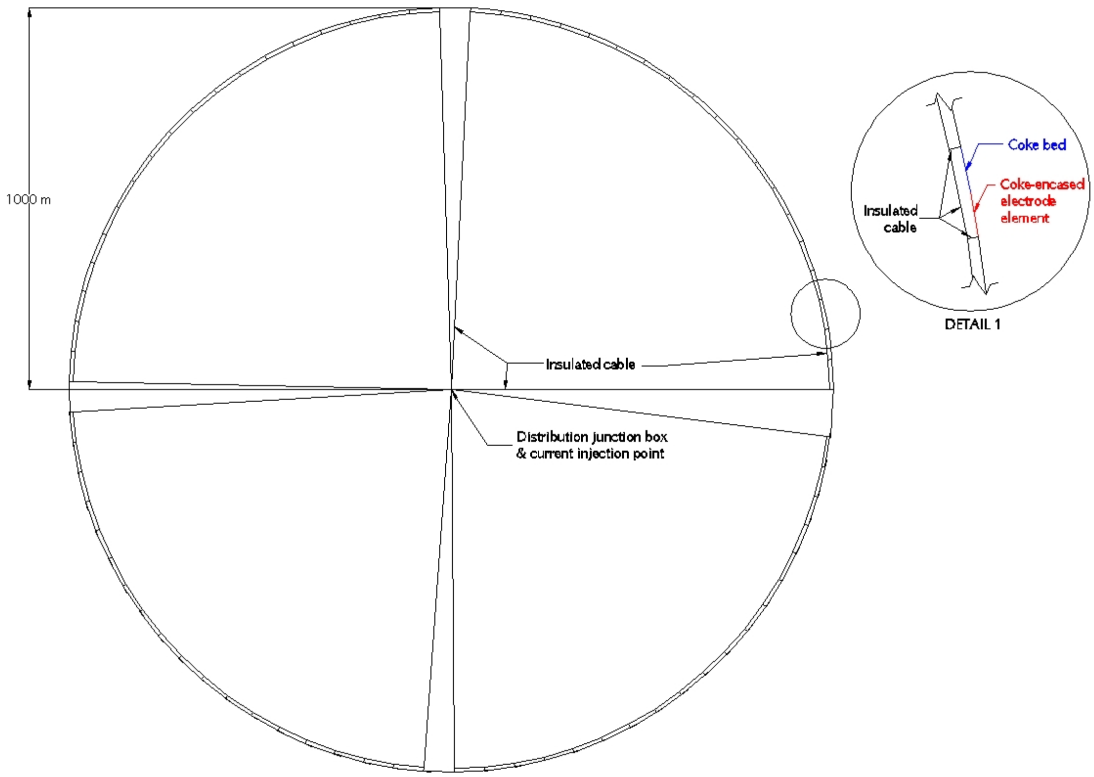


Figure 2 Electrode Model

Observation Profile and Points

GPR levels were monitored at seven observation points at locations of interest along with a rectangular surface profile covering an area of nine square kilometres encompassing the electrode. These observation points and profile are listed in Table 2. The locations at distances of 100, 150 and 200km from Gull Island were included to provide some insight to the GPR values in the vicinity of remote substations, including Churchill Falls.

Table 2 Observation Points

Observation Point/Profile	Observation Point	
	Easting*	Northing*
Electrode Location profile (3000mx3000m)		
Gull Island Converter Station	607750	5870650
Gull Island Generating. Station	605200	5869650
Muskrat Falls Generating Station	649200	5901800
Happy Valley-Goose Bay	672140	5908972
100km SW of Gull Island Generating Station	529427	5804393
150km SW of Gull Island Generating Station	491540	5771765
200km SW of Gull Island Generating Station	453654	5739136

* Easting and Northing of UTM 20

Methodology

The Electrode Review Panel Working Session meetings identified six potential land electrode locations in Labrador along with a preliminary rank for each as given in Table 3.

Table 3 Preliminary Electrode Locations and Ranking Identified During Electrode Review Panel Meetings

Rank	Site	Original		Revised		Difference	
		Easting	Northing	Easting	Northing	Δ East	Δ North
1	Bog near Pinus River	617655	5877340	617655	5877340	0	0
2	Lower/Upper Brook between Gull Island and Muskrat Falls Sites	631716	5894792	636716	5896792	-5000	-2000
3	Bog near Trans Labrador Highway south of new bridge	671013	5898962	673013	5896962	-2000	2000
4	Bog near Kenamu	702116	5920896	702116	5920896	0	0
5	Shoreline near Kinriakak (or Sebaskachu)	721938	5935115	721938	5935115	0	0
X	Low ground NW of converter station	607665	5871312	607665	5871312	0	0

The proposed locations at Lower/Upper Brook (LUB) and Trans Labrador Highway (TLH) were such that the electrode was adjacent to the boundary of the body of soil in which it was located. In order to avoid numerical issues with the simulation software and make the electrode effective, it is desirable to maintain a minimum separation equal to the diameter of the electrode between the electrode and the boundary of the body of surficial soil containing the electrode. As a result, the originally proposed locations of LUB and TLH electrodes were adjusted as indicated in Table 3.

Although the location near Pinus River was ranked the highest during the electrode review meetings, it was decided that the first location which should be considered for the electric field simulations was LUB. This decision was based on the relative proximity of the potential sites to the converter station location. If results for LUB were promising, then sites closer to the converter station would be investigated; however if the results for LUB indicated high GPR values at the converter station, then sites farther away from the converter station would be considered.

A set of five scenarios was established to perform a sensitivity analysis on the parameters defining the soil model. The scenarios are listed in Table 4.

Table 4 Modelling Scenarios

Scenario	A	B	C	D	E
Surficial					
Resistivity (Ωm)	50	50	100	50	50
Thickness (m)	50	100	100	50	50
Double Mer					
Resistivity (Ωm)	2000	2000	2000	2000	2000
Thickness (m)	2000	2000	2000	3000	2000
Granitoid					
Resistivity (Ωm)	10000	10000	10000	10000	5000
Thickness (m)	infinite	infinite	infinite	infinite	infinite

Results

Simulations were initially performed for the site at LUB. Based on the results obtained, additional simulations were performed for the potential sites at TLH and Kinriakak Point (KIN). The GPR values obtained at each of the observation points for each location and scenario considered are given in Table 5.

HATCH™

Table 5 Simulation Results for LUB, TLH, and KIN Electrode Sites

Ground Potential Rise Voltages (V)									
	Max GPR	Center of Electrode	Gull Island Conv. Station	Gull Island Gen. Station	Muskrat Falls Gen. Station	Happy Valley-Goose Bay	100km SW of Gull Island	150km SW of Gull Island	200km SW of Gull Island
Lower/Upper Brook (LUB)									
Scenario									
A	1079.99	1035.14	92.20	86.55	322.13	101.26	25.68	19.01	15.09
B	1002.86	973.01	92.16	86.51	323.34	101.34	25.68	19.01	15.09
C	1130.99	1067.19	92.50	86.82	317.06	100.82	25.71	19.02	15.10
D	1011.66	966.50	92.19	86.54	319.64	101.21	25.68	19.01	15.09
E	737.29	696.55	46.31	43.47	154.98	50.19	12.86	9.52	7.55
Bog Near Trans-Labrador Highway (TLH)									
Scenario									
A	752.32	708.01	47.93	46.26	129.06	323.80	20.64	16.12	13.22
B	713.85	683.23	48.14	46.45	130.33	325.81	20.68	16.15	13.24
C	881.78	817.95	48.81	47.08	134.04	325.92	20.81	16.23	13.29
D	710.29	665.08	47.89	46.23	128.80	317.97	20.63	16.12	13.22
E	578.60	539.49	24.49	23.62	67.39	162.46	10.42	8.12	6.65
Kinriakak Point (KIN)									
Scenario									
A	561.20	512.60	30.93	30.22	55.39	92.63	16.59	13.53	11.42
B	538.68	505.65	30.63	29.94	54.45	90.03	16.50	13.47	11.38
C	711.77	645.01	30.04	29.38	52.58	84.74	16.33	13.36	11.30
D	491.54	452.01	31.19	30.47	56.22	95.03	16.66	13.58	11.45
E	486.47	443.10	15.02	14.69	26.25	42.11	8.17	6.68	5.65

Discussion

Sensitivity of Parameters

The results show that the most sensitive parameter in the soil model at a given electrode location was the resistivity of the native granitoid. A significant drop in GPR was observed at all observation points in Scenario E when the resistivity of the native granitoid was decreased from 10,000Ωm to 5,000Ωm. Table 5 indicates there is an almost linear relationship of the GPR with the granitoid resistivity, so the presence of higher resistivity for the granitoids would result in higher GPR's at all locations. The most likely case is that the actual resistivity of the granitoids may be greater than 10,000Ωm. Therefore Scenario E is considered a very optimistic case.

Excluding Scenario E, the remaining scenarios showed subtle changes in the voltage levels at a given observation point and electrode site. This indicated that the sensitivities of the thickness of the Double Mer layer, as well as the thickness of the surficial layer in the ranges considered were small.

In general, Scenario D showed the next lowest voltage levels, followed by Scenarios B, A, and C. This order of voltage levels is consistent with the expected variations from one scenario to the other. For example, when increasing the thickness of the surficial layer from 50m to 100m, it was expected that the GPR values would decrease. With the exception of the observation point right at the electrode itself, the variations of GPR values for Scenarios A, B, C, and D were minimal.

Discounting the optimistic case of Scenario E, the range of calculated voltages at each observation point were quite narrow, especially as the observation points became farther from the electrode. This is consistent with the fact that GPR beyond the actual electrode site depends on the geology of the site and is not affected by the design of the electrode. Table 6 captures the observed trends for each case, taking the average values for Scenarios A, B, C, and D.

Table 6 Observed Trends in GPR

Ground Potential Rise Voltages (V)								
Max GPR	Center of Electrode	Gull Island Conv. Station	Gull Island Gen. Station	Muskrat Falls Gen. Station	Happy Valley-Goose Bay	100km SW of Gull Island	150km SW of Gull Island	200km SW of Gull Island
Lower/Upper Brook (LUB)								
1056	1010	92	87	321	101	26	19	15
Bog Near Trans-Labrador Highway (TLH)								
765	719	48	47	131	323	21	16	13
Kinriakak Point (KIN)								
576	529	31	30	55	91	17	13	11

The observation points at which the highest GPR values occurred were Muskrat Falls and Happy Valley-Goose Bay. This was true for all three electrode sites since in all three cases, these points were located closest to the electrode. High GPR values were also observed at the Gull Island converter and generating stations for the LUB electrode site because these locations were also relatively close to the LUB electrode.

The expanse of surficial sediments and the location of the electrode with reference to the boundary of surficial sediments influence the electrode maximum GPR significantly. The maximum GPR values in Table 6 of the LUB electrode located in a smaller area of surficial layer, the TLH electrode located close to the boundary of the surficial sediments, and the KIN electrode located in the centre of a larger surficial sediment are indicative of this influence.

Mitigation Evaluation Criteria

According to CIGRÉ [4], the need for current-reducing equipment on transformer neutrals based on observed voltage levels is summarized in Table 7.

Table 7 GPR Ranges and Corresponding Need for Mitigation

Ground Potential Rise (V)	Need for Current-Regulating Equipment
GPR < 1	Mitigation not required
1 < GPR < 10	Mitigation probably not required
10 < GPR < 30	Mitigation possibly required
30 < GPR < 100	Mitigation required

Given the GPR trends in Table 6, it can be seen that the voltage levels at all observation points are greater than 10V and thus, at the very least, mitigation measures are possibly required at all locations. Moreover, the only locations at which mitigation is probably not required are the remote locations representing remote substations including Churchill Falls.

Even in the optimistic case of Scenario E, the only locations with GPR values less than 10V are the remote locations. Therefore at all other locations, the need for mitigation measures would possibly -- if not definitely – be required.

In addition to mitigation on transformer neutrals, the GPR values obtained indicate that mitigation measures on existing infrastructure at the town of Happy Valley-Goose Bay would be required for all potential electrode sites. As the infrastructure is not currently known, the type and extent of mitigation cannot be determined at this point.

Examples of Mitigation

In a number of previous HVdc projects, there has been the need for current-regulating devices (or blocking devices) to be installed on the neutrals of nearby transformers in an effort to mitigate damaging effects of ground currents on the transformers. Some examples of projects where current-regulating devices have been used are summarized below.

East – South Interconnector (India)

The East-South Interconnector is a 1450km long, +/-500kV, 2000MW HVdc link in India which was commissioned in 2003 using land electrodes at both converter stations. The land electrode for south end is located approximately 30 km from the Kolar converter station. The site was selected based on detailed soil investigations with respect to resistivity, thermal conductivity and thermal capacity. The following main design parameters were considered [5]:

- Rated current (A) 2000
- Overload current (A) 2250

- Max step potential at site surface at Id = 2250A (V/m) 6
- Resistance to Ground (Ω) < 0.3
- Touch Voltage (V) < 40
- Max. Anodic Current density (A/m^2) < 0.5
- Max temperature on the surface of the sub-electrode (°C) 100
- Design life MAh (Million Ampere hours) 40

During commissioning of monopolar ground return operation the presence of dc currents in the neutrals of transformers in the ac network in the vicinity of the Kolar electrode and in the converter transformers due to the ground potential rise was observed with a humming sound. Verification of the electrode design revealed that the unexpected ground potential rise was due to geological conditions away from the electrode and was not related to the design of the electrode itself. This resulted in power in ground return mode being restricted to 150MW (300A).

Consequently, blocking devices were installed on the neutrals of the most affected nearby transformers. A custom designed capacitor is used to provide a low impedance path for steady state ac current while blocking the flow of dc current . A high current by-pass path is momentarily provided around the capacitor in order to solidly ground the neutral during power system disturbances. This ensures a low grounding impedance so there are no over voltages at the neutral and no impact on the settings of protection equipment in the ac system. The by-pass path is provided by two inverse-parallel pairs of silicon controlled rectifiers which are turned on whenever the voltage across the device terminals or the ac current through the device attempts to exceed predetermined threshold levels. The maximum blocking voltage required depends on the maximum steady-state ground electrode current, the location of the substation/installation and the ac system configuration. The maximum steady-state blocking capability of the devices is 400V.

The application of blocking devices enabled an increase in power flow from 150MW (300A) to 500MW (1000A)in monopolar operation. However, it was found that further increase to the monopolar power level would not be feasible because the number of additional transformers requiring blocking devices would be too large.[5]

Hydro-Quebec – New England (Canada)

During commissioning of the multi-terminal Radisson-Sandy Pond HVdc system in the early 1990's, significant dc voltage levels were observed in the vicinity of the electrode of the Radisson HVdc converter when operating in monopolar, ground return mode as a result of high soil resistivity (5,000 – 30,000Ωm) in the Canadian Shield [8]. The dc voltage across the device was estimated to be approximately 900V considering simultaneous operation in ground-return mode, where the voltage could reach 465V across the blocking device at a dc current level of 3700A, plus the voltage produced by a strong magnetic storm (GIC event) estimated to be 420V. [6]

The basic requirements identified for the blocking devices to be installed in the transformer neutrals included that:

- they must be simple passive devices in that they must not require any operator intervention to be put into service or while in service,
- they must have excellent reliability,
- they must not interfere with any existing protections or controls, produce new operating constraints, generate harmful interactions on the transmission system such as ferroresonance, overvoltages, etc., and
- they must maintain an effectively grounded transmission system

The solution adopted basically involved a permanent, relatively small, capacitor connected in series in the neutral of the transformer and a bypass electronic switch installed in parallel with the capacitor. The capacitor is short-circuited or bypassed very rapidly by a thyristor when the transient voltage reaches 1500V during fault events or transformer energization. The blocking device remains short-circuited for about 20 cycles (0.35 s) and then is reinserted automatically in the transformer neutral. A manual bypass switch is installed in parallel to keep the transformer in service during maintenance. [6]

No published information could be found regarding the reliability or effectiveness of the blocking device.

Cook Strait HVdc (New Zealand)

Until commissioning of the DC Hybrid upgrade project began in late 1992, there had been no problems arising from inter-action between HVdc earth return working and any AC network. When commissioning of the new thyristor converter pole commenced in late 1992, one pole of the original HVDC link was in operation in monopolar mode. Second order harmonic currents were produced immediately when the new harmonic filter bank was connected to the live 220 kV converter transformer (the converter transformer was energized but the associated thyristor converter was not energized) and it was quickly discovered that about 4% of the HVdc earth return from the mercury-arc pole was passing as stray current via the earthed star point of the new 220 kV converter transformer into the 220 kV network and causing DC magnetic saturation with the consequent production of second order harmonic frequencies. [7]

An extensive measurement programme was carried out to determine the potential gradients/ground potential differences between 13 substations in the South Island and a network model was developed to investigate the possible stray DC current flow via the AC network for a range of network operating and outage conditions. In conjunction with advice from transformer manufacturers neutral earthing resistors were installed at a number of locations to ensure transformer saturation would not occur in the event of HVDC earth return working at up to 2640A (possible transient monopolar current under certain conditions – a very infrequent event). Two installations required a special neutral earthing resistor arrangement.

No other stray DC current interaction of the above nature has been reported subsequently in any network in the South Island, although action has been taken where necessary for new installations installed after 1992. [7]

Vancouver Island (Canada)

During the first monopolar stage, the Vancouver Island HVdc system operated with 1200A in sea return for several years, and no effects from GPR were ever observed. However, there were problems with other equipment similar in design to the GPR blocking devices.

After the commissioning of the bipole stage, there were several false flashovers of a protective neutral spark gap at the inverter station that resulted in forced outages. The purpose of the spark gap was to limit the neutral voltage under transient conditions. The DC spark gap flash-over voltage was found to be very sensitive to ambient humidity, and was replaced with a surge arrester connected in parallel with a vacuum bypass switch. The bypass switch would protect the arrester by bypassing the arrester whenever the arrester current exceeded a pre-set level. A forced outage occurred during an HVdc disturbance because the bypass switch closed, and could not be manually opened when required.

General Comments

GPR blocking devices are unique, and there has been little operating experience with them. In the event that they are found to be required, a special effort should be placed on the design, testing, and manufacturing of these devices to ensure good reliability performance. However these devices do represent an additional element, the misoperation of which may result in forced outages and reduced overall reliability.

Further Investigation

Based on the results obtained for the KIN site, it was decided that no further simulations would be undertaken at the remaining potential electrode sites since it is not expected that lower GPR values will be obtained at the observation points for any of the remaining proposed sites.

Also, considering the results of the earlier WTO DC1110 electrode study [8] where the GPR levels at the converter station were found to be in the range of 85V for a sea electrode located in Lake Melville, it is not expected that a shore electrode on Lake Melville would produce low enough GPR values at the observation points to avoid the need for mitigation measures. Therefore, a shore electrode was not considered.

Given the trends in GPR values observed, it is expected that the actual soil conditions would have to be significantly different than those used in this study to result in GPR values at the observation points which are in the range not requiring mitigation measures.

Given the results of the WTO DC1110 electrode study [8] which found that a sea electrode located in the Strait of Belle Isle would have no impact on the Gull Island converter station, it is proposed that consideration be given to investigating potential locations for a shore or pond electrode within the Strait of Belle Isle.

Based on the experience of the Hydro Quebec – New England link related to geomagnetically induced currents (GIC) [6] it is proposed that information on past GIC events that have occurred in the Labrador and Newfoundland systems be gathered and an evaluation of the potential need for GIC mitigation measures be undertaken for the LCP. Although the mitigation measures, if required, would include blocking devices in the transformer neutrals, these devices would only be required to block currents under GIC event conditions which occur infrequently, unlike ground return operation which may occur continuously. As such, the potential impact of their misoperation is substantially less.

Conclusions

Based on the results of this study, it is concluded that none of the proposed electrode sites identified in Labrador will result in GPR values which do not require mitigation measures at the Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, and the town of Happy Valley-Goose Bay. Furthermore, mitigation measures may also be required at remote substations, including Churchill Falls.

It is therefore recommended that additional investigations be undertaken by NE-LCP to consider potential locations for a shore or pond electrode along the Strait of Belle Isle if it is desired to avoid the need for mitigation measures to account for the impacts of high GPR values resulting from ground return operation with a land electrode.

References

1. "HVDC Ground Electrode Design, EPRI EL-2020, Project 1467-1, August 1981.
2. E.W. Kimbark , "Direct Current Transmission, Vol. 1", Wiley Interscience, 1971
3. Labrador Electrode Sites, Ground Potential Simulation, Suggested Models, AMEC, July 2009.
4. General Guidelines for the Design of Ground Electrodes for HVDC Links, CIGRÉ Working Group 14.21 – TF2, July 1998.
5. R.N. Nayak, R.P. Sasmal, S.Sen, B. Pelly, P. Riedel, "Experience with Blocking Devices DUrign Monopolar Operation of +/-500kV, 2000MW Talcher-Kolar HVDC System in India", Paper presented at the Cigre Session 41, Paris, France, Sept. 2006.
6. L. Bolduc, M. Granger, G. Pare, J. Saintonge, L. Brophy, "Development of a DC Current-Blocking Device for transformer Neutrals", IEEE Transactions on Power Delivery, Vol. 20, No. 1, January 2005.
7. M. O'Brien, M. Zavahir, M. Clark, D. Boyle, P. Milosevic, "New Zealand Bipolar HVDC Erath/Sea Return Operation – Environmental Experiences", Paper presented at the Cigre Session 41, Paris, France, Sept. 2006.
8. WTO DC1110 Electrode Review Gull Island and Soldiers Pond, Final Report, March 2008.

BWM/PK:bwm

Appendix L

Project Memo

Analysis of Shoreline Pond Electrode in Lake Melville

Project Memo

January 25, 2010

TO: Peter Kuffel FROM: Ben McLeod

cc: Donald Gordon
Terry Treasure
Calvin Miles
Hugh Miller

Nalcor Energy – Lower Churchill Project
WTO DC1250

Analysis of Shoreline Pond Electrode in Lake Melville

Introduction

During the DC1250 working session meetings in June 2009, Kinriakak Point was identified as a candidate site for either a land electrode in the bog adjacent to Lake Melville or a shoreline pond electrode inside Lake Melville. As part of the electrode studies, land electrode simulations for the Gull Island converter station were performed at several candidate sites in mainland Labrador. The ground potential rise (GPR) values observed at the locations of planned and existing infrastructure were unfeasibly high, requiring mitigation measures for local and remote infrastructure. Given the poor results found in the case of the land electrode at Kinriakak Point, it was anticipated that a shoreline pond electrode configuration in the same vicinity and with the same current rating would not produce significantly better results; an analysis was undertaken to verify this.

This memo presents the results of electric field simulations and analysis conducted to investigate the viability of a shoreline pond-type electrode near Kinriakak Point.

Analysis

Lake Melville is a finite volume embedded in a vast body of high resistivity bedrock, therefore the benefit of its comparatively low resistivity on resulting GPR values will be negligible due to the dominance and abundance of the surrounding high resistivity granitoid. In addition, the exposure to the sea at Kinriakak Point via Lake Melville is limited since the expanse of water for an inland shoreline pond electrode is poor compared to that of a shoreline pond electrode located on the coast, directly exposed to the open sea. Moreover, the low resistivity influence of Lake Melville will only noticeably improve GPR values locally whereas remote GPR's will remain relatively unchanged. Given the large distance between the electrode and the locations of interest, the GPR values at these points will not improve considerably.

Different electrode configurations will impact GPR values locally; however the electric field profiles will converge radially from the electrode site long before reaching any of the locations of interest.

Therefore, the difference in GPR values for a shoreline pond configuration versus a land configuration at a given point will become less as one moves away from the electrode.

Modeling Scenarios

Lake Melville was modeled as a single volume. Its surficial expanse was represented conservatively and its volume was represented very conservatively, assuming a uniform depth of 100 m and disregarding the slope in the bed of the lake.

The salinity of Lake Melville is anticipated to be low at shallow depths (4-5 m). In order to gain insight into the sensitivity of the resistivity of the lake, a combination of varying Lake Melville models (1 layer vs. 2 layer) and granitoid resistivities (10,000 Ωm vs. 5,000 Ωm) were considered:

Table 1: Lake Melville Modeling Scenarios

Scenario	1A	1E	2A	2E
Lake Melville - Shallow				
Resistivity (Ωm)	0.2	0.2	25	25
Thickness (m)	5	5	5	5
Lake Melville - Deep				
Resistivity (Ωm)	0.2	0.2	0.2	0.2
Thickness (m)	95	95	95	95
Surficial				
Resistivity (Ωm)	50	50	50	50
Thickness (m)	50	50	50	50
Double Mer				
Resistivity (Ωm)	2000	2000	2000	2000
Thickness (m)	2000	2000	2000	2000
Granitoid				
Resistivity (Ωm)	10000	5000	10000	5000
Thickness (m)	infinite	infinite	infinite	infinite

An electrode configuration consisting of 75 high silicon cast iron elements spaced 2 m apart in a linear array was assumed. The electrode design was based on the calculated operating duty and the preliminary design established for the shoreline pond electrode at Dowden's Point. The electrode was located 30 m inside the shoreline and the resistivity of a breakwater structure was ignored which will produce optimistic results.

Simulation Results

The following Table 2 compares the results of a shoreline pond electrode near Kinriakak Point with GPR values of the land electrode simulations previously carried out at Kinriakak Point.

Table 2: Comparison of GPR's for Shoreline Pond and Land Electrodes at Kinriakak Point

Ground Potential Rise (V)						
	Center of Electrode	Gull Island Conv. Station	Gull Island Gen. Station	Muskrat Falls Gen. Station	Happy Valley-Goose Bay	Churchill Falls
Kinriakak Point (KIN)						
Shoreline Pond Electrode						
Scenario						
1A	210.59	29.06	28.44	51.02	79.40	13.12
1E	113.88	14.35	14.05	25.02	38.21	6.55
Shoreline Pond Electrode						
Scenario						
2A	650.81	31.19	30.48	61.96	100.70	14.22
2E	689.11	14.51	14.20	25.12	39.00	6.50
Land Electrode						
Scenario						
A	512.60	30.93	30.22	55.39	92.63	13.20
E	443.10	15.02	14.69	26.25	42.11	6.54

The difference in GPR results observed at the locations of interest for a shoreline pond electrode and those for a land electrode at Kinriakak Point is marginal. In the most likely case of the high resistivity bedrock (10,000 Ωm granitoid in Scenarios A), the GPR values at most locations of interest are greater than 30 V, indicating the need for mitigation [1]. Even in the optimistic case of low resistivity bedrock (5,000 Ωm granitoid in Scenarios E), mitigation measures would be required at Happy Valley-Goose Bay due to high GPR values.

Ground potential rise contour plots for Scenarios 1A and 1E for the shoreline pond electrode in Lake Melville are shown below in Figure 1 and Figure 2, respectively (Note: The position of the GPR contours is limited in accuracy).

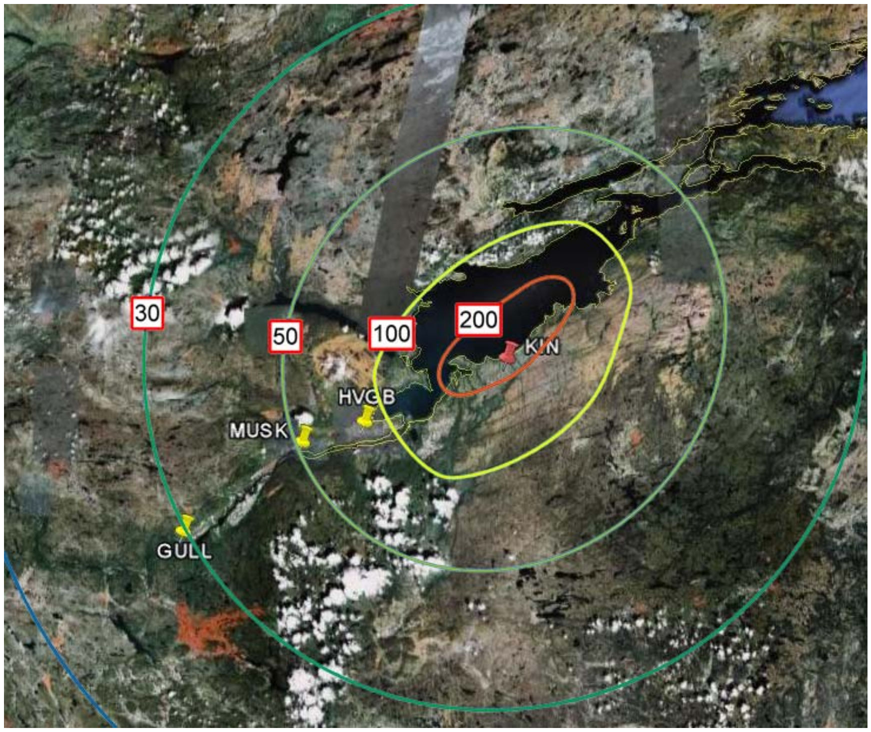


Figure 1: GPR Contour Plot for Shoreline Pond Electrode at Kinriakak Point, Scenario 1A

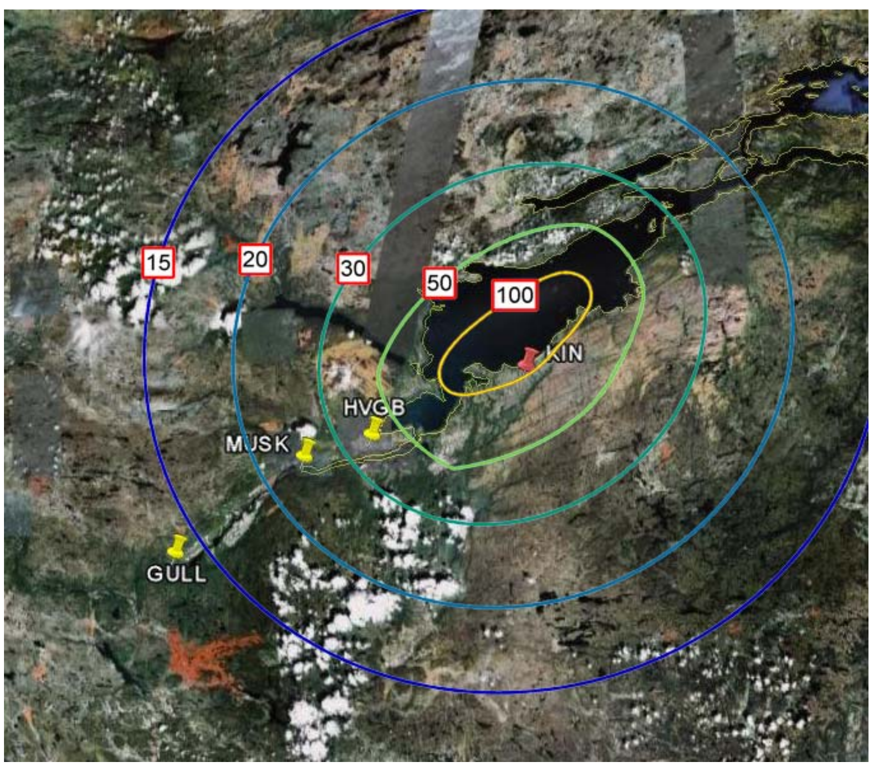


Figure 2: GPR Contour Plot for Shoreline Pond Electrode at Kinriakak Point, Scenario 1E

Conclusions

Based on the results obtained, it was found that the proposed shoreline pond electrode site at Kinriakak Point will result in GPR values (>30 V in most scenarios) which require mitigation measures at the existing and planned infrastructure locations of Gull Island converter station, the Gull Island generating station, the Muskrat Falls generating station, and the town of Happy Valley-Goose Bay. Mitigation measures may also be required at remote stations, including Churchill Falls. Furthermore, the high GPR values would complicate the development of any future infrastructure within a large radius of the electrode. Therefore, it is concluded that a shoreline pond type electrode in Lake Melville is not a viable option for the Gull Island converter station.

It was indicated to NE-LCP that consideration be given to locating a candidate site for a shoreline pond electrode in the SOBI.

References

1. CIGRÉ Working Group 14.21 – TF2, "General Guidelines for the Design of Ground Electrodes for HVDC Links", July 1998.

BWM:bwm

Appendix M

Project Memo

Electrode Review – Dowden’s Point

HATCH™

Project Memo

November 25, 2009

TO: Pete Kuffel

FROM: Rauf Ahmed, Ben McLeod

cc: Don Gordon
Terry Treasure
Calvin Miles
Hugh Miller

Nalcor Energy – Lower Churchill Project
WTO DC1250

Dowden's Point HVdc Electrode Simulations and Preliminary Infrastructure Impact Analysis

Introduction

As part of the electrode review currently underway for the Lower Churchill Project (LCP), a panel of experts was assembled by Nalcor Energy – Lower Churchill Project (NE-LCP) to identify and evaluate the viability of alternate ground electrode sites and designs for the Gull Island and Soldiers Pond converter stations. Previously in the report "DC1110 – Electrode Review – Gull Island & Soldiers Pond", sea electrodes in the Strait of Belle Isle and Conception Bay were identified as viable options. The panel had identified an alternate site for a shoreline pond electrode on the Island of Newfoundland at Dowden's Point, a location on the south shore of Conception Bay between Lance Cove Pond and Seal Cove. The Dowden's Point shoreline pond electrode will provide a ground return path for the Soldiers Pond converter station during monopolar operation.

Preliminary investigations to better identify the geological conditions at the site were undertaken and existing infrastructure in the vicinity of the potential electrode site was identified by Nalcor Energy.

This memo presents the results of electric field simulations and analysis conducted to investigate the viability of a shoreline pond electrode at Dowden's Point and to evaluate its potential impact on the known existing infrastructure within the vicinity of the electrode and remote facilities having conductive connections with infrastructure in the vicinity of the electrode.

Electrode Duty and Design

The proposed LCP multi-terminal HVdc transmission system will interconnect the Gull Island terminal in Central Labrador, with the Soldiers Pond and Salisbury terminals on the Island of Newfoundland and in New Brunswick respectively using overhead transmission lines and submarine cables for crossing the Strait of Belle Isle and Cabot Strait. The current carrying requirements for these terminals are shown in Table 1.

Table 1: Monopolar Current Duties			
	Gull Island	Soldiers Pond	Salisbury
Nominal current (A)	1780	890	890
Maximum continuous current (A)	2320	1340	980
Maximum 10-minute overload (A)	2760	1780	980

Electrode Design Duty

In general terms, the electrode duty is based on the anticipated pole outage rates which result in the need for monopolar operation of the HVdc system, load factors and planned operating modes of the HVdc transmission system. A preliminary design duty for the Soldiers Pond electrode was calculated based on the specified electrode currents and a pessimistic estimate of pole outages, load factors and HVdc system modes of operation.

The electrode duty is estimated based on the following parameters:

- The current ratings are 1340A (1.5 times the nominal current rating of 890A) in continuous monopolar operation and 1780A (2 times the nominal current rating of 890A) in monopolar operation for 10 minutes.
- The time period for determining permissible loss of material from electrolytic corrosion caused by electrode operation is assumed to be 40 years.
- In order to consider worst case conditions, the load factor is assumed to be 100%. The actual load factor is contingent on the load demand and will be less than 100%.
- A complete loss of the cables within one pole across the Strait of Belle Isle is considered to occur once in 40 years from an electrical failure or a mechanical damage and will result in the need to operate monopolar, electrode return for one year at the continuous current of 1340A.
- A scheduled pole outage rate of 0.5% is considered based on published data of existing HVdc systems. It is further assumed that prior to a scheduled outage, the dc power will be reduced to 600MW so that when entering monopolar operation the resultant electrode current will be 1340A. It is expected that many of the scheduled pole outages will use the transmission line conductors of the out-of-service pole as a metallic return path, with the result that electrode current will be zero. However, as a conservative design, it is assumed that the electrode will operate as an anode or cathode with 1340A for 70% of the scheduled outage time.
- A forced pole outage rate of 0.25% is considered based on published data of existing HVdc systems. It is further assumed that prior to a forced outage the dc power will be 800MW so that when entering monopolar operation the resultant electrode current will be 1780A. In order to consider worst case conditions, electrode operation will continue at the 1780A level for the entire duration of the forced outage. This assumes that there will be many short duration forced

outages, each lasting less than 10 minutes, allowing operation at 1780 A, and the sum total duration of all forced outages will be 0.25%.

- In steady-state bipolar operation, a continuous imbalance current of 10A is assumed – a value greater than the industry accepted maximum imbalance of +/-1% of the nominal current (+/- 8.9A for Soldiers Pond).
- During the installation and commissioning period, when only one pole of converter equipment may be available, the system will operate monopolar, metallic return.

The design duty of an electrode is measured in terms of ampere-hours of service during the design life. Table 2 shows the calculation of the Soldiers Pond electrode duty based on the above assumptions.

Table 2: Soldiers Pond Electrode Duty

Description	Anodic Operation Duty (Ah)/40 yr	Remarks
Scheduled outages	1,643,376	0.5%*70%*8760 h/y*1340A*40y
Forced outages	1,559,280	0.25%*8760 h/y*1780A*40y
Continuous imbalance	3,504,000	10A*8760h/y*40y
Duty during cable outage for one year	11,738,400	1340A*8760h/y
Total Duty over 40 year life cycle	**18,445,056**	18.45 million ampere-hours

The electrode design and its impact on infrastructure will be assessed assuming the above duty in both anodic and cathodic operation.

A very pessimistic operation of the HVdc link was considered to establish the Soldiers Pond electrode duty. As seen in Table 2, a significant portion of the calculated electrode duty is due to the continuous imbalance in bipolar operation which can be minimized through control algorithms. A safety factor is not considered in the electrode duty calculation given the pessimistic parameters used in establishing the duty. The electrode duty needs to be reviewed based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation.

Electrode Design

A preliminary basic design of the shoreline pond electrode was carried out based on the calculated duty and a safe voltage gradient of 1.25V/m for fish, invertebrates and humans in sea water [5, 7, 8]. Sensitivity to an electric field varies for different species and depends on the size and weight of the animal; the body shape and electrical resistance; the resistivity of the water; the type of current; and the electric field configuration. Typical reactions to an electrical field include attraction, narcosis, convulsions (tetanus), and death. Published literature indicates that fish might be attracted to an anode at 5V/m, tetanus could occur at 20V/m and mortality is possible at 50V/m. An average human may feel discomfort at a voltage gradient of 2.5V/m in sea water. A value of 1.25V/m is selected as safe design value [5, 7, 8].

Figures A-1 and A-2 in Appendix A show the location, plan and section of the proposed electrode in a man-made shoreline pond. It consists of the fifty (50) high silicon cast iron electrode elements each capable of 30A continuous discharge. The shoreline pond size of 102m(L)x20m(W)x4m(D) is selected to accommodate the electrode elements at a typical spacing of 2m and to satisfy a voltage gradient of 1.25V/m on the sea side of the breakwater barrier. The details of the electrode design basis are included in Appendix A. The breakwater barrier is tentatively selected considering the operational requirement of access and electrode installations. The design shall be verified for structural integrity during the detailed engineering stage.

The calculated voltage gradient at the surface of electrode is 6.56V/m and drops to an acceptable level of 1.25V/m at a distance of 0.5m from the electrode element surface assuming the elements carry equal currents. Some measures will be required to limit public access to the electrodes. The design does not take into account the current imbalance among the electrode elements. Typically the elements in the middle carry less current than the end elements if uniformly spaced. This aspect shall be studied during the detailed engineering stage to establish an optimal current distribution among the electrode elements and to adjust the shoreline pond dimensions if required.

Electrode Simulation Results

The Ground Electrode (GRELEC) software developed by Teshmont Consultants was used to calculate the ground potential rise (GPR) values for the Dowden’s Point electrode. GRELEC calculates the GPR values and gradients for a given current injection and soil model and is suitable for the analysis of a shoreline pond electrode installation. The electrode was simulated in GRELEC as a conductive body with a soil model developed based on the preliminary electrode design, anticipated geological soil properties found during site investigations [4], bathymetric data for the Conception Bay area, and approximate sea depths far from the electrode location. The resultant GPR values produced by GRELEC were then used with the Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis (CDEGS) software develop by SES Engineering to assess the potential impacts on the identified infrastructure.

The soil model used was based on modelling scenario #2 identified in the report “Dowden’s Point Electrode Ground Potential Simulation Suggested Models” included in Appendix H as the most likely scenario. The resistivity data for the soil designated as Surficial–Glacio Marine Top, Middle and Lower in Appendix H in the immediate area of Dowden's Point was based on the field work conducted in September 2009. The sea water was assigned a resistivity of 0.2Ωm, a standard textbook value for seawater. All other resistivities were assigned based on an analysis of the rock types involved and experience with these units in the Avalon Peninsula area. A calculated soil resistivity value of 1.5Ωm was used for the breakwater assuming a conservative void ratio of 19.3%. The electrode itself was modeled as a conductive body of very low resistivity (0.01Ωm) with an average width of 20m, depth 4m and length 100m, representing the shoreline pond with the 50 electrode elements distributed along its length.

Modeling the electrode as a conductive body does not provide representative GPR distributions within the shoreline pond, however, does provide GPR distribution outside the shoreline pond and breakwater. The GPR values for various locations used in the impact analysis are based on the simulation results.

Figure 1 shows the ground potential rise contours in the vicinity of the electrode based on simulations. These contours would be expected to be smooth. The contour configuration with abrupt changes as presented in Figure 1 arises from the interaction of the complexity of the soil model, the dimensions and configuration of the grid used in the simulation calculations, and the algorithm used for generating the contours. The purpose of the simulation was to assess the scale of the GPR's at various distances and specific locations for use in further analysis of the impact of such GPR's and the associated gradients.

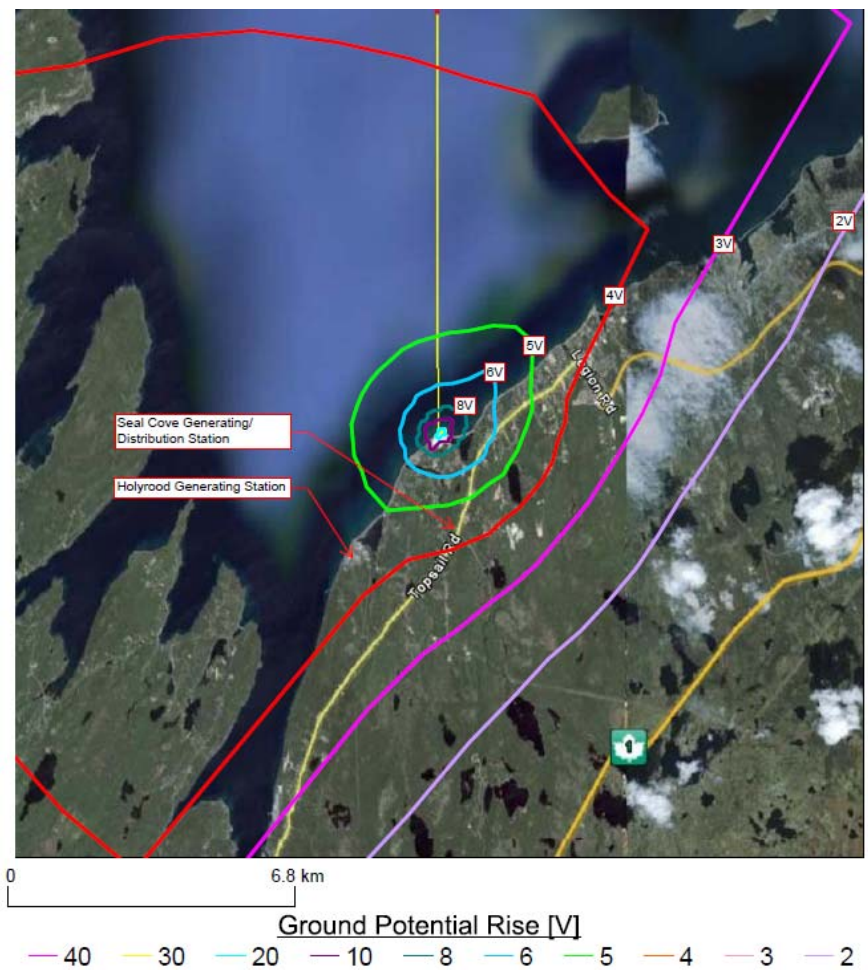


Figure 1: GPR Contours for Dowden's Point Electrode Monopolar Operation

Figures B-1 through B-4, in Appendix B show the electrode model and detailed simulation results of GPR contours around the electrode location. The maximum voltage at the electrode location is of the order of 45V and the voltage falls off rapidly inland. The GPR at a distance of 1000m inland is approximately 6.5V. The voltage along the shore line drops off gradually due to the conductive body of sea water and therefore the zone of the electrode influence extends farther along the shoreline and also to the north side of Conception Bay. It must be noted that the exact boundary between the sea and the land is not represented in detail in the soil model and therefore the resultant voltages obtained inland along the shore will be pessimistic.

Table 3 shows the simulated GPR values at the locations of interest in the zone of influence.

Table 3: GPR Values at Locations of Interest

Description	GPR Value (V) Note 1	Remarks
Holyrood Generating and Terminal Station (HRD)	4.5	2.6km from electrode
Seal Cove Generating and Distribution Station (SCV)	4.0	2.23km from electrode
Distribution Pole closest to the Electrode	6.5	
Bay Roberts Station (BRB)	3.0	On the north side of Conception Bay
Kelligrews Station (KEL)	4.0	6.0km from electrode
Hardwoods Station (HWD)	0	Assumed
Oxen Pond Station (OPD)	0	Assumed
Western Avalon Station (WAV)	0	Assumed

Notes:

- The positive GPR values in the table are for the HVdc ground electrode in anodic operation; the values will be negative for cathodic operation.

Actual GPR values will depend on the location of electrode and the above values are for the assumed location near Lance Cove. Determination of acceptable GPR values depends on the impact on environment and infrastructure which must be evaluated on a case-by-case basis. In the sea water, the preliminary electrode design results in a GPR gradient of less than 1.25V/m therefore no adverse impacts are expected. The potential impacts of the resultant GPR values on infrastructure will determine if the proposed electrode is acceptable. Absolute GPR values at locations of interest do not necessarily determine whether infrastructure will be affected; rather, the GPR difference across the expanse of the infrastructure must be examined on a case-by-case basis to analyze the presence of dc stray currents.

Infrastructure Impact Assessment and Potential Mitigation Measures

This section presents a review of the infrastructure in the vicinity of the HVdc electrode and describes how the infrastructure was modelled for the impact assessment including the assumptions made to develop the model. The infrastructure models were analyzed using the CDEGS software module MALZ by modelling equipment and circuits as resistance elements. GPR values at various locations as determined from the electrode simulations using GRELEC were used for energization of the infrastructure models. Permissible limits for dc stray currents were also identified where applicable. The models shall be refined during the detailed engineering stage based on information collected through the field program and more detailed electrode simulation results.

Appendix C lists the known infrastructure in the vicinity of the HVdc ground electrode as identified by Nalcor [1].

The infrastructure that may be affected by corrosion or may have operational issues due to dc stray currents includes:

- Local structures including station grounding grids, well casings, transmission line tower grounding systems, and distribution line grounds dissipating dc stray currents into ground,
- Distributed immersed structures and ground electrodes having conductive connections such as transmission poles connected via a skywire, two facilities bonded by a pipeline, and pole grounds of a multi-grounded distribution system connected via a distribution neutral,
- Equipment such as power transformers and distribution transformers providing conductive connections between local grounding grids and remote stations via transmission and distribution circuits.

The infrastructure at a station including the station grid and conductive connections between the remote installations and station grid, form a common interdependent network. The values of dc current in the various elements of this network depend on the connections among various elements. For a conservative estimate of dc stray currents, various elements of network are analyzed independently without factoring in the impact of common elements (e.g. station grid resistance and auto transformer common windings). This approach will produce pessimistic results. The connections among the remote terminal stations and infrastructure are also ignored in the analysis where these connections will have a minor impact on dc stray currents.

The infrastructure farther away along the shore is not considered in this analysis but should be investigated during the detailed engineering stage.

Holyrood Generating Station and 230 kV Transmission Station

The known structures and conductive connections identified by Nalcor [1] at the Holyrood generating and transmission station together with its connections to the remote station and facilities are reviewed in the following sections.

Local Structures

The impact on the local grounding, foundation rebar and anchors, and buried conductive objects depends on the expanse of the generation and transmission line facility and GPR gradients. Typically the grounding grid of a facility creates a uniform potential plane for the facility and the impact on the foundation steel, fences (if bonded to grounding grid), and above ground conductive structures within the facility is negligible and is not of concern. Any buried metallic structure extending below the grounding grid (e.g. well casing or structural steel bonded to the grounding grid) or extending outside the grounding grid limits but not connected to the remote structures can dissipate a significant amount of current under cathodic operation of the HVdc electrode, and these structures should be identified and analyzed during the detailed engineering stage.

The estimated current through the conductive connection of the ground grid to remote earth from the GPR gradients caused by the operation of the HVdc electrode was found to be approximately 4.627A, consisting of 0.185A from the skywires, 4.082A from the 230 kV system and 0.360A from the 69 kV system. The 138 kV system does not contribute any current, rather it forms a parallel path and sinks part of the current collected by the 230 kV system during cathodic operation of the HVdc electrode and contributes current for the 230 kV remote end dissipation during anodic operation of the HVdc electrode. The loss of grounding grid copper is estimated to be 75.36kg resulting from this current over the life cycle of the electrode in cathodic operation. The generating facility is roughly 600m wide and 680m long and is expected to have a large ground grid. The size of grid and amount of copper should be verified along with the loss of material during detail engineering in order to define maintenance requirements and a replacement schedule of the grounding grid if necessary.

The allowed percentage loss will depend on the age and condition of the grounding grid. A loss of 10% of material for a new grounding grid is not of concern. A typical problem is point corrosion of bonded copper ground rods and grounding connections. Monitoring of the grounding grid and regular replacement as required should be implemented to ensure the integrity of grid system even if loss of material is acceptable for the electrode duty.

Conductive Connection of the Facility to the Remote Earth

The transmission line skywires and above ground fuel transfer pipeline of length 1.26km provide conductive connections with the transmission station and generating station.

230 kV Line Skywires

The skywires are strung on the TL217(WAV), TL218(OPD) and TL242(HWD) lines for a distance of only 1.6km from the transmission station. The potential difference between towers will result in dc stray current in the skywires. This dc current will cause corrosion of the steel grillage foundation for steel towers, the retaining plate of wood structures, the guywire anchors (if applicable), and the tower footing grounding system. Normally the foundation steel, guywire anchors and tower footing grounding system form a parallel circuit and the tower stray current will not divide between the foundation steel, anchors and grounding system equally. An approximation of the current division would be in proportion to the surface area in contact with soil.

The tolerable loss of steel during the life of foundation will depend on the age of the foundation, area of foundation steel in contact with earth, and the safety factor used in the design. As a conservative estimate it is assumed that a 1% loss over a 40 year life would be acceptable. A higher loss is acceptable if a higher design margin is used. In case only foundation anchors are in contact with the soil, the loss of anchor material needs to be considered. The guywire anchors are normally designed with a higher design margin of 3 or 4, therefore it is assumed a loss of 10% of anchor material is acceptable. The grounding system is effective even if 50% of the rod or counterpoise material is lost.

The highest dc stray current will flow through the tower footing farthest away from the station and therefore permissible dc stray current through the steel foundation, guywire anchors and tower grounding system is compared with 100% value of the current at this tower footing.

The permissible loss of material for foundation steel, guywire anchors and grounding grid was estimated. Based on the electrode duty, the corresponding maximum permissible dc stray currents were then calculated. These values along with the calculated dc stray current values based on simulation results are summarized in Table 4.

Table 4: 230 kV Tower Footing Permissible Material Loss and dc Stray Current

Description	Permissible Loss of Material (kg)	Permissible dc stray Current (A)	Calculated dc Stray Current (A)	Remarks
Foundation Steel	6.00[Note 1]	0.419	0.048	1% of 600kg steel foundation
Guywire Anchors	1.78	0.124	0.048	10% of two (2) steel anchors, each 22mm dia. and 3m long.
Grounding System	7.57	0.465	0.048	50% of two (2) copper rods, each 19mm dia. and 3m long.

Notes:

2. The permissible material loss of foundation steel will apply in the case where only the foundation steel is in contact with soil.

Details of the model, permissible material loss over the life cycle of the electrode in operation as an anode, and simulation results of the skywire network are included in Appendix D.

As seen in Table 4, the actual stray currents are less than the acceptable dc stray currents. The calculated loss should be verified based on the actual foundation steel, guywire anchors and structure grounding arrangement during the detailed engineering stage.

The 230 kV line TL218 is of wood pole construction with the poles supported on bearing plates. The pole grounding system consists of five turns of grounding wire wrapped around the buried section of the pole and its bonding to the bearing plate. The bearing plate is 6mm thick and needs to be reviewed for acceptable loss of material.

If corrosion of the foundation steel for a steel tower, the bearing plate for a wood pole or guywire anchors is deemed to be a concern, a proven mitigation measure is to insulate the skywire connection to the station and sectionalize it along the transmission line with low voltage insulators. The low voltage insulators would spark over in the event of a lightning strike. Additional items like arcing horns across the low voltage insulators can be added to improve flash over reliability.

138 kV and 69 kV Lines

The lines are without skywires and conductive interference with structure foundations does not apply.

Above Ground Fuel Transfer Pipeline

The existing 18 inch main line between the generation station and storage facility and the 16 inch branch lines to the tanks at the storage facility are of carbon steel construction with 3/8 inch wall thickness and are insulated by a mineral-insulated fibre over its entire length. A heat tracing system is employed over the length of the pipeline to guard against freezing. The flow of current through the pipeline needs to be reviewed considering the grounding and bonding arrangement at the ends, and fuel terminal safety requirements. Corrosion along the pipeline run is not an issue since it is insulated.

The voltage across the two ends of the pipeline will be small since it runs parallel to the shoreline where the voltage gradient is low.

If the current flow through the pipeline is deemed a concern, the connection to the generating station can be insulated using an insulation flange or section if the pipeline provides conductive connections between the two facilities. The insulation of the pipeline into sections is a common practice for cathodic protection to insulate the cathodically protected sections from non-protected sections. Another mitigation measure could include adding or modifying cathodic protection to the pipeline.

Conductive Connection of the Facility through Equipment

The 230 kV, 138 kV, 69 kV and distribution phase conductors provide a connection through the facility equipment since the equipment phases are arranged in wye grounded configuration at the local and remote ends, and the equipment neutrals are tied to the facility ground grid.

230 kV System

The dc current flowing through the neutral of a power transformer due to GPR by an HVdc ground electrode can be quantified by analyzing the dc equivalent circuit of transmission line phase conductors connecting various stations, station ground grids and transformer windings. A dc current level in excess of 1.5 times that of the excitation current [2] can cause operational problems.

Appendix E shows the equivalent circuit formed for the 230 kV system connecting the Holyrood transmission station 230 kV transformer windings with the remote Western Avalon, Oxen Pond, and Hardwoods stations. The 230 kV windings of all transformers at Holyrood station except T5 and T10 provide a path to the remote stations.

The permissible limits and calculated dc stray currents in the transformer windings and transformer winding dc resistance for transformers installed at Holyrood, Western Avalon, Oxen Pond and Hardwoods transmission stations are shown in Table 5. Detailed calculations are provided in Appendix E.

Table 5: Permissible and Calculated dc Stray Currents for 230 kV Transformers

Transformer Designation/Base Ratings	Transf. Winding dc Resistance Note 1 (Ω)	Permissible 1-Ø Limit of dc Current Note 2 (A)	Calculated 1-Ø Stray dc Current (A)	Remarks
HRD_T1/180MVA	0.687	0.678	0.412	Acceptable
HRD_T2/115MVA	1.002	0.722	0.282	Acceptable
HRD_T3/100MVA Note 3	1.207	0.64	0.234	Acceptable
HRD_T6/25MVA	5.284	0.094	0.051	Acceptable
HRD_T7/25MVA	5.568	0.094	0.051	Acceptable
HRD_T8/75MVA	0.862	0.282	0.328	Less than 2x excitation current
WAV_T1/15MVA	13.90	0.094	0.012	Acceptable
WAV_T2/15MVA	14.31	0.094	0.012	Acceptable
WAV_T3/25MVA	5.645	0.094	0.030	Acceptable
WAV_T4/25MVA	5.569	0.094	0.030	Acceptable
WAV_T5/75MVA	0.870	0.282	0.194	Acceptable
OPD_T1/40MVA	3.171	0.251	0.083	Acceptable
OPD_T2/75MVA	0.856	0.471	0.309	Acceptable
OPD_T3/75MVA	1.530	0.471	0.173	Acceptable
HWD_T1/40MVA	3.861	0.251	0.092	Acceptable
HWD_T2/40MVA	3.547	0.251	0.100	Acceptable
HWD_T3/40MVA	4.025	0.251	0.088	Acceptable
HWD_T4/75MVA	1.516	0.471	0.235	Acceptable

Notes:

4. The dc resistance is based on nameplate load loss data provided by Nalcor. The split of the resistance is proportional to the square of the voltage ratio for two-winding transformers, as per typical industry practice.
5. Industry accepted values of the excitation current % of the rated base (OA) transformer rating current is typically less than 0.5% of rated current at base MVA for two/three winding transformers and 0.3% for auto transformers.
6. Transformer base rating calculated from OFAF rating of 170MVA.

As seen in Table 5, the calculated dc stray current levels at Holyrood generating station through the transformer windings are less than the tolerable limits, except for T8; the value of dc stray current is greater than 1.5 times the excitation current but less than 2 times the excitation current, the level at which transformer performance may be compromised [2].

The actual excitation current values, transformer core construction and permissible dc current values should be confirmed during the detailed engineering stage to verify the typical values used. Typically a higher level of dc stray current is tolerable for a three-limb core-type three-phase transformer than a shell–type, three-phase transformer or a single-phase transformer design [6]. The excitation current values can be confirmed either by contacting the transformer manufacturer or from test reports (if available). The acceptable stray dc current levels should also be confirmed by the manufacturers.

The dc stray currents of the magnitudes indicated in Table 5 will cause limited half cycle saturation of transformer cores which would result in additional harmonics on the system. The impact of this distortion on generator units, capacitors and filters should be reviewed and analyzed during the detailed engineering stage.

138 kV System

The 138 kV windings of 230/138 kV auto transformers T6, T7 and T8 at Holyrood transmission station provide limited connectivity to the remote station as there is only one wye grounded transformer at Bay Roberts station.

The data for the 138 kV network model and results are shown in Appendix E. Although the GPR at Holyrood (4.5V) is greater than the GPR at Bay Roberts (3V), the current in the 138 kV system does not flow from Holyrood to Bay Roberts. Instead, Bay Roberts contributes current that is sunk into the remote 230 kV network (Western Avalon, Oxen Pond and Hardwoods) via the 230/138 kV auto transformers at Holyrood because the GPR at Bay Roberts is relatively higher than the GPR at the remote stations (each considered to be 0V). The current injected at Bay Roberts station is 0.132A (0.044A per phase). This 0.044A per phase current is distributed among the three auto transformers T6, T7 and T8 and its contribution is negligible.

The loss of grounding grid material at Bay Roberts will depend on the current calculated there and the current dissipated through the local distribution neutral. It is expected that this will be a small loss of material for the substation grounding grid.

69 kV System

The 69 kV windings of 230/69 kV delta/wye grounded transformers T5 and T10 provide a path to the remote Newfoundland Power Seal Cove and Kelligrews stations. The model of the network used in the analysis is included in Appendix E.

Table 6 shows the transformer winding dc resistance and permissible dc stray current values used in the analysis along with the calculated stray dc current values.

Table 6: Permissible and Calculated dc Stray Currents for 69 kV Transformers				
Transformer Designation/Base Ratings	**Transf. Winding dc Resistance** Note 1 **(Ω)**	**Permissible 1-Ø Limit of dc Current** Note 2 **(A)**	**Calculated 1-Ø Stray dc Current (A)**	**Remarks**
HRD_T5/15MVA	1.065	0.188	0.060	Acceptable
HRD_T10/15MVA	1.065	0.188	0.060	Acceptable
KEL-T1/11.25MVA	1.639	0.141	0.050	Acceptable
SCV-T1/2.5MVA	15.217	0.031	0.007	Acceptable
SCV-T2/11.20MVA	1.654	0.141	0.064	Acceptable

Notes:

3. The dc resistance is based on nameplate load loss data. The split of the resistance is proportional to the square of the voltage ratio for two-winding transformers, as per typical industry practice.
4. Industry accepted values of the excitation current % of the rated base (OA) transformer rating current is typically less than 0.5% of rated current at base MVA.

As seen in Table 6, the actual stray current values are less than the tolerable limits.

The actual excitation current values and the permissible dc current should be confirmed during the detailed engineering stage to verify the typical values used. The excitation current values can be confirmed either by contacting the transformer manufacturer or from test reports (if available). The acceptable stray dc current levels should also be confirmed by the manufacturers.

Suitable mitigation measures, if required, include the addition of neutral grounding resistors (if feasible) or the replacement of the transformer with a higher capacity unit.

16kV System, Plant Distribution and Holyrood Substation

The generator supplies the 16kV delta connected windings of the transformer and therefore a path for dc stray path is not available through the generator windings. The impact of half cycle saturation of the 230/16kV transformer units and its impact on the generator units should be investigated during the detailed engineering stage. The 2400V, 600V and 120/208V plant distribution circuits are local and will not be impacted by dc stray current.

The only external distribution link is through Holyrood substation transformer T1 (69-2.4/4.16kV) and may have issues if the link is supplying power during electrode operation. Information provided indicates that the external supply is required only if the plant supply is lost and therefore it was assumed that the probability of simultaneous electrode operation and requirement of external supply is low, and therefore was not considered in this analysis. This low probability event should be addressed during the detailed engineering stage.

Seal Cove Generating Station and NL Power Substation

The known infrastructure identified by Nalcor at the Seal Cove generating station [1] is analyzed in the following sections.

Local Structures

The above analysis for the Holyrood generating station local structures is applicable for the Seal Cove facility. The site is approximately of size 80mx70m. The estimated current from the local GPR gradient was found to be approximately 1.089A, consisting of 0.211A from 69 kV system and 0.878A from distribution neutral; the current is injected into ground for anodic operation of the HVdc ground electrode. The loss of grounding grid copper resulting from this current over the life cycle of the electrode in cathodic operation is estimated to be 17.73kg. The value is sensitive to the location of the electrode and will change if the location of the electrode is adjusted. The allowed percentage will depend on the age and condition of the grounding grid. A loss of 10% of a new grounding grid shall not be a concern. A typical problem is point corrosion of bonded copper ground rods and grounding connections. The monitoring of the grounding grid and regular replacement as required should be implemented to ensure the integrity of grid system even if loss of material is acceptable for the electrode duty.

Conductive Connection of the Facility to the Remote Earth

The transmission line skywires, distribution system neutral and the 1.2km-long, above ground penstock can provide a conductive connection with the transmission station and generating station.

69 kV Line Skywires

The 69 kV lines (52L from Kelligrews to Seal Cove Generating Station and 38L from Seal Cove Generating Station to Holyrood Transmission Station) are without skywires and therefore stray dc currents are not an issue.

12.47 kV Distribution Neutral

It is assumed that the generating station supplies the local multi-grounded neutral distribution system through the Newfoundland Power 69/12.47 kV substation. The simplified distribution system model and its impact on the distribution substation are analyzed in Section 4.3.

Penstock

Some of the penstock sections are of woodstave construction and it is expected the penstock will not be impacted significantly. The penstock installation, including supports and sections in contact with the earth, need to be reviewed during the detailed engineering stage to quantify the impact of the electrode operation. In the event that adverse impacts are found to exist, potential mitigation measures include isolation of the penstock from the station grid.

Conductive Connection of the Facility through Equipment

The 69 kV and 12.47 kV phase conductors provide a connection through the facility equipment since the equipment phases are arranged in wye grounded configuration at both local and remote ends and the equipment neutrals are tied to the facility ground grid.

69 kV System

The analysis of 69 kV system is included in Section 4.1.3 as part of the Holyrood transmission station analysis. As seen in Table 6, the actual stray current value is less than the tolerable limits and mitigation is not required. The dc stray current levels are sensitive to the electrode location and dc stray current in T2 may become problematic if the distance between the electrode and the station is reduced.

12.47 kV Distribution Transformer

The distribution system and the impact of electrode operation on the distribution substation are analyzed in Section 4.3.

Multi-Grounded Distribution System

The impact of an HVdc ground electrode on a distribution system can be estimated by analyzing the dc equivalent circuit of the multi-grounded neutral, distribution transformers, phase conductors, and distribution station ground grids. Appendix F shows the equivalent network and assumptions made to simplify the network for this analysis.

The current through the substation distribution neutral is critical and depends on the location of the distribution substation relative to the HVdc ground electrode, distribution neutral ground impedance, population of the pole-mounted distribution transformers, and expanse of the distribution network. In general, lower rating pole-mounted distribution transformers are connected phase-to-ground on the HV side. The low side distribution neutral is normally connected to the pole ground and house residential ground electrode; the residential ground electrode will provide a path in parallel with the pole grounds for dc stray currents. The current through the LV side winding can be a concern if the distribution transformer and service entrance are separated by 400m to 500m and one transformer supplies multiple locations. A typical transformer size of 25kVA with a permissible dc stray current limit of 23mA through the transformer was assumed for the analysis. The network was analyzed using the MALZ module in the CDEGS software package.

Results of the analysis show that the highest dc stray current through a transformer winding is 2.4mA, which is less than the permissible limit of 23mA. The highest dc stray current through a distribution neutral ground is 62mA near the electrode location which is less than the permissible current of 0.232A for a 50% material loss of a 19mm diameter and 3 meter long copper ground rod.

In case a smaller size transformer of 5kVA or 10kVA is used and the transformers are located farther apart, the dc stray current may exceed the permissible limits. A detailed review of the existing transformer sizes should be undertaken during the detailed engineering stage and if deemed necessary replacement of smaller units with larger units (25kVA) would provide suitable mitigation. The segregation of HV ground from LV neutral through a spark gap could eliminate some of operational issues with the distribution circuit [5]. This spark gap isolates the distribution neutrals from HV multi-grounded neutrals and increases the dc stray current path resistance. The addition of a spark gap between the HV winding and LV winding neutrals will require separate grounds on the pole for the HV neutral and the distribution neutral.

There may be situations where the dc stray current through a pole ground rod can exceed the permissible limit, especially for poles in close proximity to the HVdc electrode and where large GPR differences exist between the grounded locations. The loss of pole ground rods is not an issue since these can be inspected and replaced as required, and a material loss of 50% for a ground rod is acceptable.

Bridges, Other Infrastructure and Utilities

The potential difference across a typical bridge or structure of 100m in length or smaller will be negligible. In case the structure is connected to remote earth via a distribution circuit or any other conductive connection, the dc current will not cause significant corrosion to a large structure. If the connection to the remote earth is a concern for the system connected at the other end (e.g. distribution transformer), the system can be isolated.

Telephone lines and facilities in the area will not be impacted. A ground potential of 70V does not cause any operational issues and does not constitute a safety hazard since the insulated telephone circuits do not allow stray current through the network, and the combined potential difference (a GPR of 70V and a telephone loop voltage of 48V) is a non-lethal hazard to the telephone company personnel. The actual GPR values are less than 70V.

Conclusions

The results of this analysis show that based on the currently known geological conditions, operation of a shoreline pond electrode at Dowden's Point would have minimal adverse impact on the existing infrastructure identified by Nalcor Energy.

Any critical infrastructure along the shoreline and on the northern side of Conception Bay should be identified and analyzed for potential adverse impacts. Based on the present analysis, it is anticipated that a typical station terminal, multi-grounded neutral distribution network or pipeline will not be impacted significantly by the operation of the HVdc electrode. Considering the GPR profiles obtained in the vicinity of the shoreline pond electrode, any adverse affects not captured in this preliminary screening can be reliably mitigated.

Based on the results to date, a shoreline pond electrode at Dowden's Point is a viable alternative for the Soldiers Pond converter station. If a shoreline pond electrode at Dowden's Point is to be pursued, additional site surveys will be required to further investigate geological conditions and to identify physical impediments which may impact the size and location of the shoreline pond. Assumptions on the existing infrastructure, power transformer excitation currents and tolerable dc stay currents used in this analysis should be verified. Additional simulations should be undertaken during the detailed engineering stage to further substantiate the results of this preliminary analysis and to quantify the impact of the limited transformer half cycle saturation caused by dc stray currents on the system. If it is decided to proceed with this location, a more detailed study would be prudent.

References

1. Information provided by Nalcor, E-mail message dated July 28, 2009.
2. E.W. Kimbark, “Direct Current Transmission, Vol. 1”, Wiley Interscience, 1971.
3. “Electrical Transmission and Distribution Reference Book”, ABB Power T&D Company, Chapter 5 “Power Transformers and Reactors”, 1997.
4. “Dowden’s Point Electrode, Ground Potential Simulation, Suggested Models”, AMEC, September 30, 2009.
5. “HVDC Ground Electrode Design”, EPRI EL-2020, Project 1467-1, August 1981.
6. “Proceedings: Geomagnetically Induced Current Conference” EPRI, TR-100450, June 1992.
7. Kalmijn, “Electroreception in Sharks and Rays” Nature 212, 1966.
8. Balayev, L.A and N.N Fursa, 1982 “The Behaviour of Ecologically Different Fish in Electric Fields, Threshold of Anode Reaction and Tetanus”.
9. “DC1110 – Electrode Review – Gull Island & Soldiers Pond”, Hatch Ltd., March 2008.

RA/BWM:bwm

Appendix A

Shoreline Pond Electrode Near Dowden's Point

Location and Design

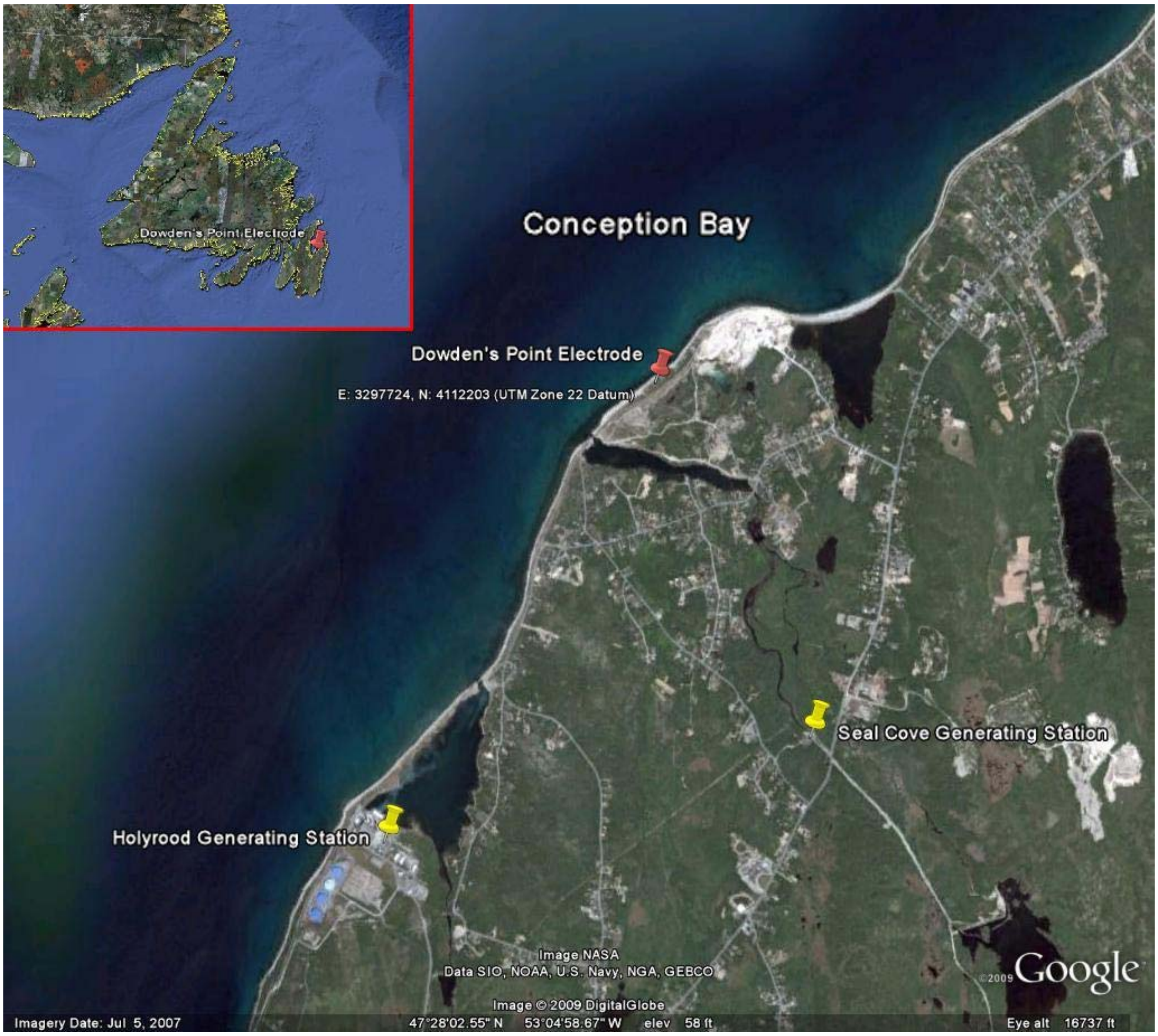
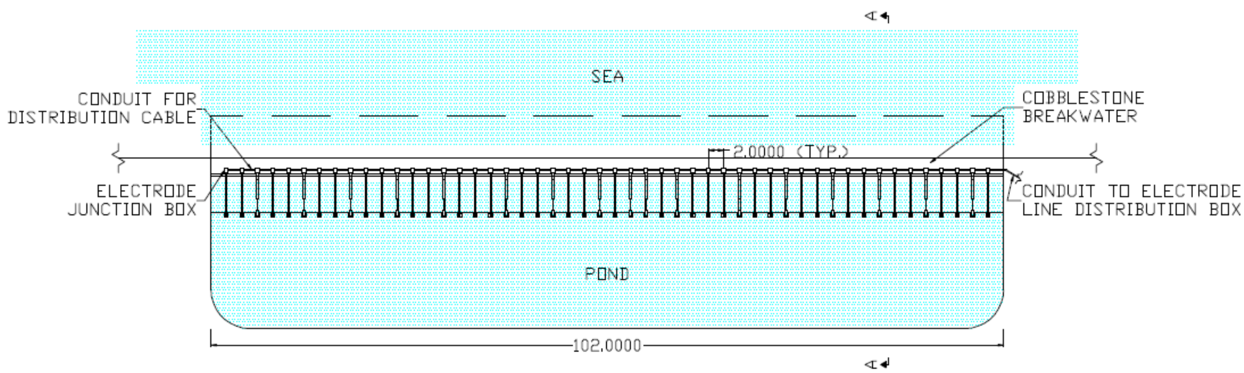


Figure A-1: Dowden's Point Electrode Location



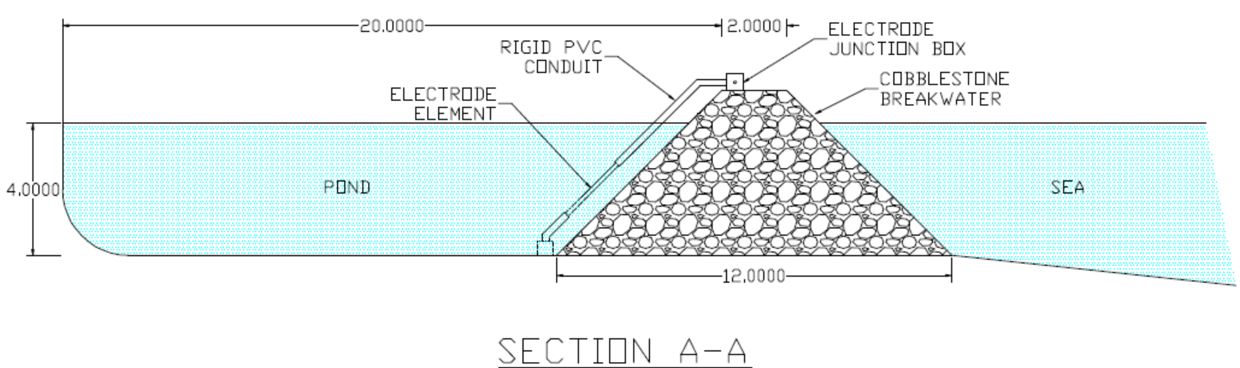


Figure A-2: HVdc Shoreline Pond Electrode Plan and Section

Table A-1: Electrode Design Basis Calculations

Anode Element Resistance and Current Density

References:

Anotec element 4884H: 122mm diameter and 2130mm long

IEEE 80, Section 14.6 "Concrete-Encased Electrodes"

Anode Resistance					***Remarks***
Resistivity of the surrounding volume	ρ	=	0.2	Ωm	Salt water
Length of the anode	L	=	2.13	m	From Anotec
Diameter of the anode	d	=	0.122	m	From Anotec
Resistance of anode in uniform volume	$R_{anode} = \rho / 2\pi L\ [\ LN(8L/d) - 1]$	=	0.05887	Ω	ref. IEEE 80, Equation 59

Current Density

Electrode current	I_{tot}	=	1340	A	
Current per anode	I_{anode}	=	30	A	From Anotec
Number of anode elements	$N_{anode} = I_{tot}/I_{anode}$	=	44.667		
		=	50		
Anode element surface area	A_{anode}	=	0.82	m^2	From Anotec
Surface area of anodes	A_{tot}	=	41	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	32.683	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	6.537	V/m	
Voltage gradient required at breakwater	$E_{breakwater}$	=	1.25	V/m	Assumed
Currrent density required at breakwater	$J_{breakwater} = J_{tot} {*} E_{breakwater}/E_{tot}$	=	6.25	A/m^2	
Area of breakerwater	$A_{breakwater} = I_{tot}/J_{breakwater}$	=	214.400	m^2	

A 100mx20m pond of depth 4m will provide a safe and conservative design.

Appendix B

Electric Field Simulation Results

Shoreline Pond Electrode Model and GPR Contour Plots

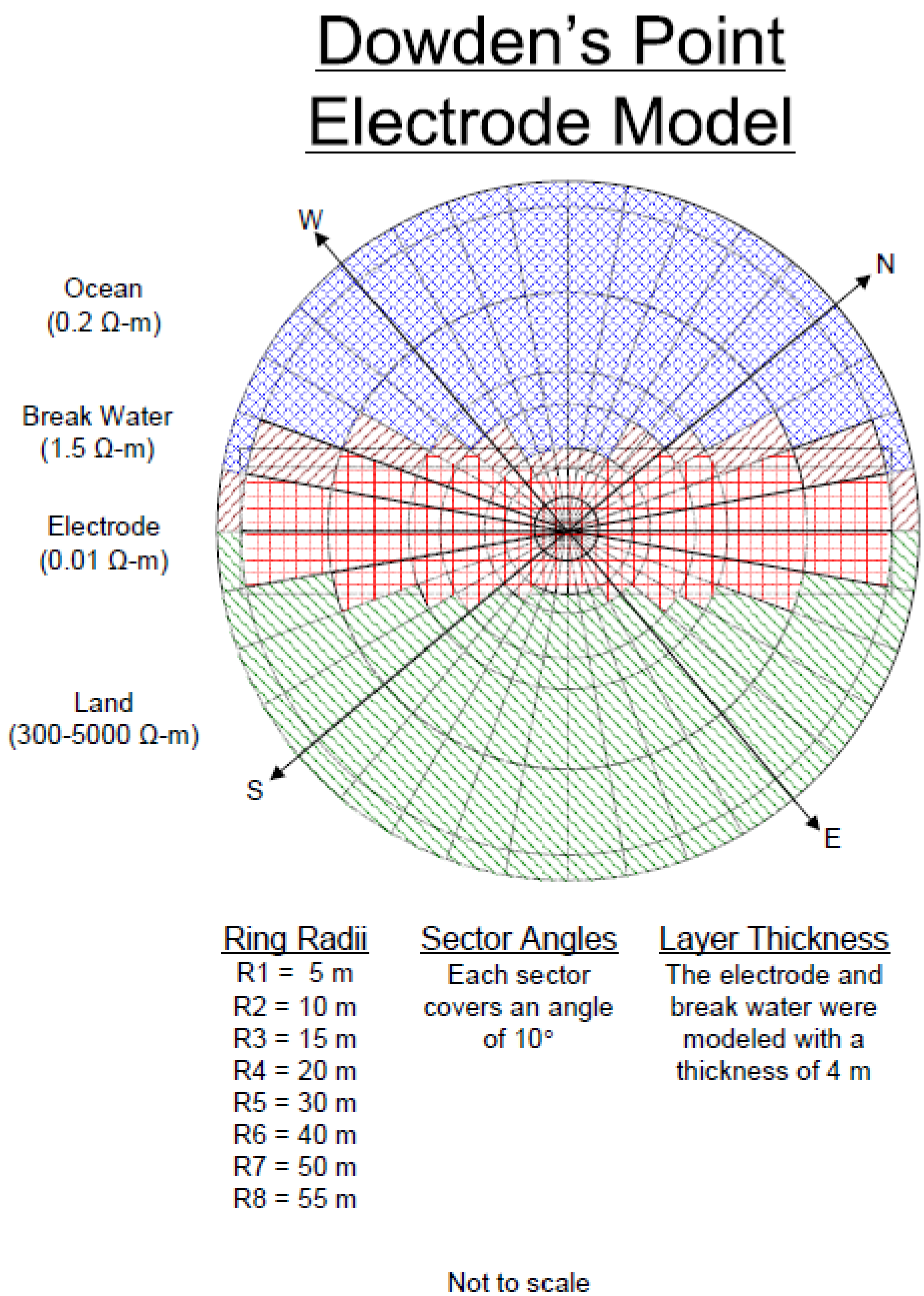


Figure B-1: Shoreline Pond Electrode Soil Model

The soil model is based on modelling scenario #2 for soil inland and under the sea, bathymetric data for sea depths around Dowden's Point and rough estimates of the sea depths farther away.

HATCH™

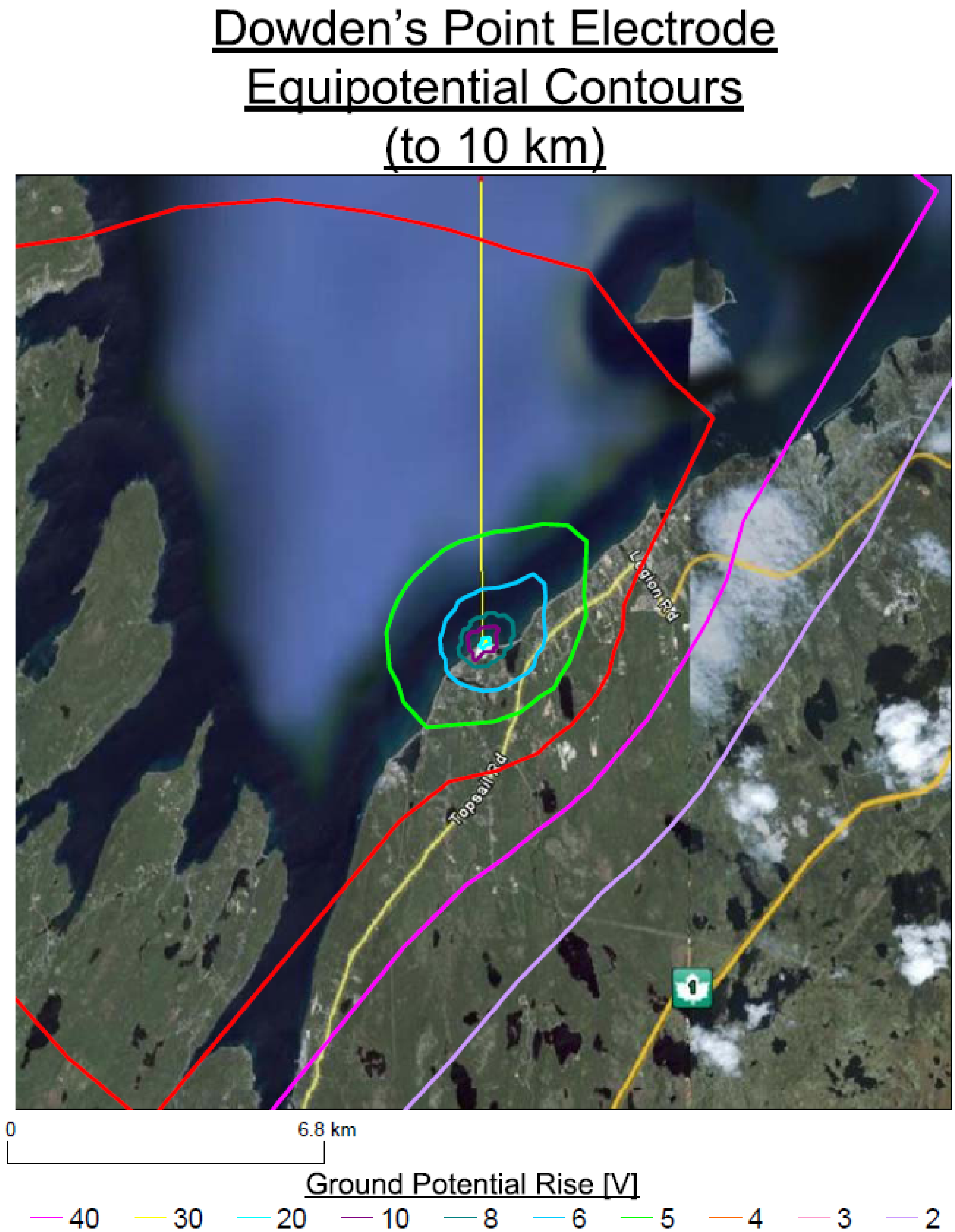


Figure B-2: GPR Contours (10km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

WorkingTogether SAFELY

HATCH™

Dowden's Point Electrode Equipotential Contours (to 25 km)

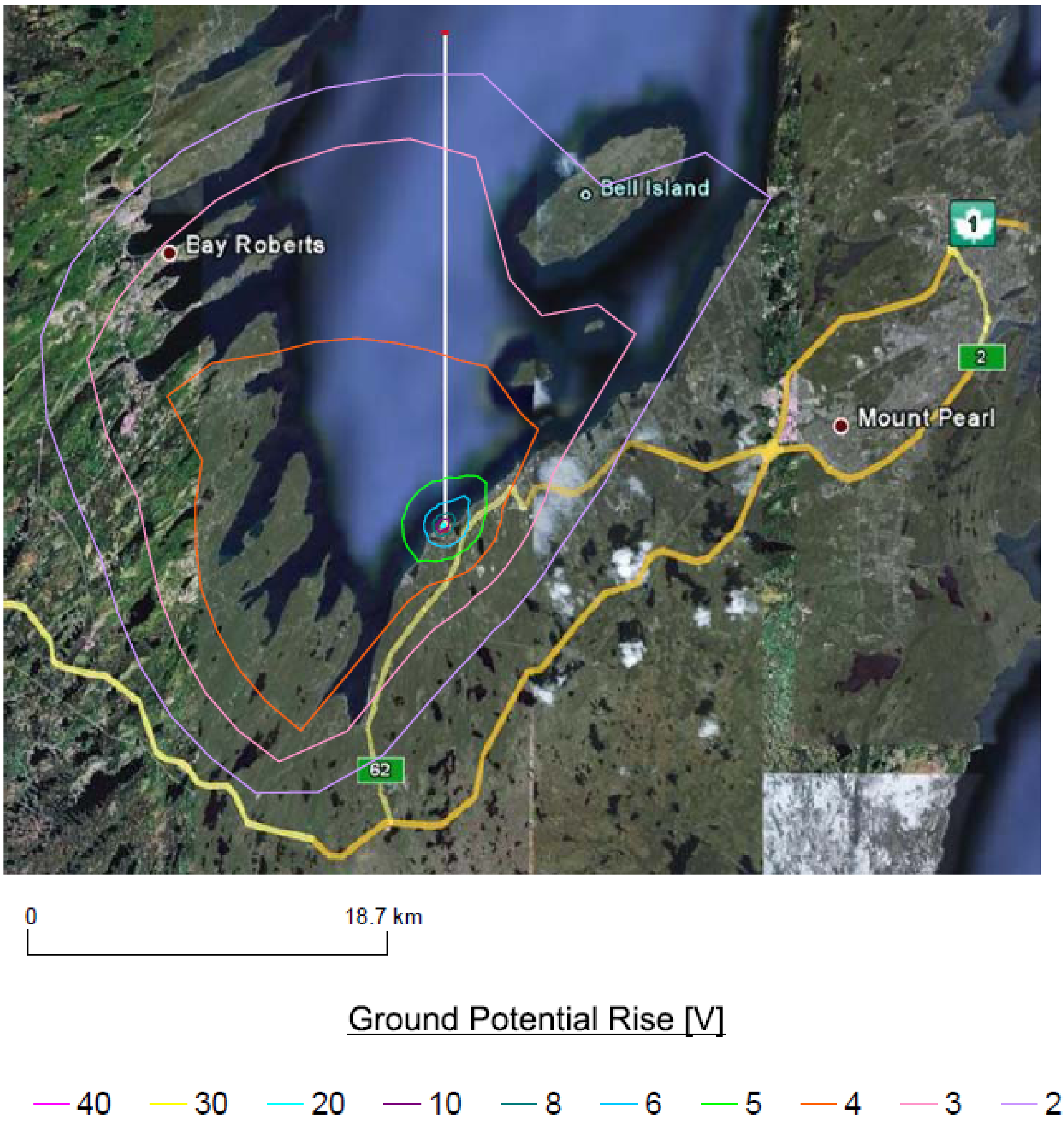


Figure B-3: GPR Contours (25km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

HATCH™

Dowden's Point Electrode Equipotential Contours (to 120 km)

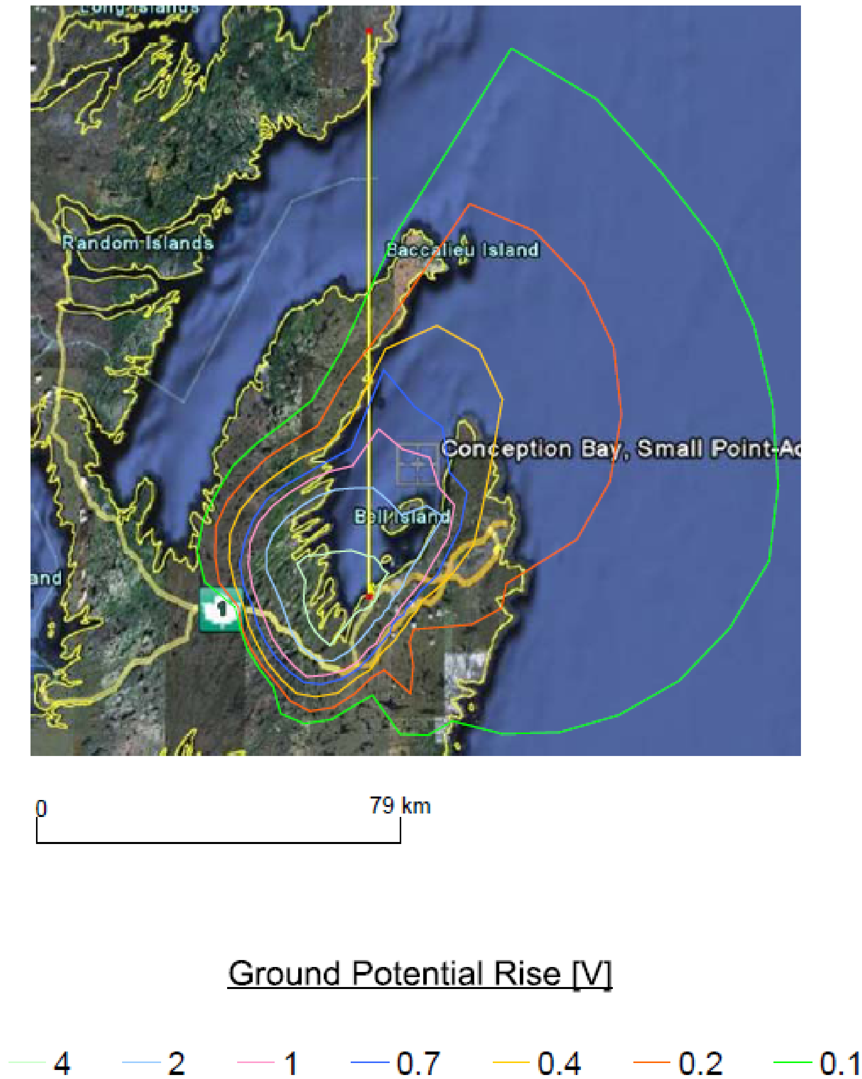


Figure B-4: GPR Contours (120km Profile)

*Note: Abrupt changes in GPR contours are due to software plotting limitations when joining a finite number of points of equal potential. The contours in theory are smooth.

WorkingTogether SAFELY

Appendix C

Known Infrastructure Near Dowden's Point

Shoreline Pond Electrode Location

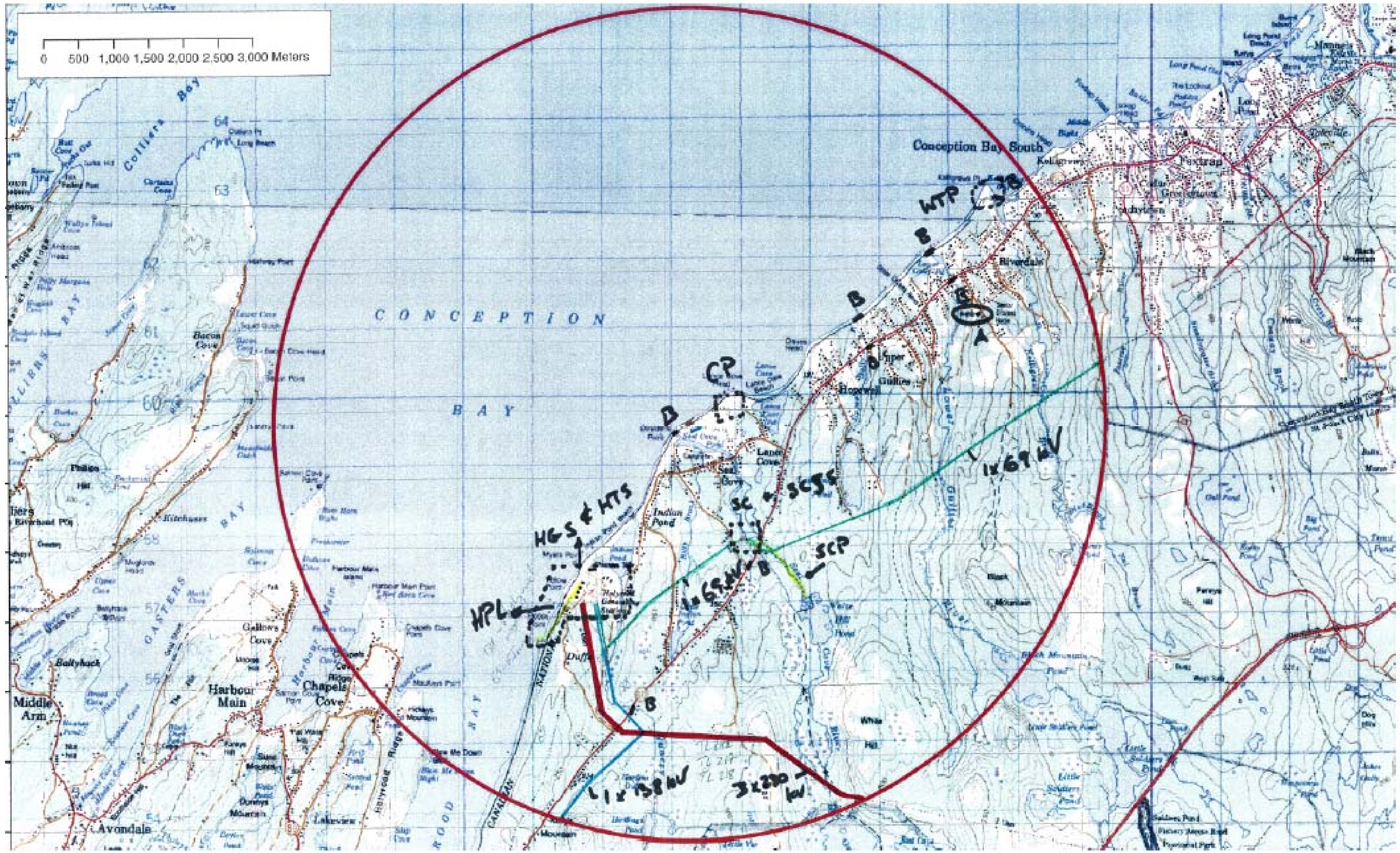
HATCH™

Table C-1: Existing Infrastructure in the Vicinity of the Dowden's Point HVdc Electrode

Distances estimated from response to infrastructure data request prepared by John Walsh, received July 28, 2009.

Identifier	Description	Min Distance from Electrode (m)	Notes
A	Sports Arena	4100	Steel building
B1	Bridge	500	
B2	Bridge	2600	
B3	Bridge	2600	
B4	Bridge	4000	
B5	Bridge	4000	
B6	Bridge	4400	
B7	Bridge	2200	
CP	Concrete mix plant	500	
HGS	Holyrood generating station	2600	3 thermal units, pipeline connection & jetty for refuelling, gas turbine
HTS	Holyrood transmission station	2600	3x230 kV lines, 1x138 kV line, 1x69 kV lines, 2x69 kV:230 kV trafos, 3x18kV:230 kV trafos, etc.
HPL	Holyrood pipeline	2600	1.29 km above ground pipeline connecting storage tanks to tanker jetty for fuel transfer
SC	Seal Cove generating station	2000	Hydro station
SCSS	Seal cove substation	2000	2x69 kV lines, steps down to 12.5 kV for distribution
SCP	Seal Cove Penstock	2000	1.2km long steel penstock, 2m in diameter
WTP	Wastewater treatment plant	5200	Connected to sea via outfall pipe
	Water/Sewer system		Cast iron & PVC used throughout area to connect to town of CBS, some artesian wells to southern extent of route 60
	230 kV lines TL217, TL218 & TL242	2600	Approximate length within zone for each line is 5.7km, generally move away from electrode
	138 kV line 39L	2600	Approximate length within zone 3.7km, generally moves away from electrode
	69 kV line 38L (Holyrood to Seal Cove)	2000	Approximate length 4km from Holyrood to Seal Cove
	69 kV line 52L (Kelligrews to Seal Cove)	2000	Approximate length within zone of 6km, generally moves away from electrode
	12.5 kV, 3 phase distribution	1200	Approximate length within zone is 8.7km, runs along route 60
	12.5 kV, 2 phase distribution	700	Approximate length within zone is 5.25km, runs along Seal Cove Road
	12.5 kV, 1 phase distribution	< 500	Approximate length within zone is 36km

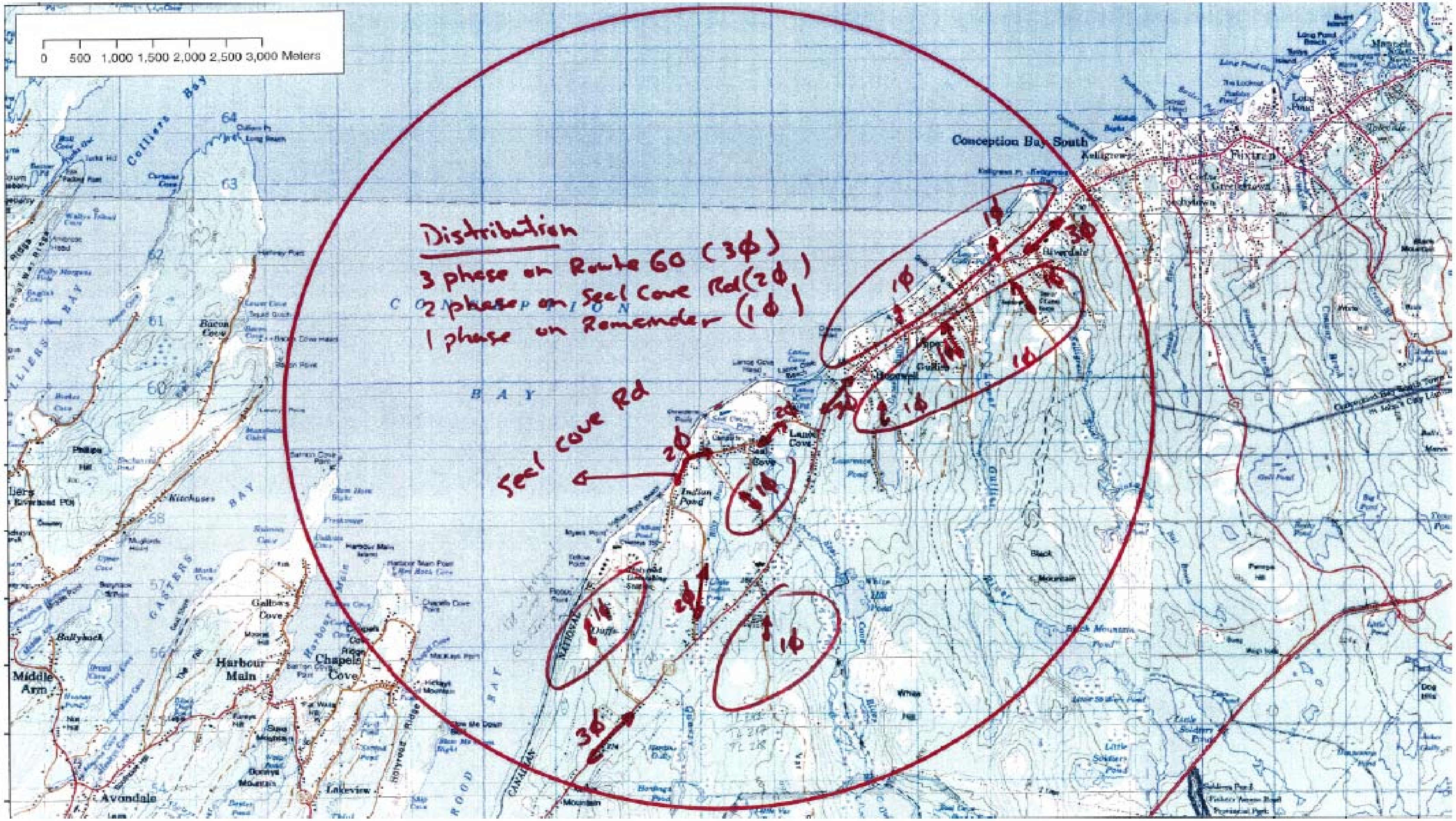
HATCH™



MAP – 1

Figure C-1: HV Transmission/Generation Infrastructure

HATCH™



MAP – 2

Figure C-2: 12.47 kV Distribution Infrastructure

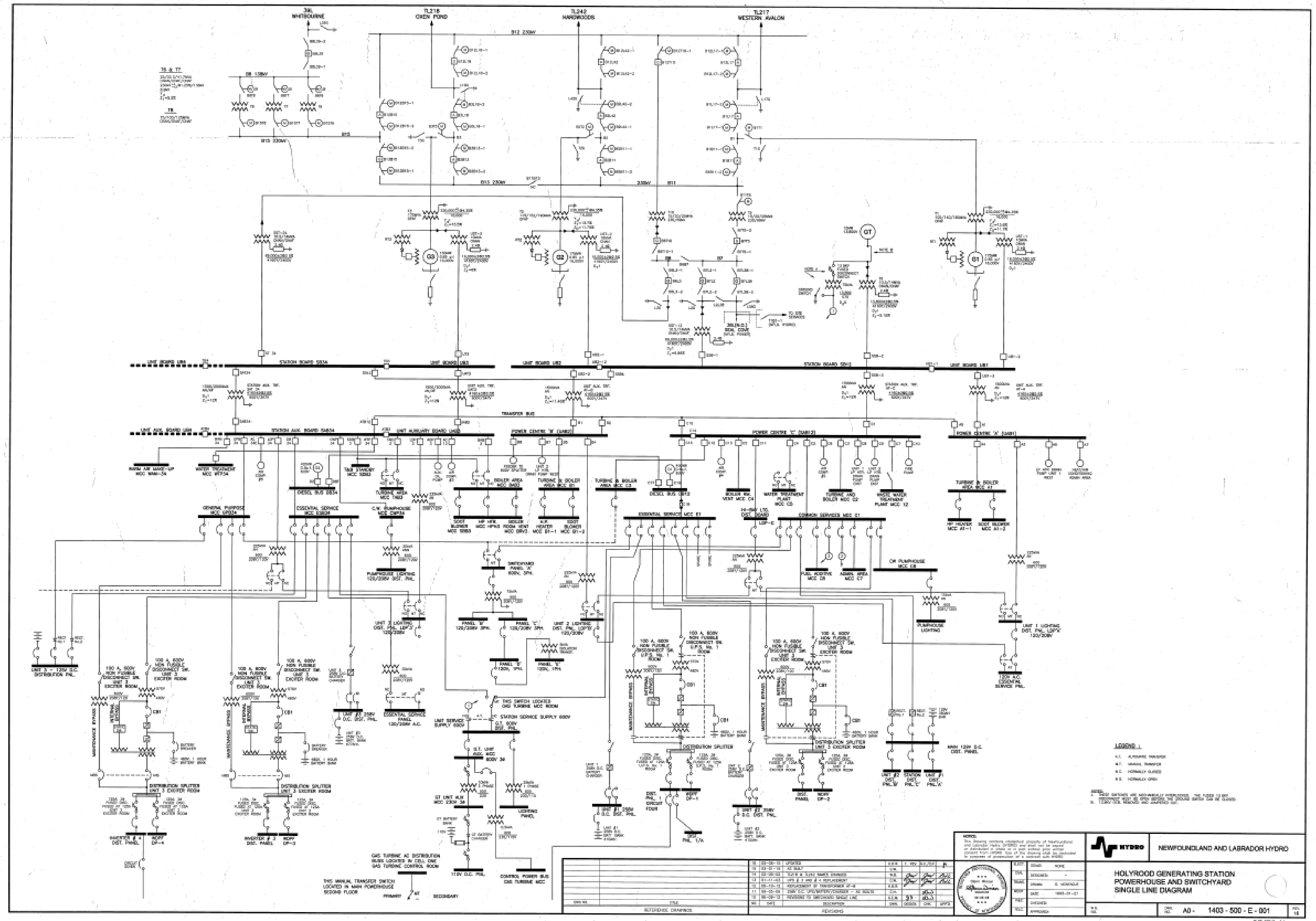


Figure C-3: Holyrood Generating and Transmission Station Single Line Diagram

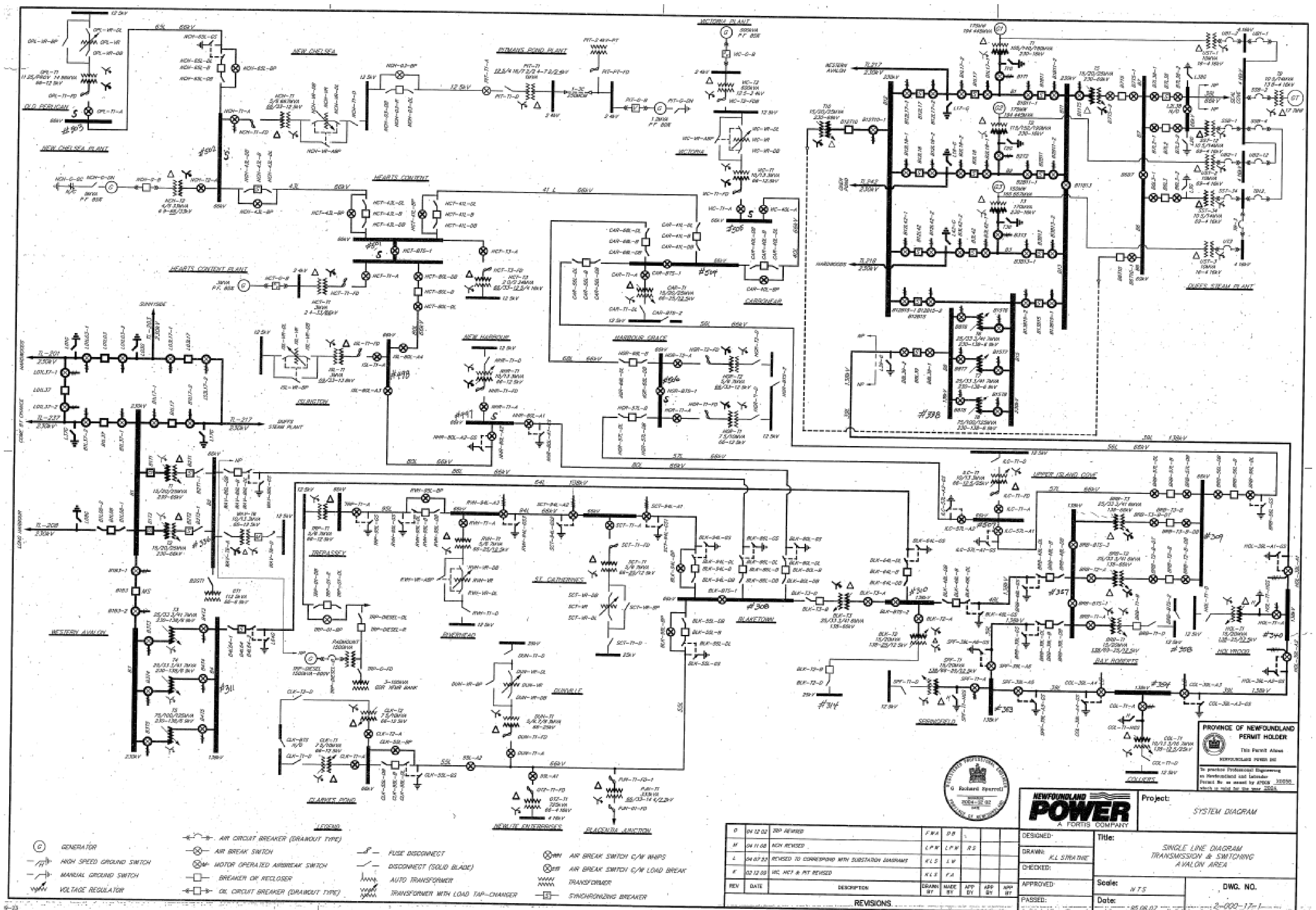


Figure C-4: Seal Cove Generating and Transmission Station Single Line Diagram

Table C-2: 230 kV Transmission Line TL 217 Data

General:	
Transmission Line Name:	TL 217
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Western Avalon Station
Tower/Span:	
Type of Tower:	Steel Lattice
Type of Foundation:	Steel Grillage
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	250 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	76.7km
Conductors	
Phase conductor number/size/type:	804 kcmil 23/19 AACSR/TW
Skywire number/size/type:	9/16" Steel Wire (5/8" EHS Steel Wire assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station only)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohm
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table C-3: 230 kV Transmission Line TL 218 Data

General:	
Transmission Line Name:	TL 218
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Oxen Pond Station
Tower/Span:	
Type of Tower:	Wood Pole
Type of Foundation:	Wood Pole
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	200 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	37.3km
Conductors	
Phase conductor number/size/type:	795 ACSR 26/7 "Drake" 37 Strand AASC Arvidal
Skywire number/size/type:	7/16" Steel Wire (5/8" EHS Steel Wire Assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station only)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table C-4: 230 kV Transmission Line TL 242 Data

General:	
Transmission Line Name:	TL 242
Voltage Rating:	230 kV
Terminal Stations:	Holyrood Terminal Station
Remote end Terminal Station	Hardwoods Station
Tower/Span:	
Type of Tower:	Steel Lattice
Type of Foundation:	Steel Grillage
Conduction Configuration (phase/skywire):	3 Phase with selected length of OHGW (Skywire)
Approximate Span:	220 m
Transmission line plan drawing(s)	Exist
Length of Transmission Line	27.2km
Conductors	
Phase conductor number/size/type:	804 kcmil 23/19 AACSR/TW
Skywire number/size/type:	9/16" Steel Wire (5/8" EHS Steel Wire Assumed)
Grounding/Continuity	
Skywire is continuous (yes/no):	No (1 mile or 1.6 km out from Holyrood Station)
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	15 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table C-5: 138 kV Transmission Line 39L data

General:	
Transmission Line Name:	39L
Voltage Rating:	138 kV
Terminal Stations:	Holyrood Terminal Station
Tower/Span:	
Type of Tower:	Wooden H-Frame
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase
Approximate Span:	100-200 m
Transmission line plan drawing(s)	
Length of Transmission Line	41.89km (to Bay Roberts Station)
Conductors	
Phase conductor number/size/type:	397.5 MCM ACSR
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	No
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

HATCH™

Table C-6: 69 kV Transmission Line 52L Data

General:	
Transmission Line Name:	52L
Voltage Rating:	69 kV
Terminal Stations:	Kelligrews to Seal Cove Generation Station
Remote end Terminal Station	Single line diagram including transformer data is known.
Tower/Span:	
Type of Tower:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase no OHGW
Approximate Span:	70-90 m
Transmission line plan drawing(s)	
Transmission Line Length	8.22km
Conductors	
Phase conductor number/size/type:	477 MCM ASC
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	None
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table C-7: 69 kV Transmission Line 38L Data

General:	
Transmission Line Name:	38L
Voltage Rating:	69 kV
Terminal Stations:	Seal Cove to Holyrood
Tower/Span:	
Type of Tower:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration (phase/skywire):	3 Phase no OHGW
Approximate Span:	70-90 m
Transmission line plan drawing(s)	
Transmission Line Length	3.54km
Conductors	
Phase conductor number/size/type:	715.5 MCM ASC, 397.5 MCM ACSR
Skywire number/size/type:	N/A
Grounding/Continuity	
Skywire is continuous (yes/no):	None
All Towers Grounded (yes/no):	Yes
Tower Grounding Impedance:	20 Ohms
Counterpoise Connections between Towers	No

*Assumptions highlighted.

Table C-8: 12.47 kV Distribution System Data

General:	
Distribution Line Name:	Two main feeders from Seal Cove distribution Station
Voltage Rating:	12.47 kV
Terminal distribution Station:	Seal Cove Distribution Station
Pole/Span:	
Type of pole:	Wooden Single Pole
Type of Foundation:	Wood Poles
Conduction Configuration:	3 Phase, 2 phase and Single phase
Approximate Span:	60m-70m
Distribution system area map	Not Available
Conductors/Distribution Transformer	
Phase conductor size/type:	2/0 ACSR
Neutral Size:	1/0 ACSR
Distribution transformer (single phase or three phase Y grounded)	
Typical distribution transformer sizes	25kVA (assumed five per kilometre)
Grounding/Continuity	
Neutral is continuous (yes/no):	Yes
Grounding per CSA standards, four grounds per 1000m run and at transformers (yes/no)	Yes
Pole Grounding Impedance (Pole ground rod in parallel with residential ground rod(s))	25 Ohms
Residential Connections	
Provide description and sketch of single phase distribution transformers and house connections	Typical 120/240 connection with mid point grounding
Confirm hose ground type (ground rods, ground plates, or cold water system)	Ground Rod
Provide estimate of typical ground resistance	Considered in parallel with pole ground rod.

*Assumptions highlighted.

Table C-9: Holyrood Generating Station Data

General	
Description of Structure:	Holyrood Thermal Generation Station
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	Yes via pipeline and Jetty for refuelling (see below)
Approximate size of structure (length m x width m or diameter m)	Approx 600m x 680m on site including transmission station
Single Line Diagram	Available
Conductive Connection	
Fuel transfer pipeline	Yes

*Assumptions highlighted.

Table C-10: Holyrood Transmission Station Data

General:	
Voltage Rating	230 kV, 138 kV, 69 kV
Single line diagram showing transformers, lines and feeders	Provided
Grounding and Conductive Connections	
Station ground electrode Impedance:	0.5 Ohms
Transformer winding connections of 230/69 kV transformers T5 and T10	Delta/Wye-grounded
Transformer winding connections of 230/138 kV auto transformers T6, T7 and T8	Wye-grounded/Wye-grounded
230 kV T/L Skywires	Yes
Remote end 230 kV station through transformer windings	Yes
138 kV T/L Skywires	No
Remote end 138 kV station	No
69 kV T/L Skywires	No
Remote end 69 kV station	
Grounding connections to generating station	Yes

*Assumptions highlighted.

Table C-11: Seal Cove Generation Station Data

General	
Description of Structure:	Seal Cove Hydroelectric Generation Station
Single Line Diagram	Provided
Approximate size of structure (length m x width m or diameter m)	Approx 80 m x 70 m on site (building and substation) Penstock connection
Conductive Connections and Grounding	
Ground grid impedance	0.5 Ohms
Are structure members in contact with sea body of water?	No
Remote metallic connection through penstock	Yes
Connection to Newfoundland Hydro Substation	Yes
Connection to remote station through 69 kV circuit	

*Assumptions highlighted.

Table C-12: Newfoundland Power Substation Data

General:	
Voltage Rating:	69 kV, 12.5 kV
Single line diagram	
Grounding and Conductive Connections	
Station ground electrode impedance:	0.5 Ohms
Distribution feeder neutral connections to station ground/ neutral size	Yes, 2/0 ACSR distribution neutral
Connection to utility distribution transformers via distribution circuit conductors/ distribution feeder conduction sizes	Yes, 4/0 ACSR for distribution neutral
Connection to remote station via 69 kV Line Conductor/Conductor size	Yes

*Assumptions highlighted.

Table C-13: Pipeline for Holyrood Fuel Transfer Data

Metallic Pipeline Name:	
Type of steel:	Carbon steel ASTM A53/D106Grb Type
Diameter of pipe (mm):	18" mainline; 16" branch lines to tanks
Wall thickness (mm):	3/8" (on 18" diameter) standard wall
Length (km):	1.29 km
Type of insulation/coating:	No coating; pre-formed mineral fibre insulation
Leakage resistance of coating (Ohms/m^2):	N/A
Longitudinal resistance (Ohms/m^2):	N/A
Cathodic protection scheme (impressed current or sacrificial anode) and details	No
Confirm hose ground type (ground rods, ground plates, or cold water system)	GFI protection on heat tracing
Provide estimate of typical ground resistance	

*Assumptions highlighted.

Table C-14: Penstock for Seal Cove Station Data

Metallic Pipeline Name:	Penstock
Type of steel:	
Diameter of pipe (mm):	
Wall thickness (mm):	
Length (km):	1.2 km
Type of insulation/coating:	No coating or insulation
Leakage resistance of coating (Ohms/m^2):	
Longitudinal resistance (Ohms/m^2):	
Cathodic protection scheme (impressed current or sacrificial anode) and details	No
Confirm hose ground type (ground rods, ground plates, or cold water system)	
Provide estimate of typical ground resistance	

*Assumptions highlighted.

Table C-15: Concrete Mix Plant Data

Structure Name:	
Description of Structure:	Concrete Mix Plant
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	Approx 300 m x 300 m area. Contains building (small batch plant), lay down areas, and yard for equipment and trucks.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table C-16: Wastewater Treatment Plant Data

Structure Name:	
Description of Structure:	Wastewater Treatment Plant
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	Yes Via outfall pipe, unsure if pipe is metal or PVC
Approximate size of structure (length m x width m or diameter m)	Approx size of 160 m x 70 m in area. Contains two buildings.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table C-17: Sports Arena Data

Structure Name:	
Description of Structure:	Arena, steel building
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	Approx size of 100 m x 90 m in area. Contains one building.
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table C-18: Various Bridges

Structure Name:	
Description of Structure:	Bridges
Is structure connected to the power system grounding system? If yes provide connection details	
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	<100
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Table C-19: Water and Sewer Infrastructure for the Town of Conception Bay South

Structure Name:	
Description of Structure:	Water and Sewer Pipes
Is structure connected to the power system grounding system? If yes provide connection details	Yes
Are structure members in contact with sea body of water? If yes provide connection details	No
Approximate size of structure (length m x width m or diameter m)	
Information on cathodic protection system if applicable for the structure.	No

*Assumptions highlighted.

Appendix D

230 kV Skywire Impact Assessment

Model, Data and Results

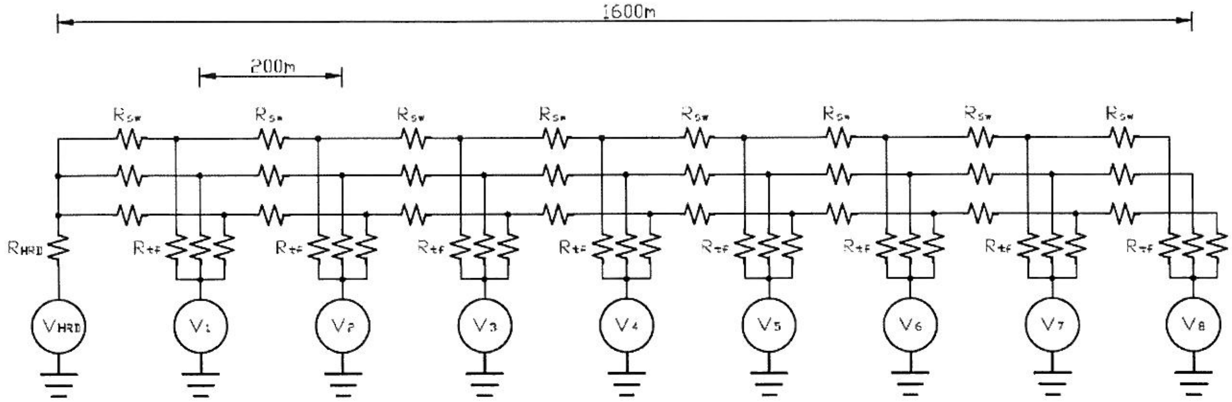


Figure D-1: Skywire Model

Table D-1: Skywire Network Data

Station Grounding Grids						**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5			Assumed
Tower Footing Resistance						
Tower Footing Resistance	R_{tf}	Ω	15			Assumed
Skywire Resistance						
Line Designation			**TL217 (HRD-WAV)**	**TL218 (HRD-OPD)**	**TL242 (HRD-HWD)**	
Length of Skywire	l_{tot}	m	1600	1600	1600	
Span of Skywire	l	m	200	200	200	See Note 2
Number of Towers	$N_{towers}=l_{tot}/l$		8	8	8	
DC Resistance (@ 20°C)	R_{cond}	Ω/km	1.405	1.405	1.405	See Note 1
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.281	0.281	0.281	

Notes:

1. All skywires assumed to be steel wire 5/8" (R_{dc} = 2.261Ω/mile, from CDEGS)
   Actual skywires are 9/16" steel (TL217 & TL242) and 7/16" steel (TL218)
2. Span of all skywires assumed to be 200m (i.e., 1600/200 = 8 segments from Holyrood)
   Actual spans are 250m (TL217), 200m (TL218) and 220m (TL242)

Table D-2: Skywire Network Simulation Results

Tower Designation	GPR (V)	Calculated dc Stray Current (I_{dc})	Permissible Current through Steel Foundation	Permissible Current through Steel Guywire Anchors	Permissible Current through Copper Grounding Rods
Holyrood Terminal Station	4.500	0.1853			
1st Tower from Holyrood	4.400	0.0008	0.4194	0.1243	0.4648
2nd Tower from Holyrood	4.300	-0.0058	0.4194	0.1243	0.4648
3rd Tower from Holyrood	4.200	-0.0124	0.4194	0.1243	0.4648
4th Tower from Holyrood	4.100	-0.0192	0.4194	0.1243	0.4648
5th Tower from Holyrood	4.000	-0.0260	0.4194	0.1243	0.4648
6th Tower from Holyrood	3.900	-0.0331	0.4194	0.1243	0.4648
7th Tower from Holyrood	3.800	-0.0404	0.4194	0.1243	0.4648
8th Tower from Holyrood	3.700	-0.0481	0.4194	0.1243	0.4648

Notes

1. The current division between the steel foundation, guywire anchors and copper rods will depend on the surface area in contact with the earth for each element. A current equal to 100% of the total current through the tower is considered for each element as a conservative approach.
2. The polarity of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into tower; -ve from tower into ground.
3. The network was analyzed as a resistive network in the CDEGS software module MALZ.

Appendix E

Equipment Impact Assessment

230 kV, 138 kV, 69 kV

Models, Data and Results

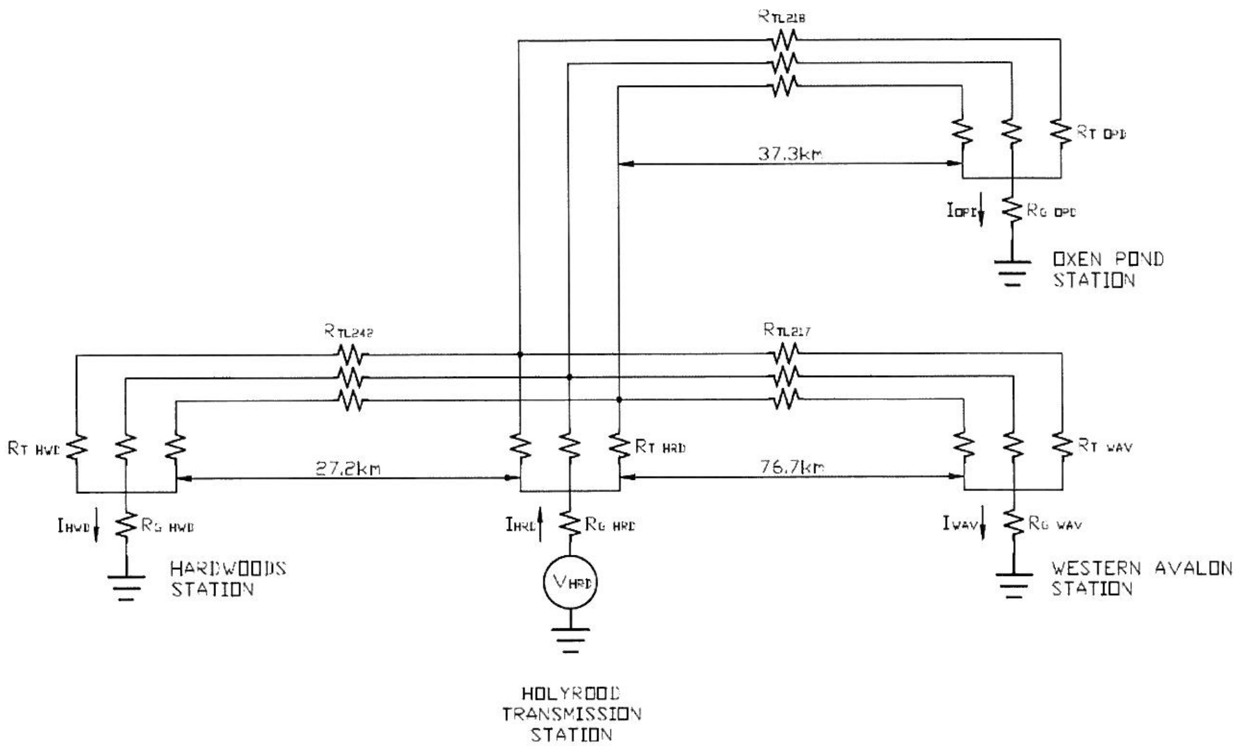


Figure E-1: 230 kV Transmission Network Model

Table E-1: 230 kV Transmission Network Data

230kV Transformer Data
Holyrood Terminal Station

Transformer Designation			**HRD_T1**	**HRD_T2**	**HRD_T3**	**HRD_T6**	**HRD_T7**	**HRD_T8**	**Remarks**
Transformer Type			Two Winding	Two Winding	Two Winding	Auto	Auto	Auto	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	105.000	**115.000**	101.998	**25.000**	**25.000**	**75.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	140.000	152.000	127.532	33.300	33.300	100.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	**180.000**	190.000	**170.000**	41.700	41.700	125.000	
High Voltage	V_H	kV	230.000	230.000	230.000	230.000	230.000	230.000	
Low Voltage	V_L	kV	16.000	16.000	16.000	138.000	138.000	138.000	
Tertiary Voltage	V_T	kV	N/A	N/A	N/A	6.900	6.900	6.900	
Load Loss at Base MVA	kW_{loss}	kW	422.770	252.050	662.600	62.430	65.800	91.660	Nalcor Input (Transformer databook sheets)
Rated 230kV Current at Base MVA	I_{rated}	A	451.853	288.684	426.750	62.757	62.757	188.272	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500	0.300	0.300	0.300	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	1.355	1.443	1.280	0.188	0.188	0.565	Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.452	0.481	0.427	0.063	0.063	0.188	
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.678	0.722	0.640	0.094	0.094	0.282	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.235	0.219	0.390	0.250	0.263	0.122	
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	293.889	460.000	311.176	2,116.000	2,116.000	705.333	
DC Resistance	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	0.690	1.008	1.213	5.284	5.569	0.862	
230kV Winding Resistance	R_{dc230}	Ω	0.687	1.003	1.207	5.284	5.569	0.862	See Notes 3 and 4

Equivalent Resistance of 230kV Windings	$R_{HRD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.208

230kV Transformer Data
Western Avalon

Transformer Designation			**WAV_T1**	**WAV_T2**	**WAV_T3**	**WAV_T4**	**WAV_T5**		**Remarks**
Transformer Type			Two Winding	Two Winding	Auto	Auto	Auto		
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta		
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**	**15.000**	**25.000**	**25.000**	**75.000**		Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000	20.000	33.000	33.000	100.000		
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	25.000	25.000	33.300	33.300	125.000		
High Voltage	V_H	kV	230.000	230.000	230.000	230.000	230.000		
Low Voltage	V_L	kV	66.000	66.000	138.000	138.000	138.000		
Tertiary Voltage	V_T	kV	N/A	N/A	6.900	6.900	6.900		
Load Loss at Base MVA	kW_{loss}	kW	64.000	65.870	66.700	65.800	92.500		Nalcor Input (Transformer databook sheets)
Rated 230kV Current at Base MVA	I_{rated}	A	37.654	37.654	62.757	62.757	188.272		
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.300	0.300	0.300		Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.188	0.188	0.188	0.188	0.565		Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.063	0.063	0.063	0.063	0.188		
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.094	0.094	0.282		
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.427	0.439	0.267	0.263	0.123		
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	3,526.667	3,526.667	2,116.000	2,116.000	705.333		
DC Resistance	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	15.047	15.487	5.645	5.569	0.870		
230kV Winding Resistance	R_{dc230}	Ω	13.902	14.309	5.645	5.569	0.870		See Notes 3 and 4

Equivalent Resistance of 230kV Windings	$R_{WAV}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}\|\|R_{T5}$	Ω	0.607

230kV Transformer Data
Oxen Pond

Transformer Designation			OPD_T1	OPD_T2	OPD_T3				Remarks
Transformer Type			Two Winding	Two Winding	Two Winding				
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta				
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**40.000**	**75.000**	**75.000**				Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	53.300	100.000	100.000				
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	66.600	125.000	125.000				
High Voltage	V_H	kV	230.000	230.000	230.000				
Low Voltage	V_L	kV	66.000	66.000	66.000				
Tertiary Voltage	V_T	kV	N/A	N/A	N/A				
Load Loss at Base MVA	kW_{loss}	kW	103.900	98.559	176.100				Nalcor Input (Transformer databook sheets)
Rated 230kV Current at Base MVA	I_{rated}	A	100.412	188.272	188.272				
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500				Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.502	0.941	0.941				Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.167	0.314	0.314				
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.471	0.471				
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.260	0.131	0.235				
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,322.500	705.333	705.333				
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}$/100	Ω	3.435	0.927	1.656				
230kV Winding Resistance	R_{dc230}	Ω	3.174	0.856	1.530				See Notes 3 and 4

Equivalent Resistance of 230kV Windings	$R_{OPD}=R_{T1}\|\|R_{T2}\|\|R_{T3}$	Ω	0.468

230kV Transformer Data
Hardwoods

Transformer Designation			HWD_T1	HWD_T2	HWD_T3	HWD_T4			Remarks
Transformer Type			Two Winding	Two Winding	Two Winding	Two Winding			
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Delta	Wye Gnd./ Zig Zag			
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**40.000**	**40.000**	**40.000**	**75.000**			Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	53.300	53.300	53.300	100.000			
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	66.600	66.600	66.600	125.000			
High Voltage	V_H	kV	230.000	230.000	230.000	230.000			
Low Voltage	V_L	kV	66.000	66.000	66.000	66.000			
Tertiary Voltage	V_T	kV	N/A	N/A	N/A	N/A			
Load Loss at Base MVA	kW_{loss}	kW	126.380	116.100	131.770	174.470			Nalcor Input (Transformer databook sheets)
Rated 230kV Current at Base MVA	I_{rated}	A	100.412	100.412	100.412	188.272			
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	0.500	0.500			Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.502	0.502	0.502	0.941			Division by 1.667 or 1.333 if ONAN rating is not the base rating
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.167	0.167	0.167	0.314			
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.251	0.251	0.471			
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.316	0.290	0.329	0.233			
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,322.500	1,322.500	1,322.500	705.333			
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}$/100	Ω	4.178	3.839	4.357	1.641			
230kV Winding Resistance	R_{dc230}	Ω	3.861	3.547	4.025	1.516			See Notes 3 and 4

Equivalent Resistance of 230kV Windings	$R_{HWD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}$	Ω	0.690

Terminal Station Ground Grid Impedances

			Resistance						Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5						Assumed
Western Avalon Grounding Grid Resistance	$R_{G\ WAV}$	Ω	0.5						Assumed
Oxen Pond Grounding Grid Resistance	$R_{G\ OPD}$	Ω	0.5						Assumed
Hardwoods Grounding Grid Resistance	$R_{G\ HWD}$	Ω	0.5						Assumed

230kV Transmission Lines

			TL217 (HRD-WAV)	TL218 (HRD-OPD)	TL242 (HRD-HWD)				Remarks
Length of Transmission Line	l	km	76.663	37.29	27.21				Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.01077	0.0036	0.00383				Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	5.69733	1.8780	2.02607				

Notes
1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio.
4. Resistances of Delta windings are ignored for auto transformers.
5. The 230kV transfomer windings connected in Delta are not included in the tables.

HATCH™

Nalcor Energy - Lower Churchill Project
DC1250 - Electrode Review Types and Locations

Table E-2: 230 kV Transmission Network Simulation Results

230kV Transformer Results
Holyrood Terminal Station

Transformer Designation			HRD_T1	HRD_T2	HRD_T3	HRD_T6	HRD_T7	HRD_T8
230kV Winding Resistance	R_{dc230}	Ω	0.687	1.003	1.207	5.284	5.569	0.862
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.678	0.722	0.640	0.094	0.094	0.282
Calculated DC Current (1-phase)	I_{dc}	A	0.412	0.282	0.234	0.054	0.051	0.328

Stray DC Current at Holyrood	I_{HRD}	A	4.082
Stray DC Current at Holyrood (per phase)	I_{HRD} /3	A	1.361
Equivalent Resistance of 230kV Transformers	$R_{HRD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.208

230kV Transformer Results
Western Avalon

Transformer Designation			WAV_T1	WAV_T2	WAV_T3	WAV_T4	WAV_T5	
230kV Winding Resistance	R_{dc230}	Ω	13.902	14.309	5.645	5.569	0.870	
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.094	0.094	0.282	
Calculated DC Current (1-phase)	I_{dc}	A	0.012	0.012	0.030	0.030	0.194	

Stray DC Current at Western Avalon	I_{WAV}	A	0.836
Stray DC Current at Western Avalon (per phase)	I_{WAV} /3	A	0.279
Equivalent Resistance of 230kV Transformers	$R_{WAV}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}\|\|R_{T5}$	Ω	0.607

230kV Transformer Results
Oxen Pond

Transformer Designation			OPD_T1	OPD_T2	OPD_T3			
230kV Winding Resistance	R_{dc230}	Ω	3.174	0.856	1.530			
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.471	0.471			
Calculated DC Current (1-phase)	I_{dc}	A	0.083	0.309	0.173			

Stray DC Current at Oxen Pond	I_{OPD}	A	1.697
Stray DC Current at Oxen Pond (per phase)	I_{OPD} /3	A	0.566
Equivalent Resistance of 230kV Transformers	$R_{OPD}=R_{T1}\|\|R_{T2}\|\|R_{T3}$	Ω	0.468

230kV Transformer Results
Hardwoods

Transformer Designation			HWD_T1	HWD_T2	HWD_T3	HWD_T4		
230kV Winding Resistance	R_{dc230}	Ω	3.861	3.547	4.025	1.516		
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.251	0.251	0.251	0.471		
Calculated DC Current (1-phase)	I_{dc}	A	0.092	0.100	0.088	0.235		

Stray DC Current at Hardwoods	I_{HWD}	A	1.548
Stray DC Current at Hardwoods (per phase)	I_{HWD} /3	A	0.516
Equivalent Resistance of 230kV Transformers	$R_{HWD}=R_{T1}\|\|R_{T2}\|\|R_{T3}\|\|R_{T4}$	Ω	0.690

Notes:
1. The network was analyzed as a resistive network in the CDEGS software module MALZ.

WorkingTogether SAFELY

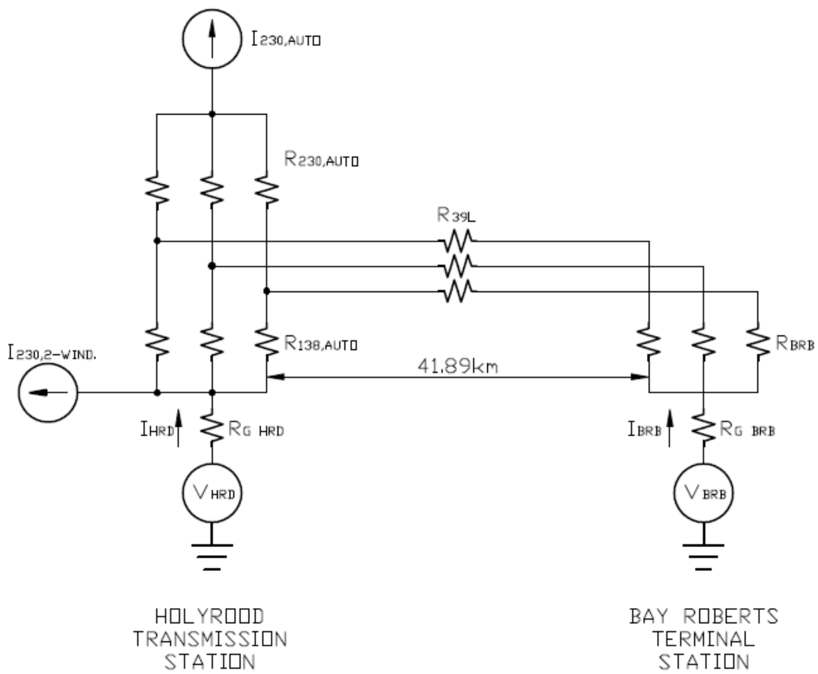


Figure E-2: 138 kV Transmission Network Model

Table E-3: 138 kV Transmission Network Data

138kV Transformer Winding Data
Holyrood Terminal Station

Transformer Designation			HRD_T6	HRD_T7	HRD_T8	Remarks
Transformer Type			Auto	Auto	Auto	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	Wye Gnd./ Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**25.000**	**25.000**	**75.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	33.300	33.300	100.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	41.700	41.700	125.000	
High Voltage	V_H	kV	230.000	230.000	230.000	
Low Voltage	V_L	kV	138.000	138.000	138.000	
Tertiary Voltage	V_T	kV	6.900	6.900	6.900	
Load Loss at Base MVA	kW_{loss}	kW	62.430	65.800	91.660	Nalcor Input (Transformer databook sheets)
Rated 230kV Current at Base MVA	I_{rated}	A	62.757	62.757	188.272	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.300	0.300	0.300	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.188	0.188	0.565	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.063	0.063	0.188	
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.094	0.094	0.282	230kV excitation current citeria used
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.250	0.263	0.122	
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	2,116.000	2,116.000	705.333	
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}/100$	Ω	5.284	5.569	0.862	
138kV Winding Resistance	R_{dc138}	Ω	2.114	2.228	0.345	See Notes 3 and 4

Equivalent Resistance of 230kV Transformers	$R_{HRD}=R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.262

138kV Transformer Winding Data
Bay Roberts

Transformer Designation			BRB_T1			Remarks
Transformer Type			Auto			
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Wye			
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**			Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000			
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A			
High Voltage	V_H	kV	138.000			Dual voltage transformer, 138kV and 66kV
Low Voltage	V_L	kV	12.500			Dual voltage transformer, 25kV and 12.5kV
Tertiary Voltage	V_T	kV	N/A			
Load Loss at Base MVA	kW_{loss}	kW	65.000			Typical value asumed.
Rated 138kV Current at Base MVA	I_{rated}	A	62.757			
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500			Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.314			
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.105			
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.157			
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.433			
Transformer Base Impedance	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,269.600			
DC Resistance	$R_{dc}=R_{tb}$ * $R_{\%}/100$	Ω	5.502			
138kV Winding Resistance	R_{dc138}	Ω	5.457			See Notes 3 and 4

Equivalent Resistance of 138kV Transformers	$R_{BRB}=R_{T1}$	Ω	5.457

HATCH™

Station Grounding Grids

Description			Resistance			Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5			Assumed
Bay Roberts Grounding Grid Resistance	$R_{G\ BRB}$	Ω	0.5			Assumed

138kV Transmission Line

			39L (HRD-BRB)			Remarks
Length of Transmission Line	l	km	41.89			Five sections, Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.0321148			Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	6.12			

Notes

1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio; for a 230/138kV transformer split is 60% (mid tap and above) and 40% (from neutral to mid tap).
4. Resistances of Delta windings are ignored for auto transformers.
5. The 138kV transfomer windings connected in Delta are not included in the tables.

HATCH™

Table E-4: 138 kV Transmission Network Simulation Results

138kV Transformer Results
Holyrood Terminal Station

Transformer Designation			**HRD_T6**	**HRD_T7**	**HRD_T8**
138kV Winding Resistance	R_{dc138}	Ω	2.114	2.228	0.345
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.094	0.094	0.282
Calculated DC Current (1-phase)	I_{dc}	A	0.048	0.046	0.295

Stray DC Current through T6, T7 and T8 Windings	I_{HRD}	A	1.167
Stray DC Current through T6, T7 and T8 (per phase)	$I_{HRD}/3$	A	0.389
Equivalent Resistance of 230kV Transformers	$R_{HRD}=R_{T6}\|\|R_{T7}\|\|R_{T8}$	Ω	0.262

138kV Transformer Results
Bay Roberts

Transformer Designation			**BRB_T1**
138kV Winding Resistance	R_{dc138}	Ω	3.861
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1} * 1.5$	A	0.251
Calculated DC Current (1-phase)	I_{dc}	A	0.044

Stray DC Current at Bay Roberts	I_{BRB}	A	0.132
Stray DC Current at Bay Roberts (per phase)	$I_{BRB}/3$	A	0.044
Equivalent Resistance of 138kV Transformers	$R_{BRB}=R_{T1}$	Ω	3.861

Notes:
1. The network was analyzed as a resistive network in the CDEGS software module MALZ.

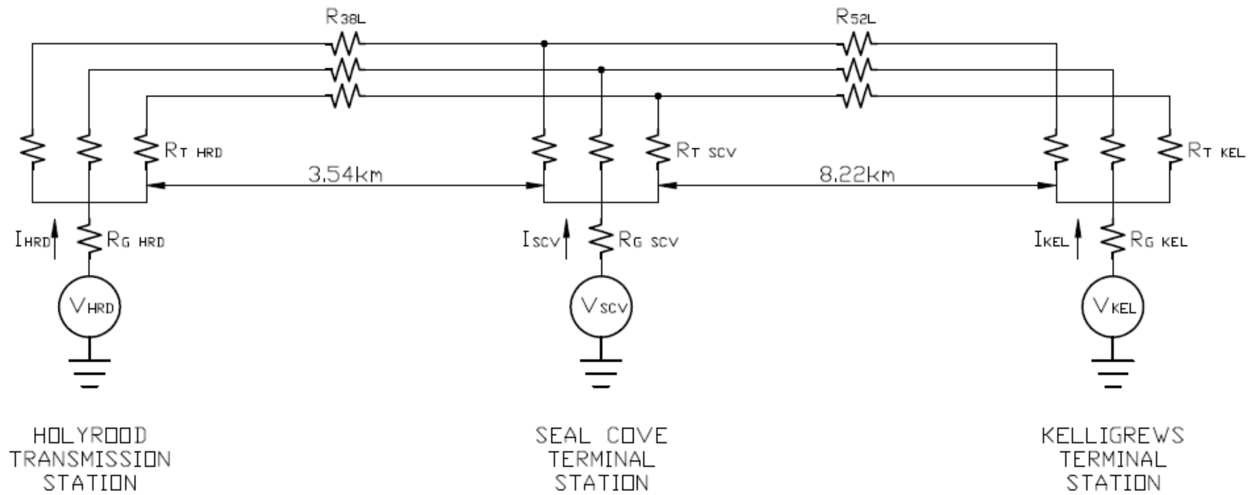


Figure E-3: 69 kV Transmission Network Model

Table E-5: 69 kV Transmission Network Data

69kV Transformer Data
Holyrood Terminal Station

Transformer Designation			HRD_T5	HRD_T10	Remarks
Transformer Type			Two Winding	Two Winding	
Winding Connections (High/Low/Tertiary)			Delta/ Wye Gnd.	Delta/ Wye Gnd.	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**15.000**	**15.000**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	20.000	20.000	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	25.000	25.000	
High Voltage	V_H	kV	230.000	230.000	
Low Voltage	V_L	kV	69.000	69.000	
Tertiary Voltage	V_T	kV	N/A	N/A	
Load Loss at Base MVA	kW_{loss}	kW	54.840	54.840	Nalcor Input (Transformer databook sheets)
Rated 69kV Current at Base MVA	I_{rated}	A	125.515	125.515	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.376	0.376	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.125	0.125	
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.188	0.188	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.366	0.366	
Transformer Base Impedance, 230kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	3,526.667	3,526.667	
DC Resistance from 230kV	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	12.893	12.893	
69kV Winding Resistance	R_{dc69}	Ω	1.065	1.065	See Notes 3 and 4

Equivalent Resistance of 69kV Windings	$R_{HRD}=R_{T5}\|\|R_{T10}$	Ω	0.532

69kV Transformer Data
Seal Cove

Transformer Designation			SCV_T1	SCV_T2	Remarks
Transformer Type			Two Winding	Two Winding	
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta	Wye Gnd./ Delta	
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**2.500**	**11.200**	Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	3.333	N/A	
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A	N/A	
High Voltage	V_H	kV	69.000	69.000	
Low Voltage	V_L	kV	2.400	12.470	
Tertiary Voltage	V_T	kV	N/A	N/A	
Load Loss at Base MVA	kW_{loss}	kW	20.000	45.000	Typical values assumed
Rated 69kV Current at Base MVA	I_{rated}	A	20.919	93.718	
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500	0.500	Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.063	0.281	
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.021	0.094	
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.031	0.141	
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.800	0.402	
Transformer Base Impedance, 69kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	1,904.400	425.089	
DC Resistance from 69kV	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	15.235	1.708	
69kV Winding Resistance	R_{dc69}	Ω	15.217	1.654	See Notes 3 and 4

Equivalent Resistance of 69kV Windings	$R_{SCV}=R_{T1}\|\|R_{T2}$	Ω	1.492

69kV Transformer Data
Kelligrews

Transformer Designation			KEL_T1		Remarks
Transformer Type			Two Winding		
Winding Connections (High/Low/Tertiary)			Wye Gnd./ Delta		
Rated MVA (ONAN)	$MVA_{rated\ ONAN}$	MVA	**11.250**		Nalcor Input (SLDs and transformer databook sheets)
Rated MVA (ONAF)	$MVA_{rated\ ONAF}$	MVA	14.950		
Rated MVA (OFAF)	$MVA_{rated\ OFAF}$	MVA	N/A		
High Voltage	V_H	kV	69.000		
Low Voltage	V_L	kV	12.470		
Tertiary Voltage	V_T	kV	N/A		
Load Loss at Base MVA	kW_{loss}	kW	45.000		Calculated based on positive sequence resistance
Rated 69kV Current at Base MVA	I_{rated}	A	94.136		
Excitation Current (% of rated current)	$I_{e3p\%}$	%	0.500		Typical value based on manufacturer's inputs
Excitation Current (3-phase)	$I_{e3p}=I_{e3p\%} \cdot I_{rated}$ /100	A	0.282		
Excitation Current (1-phase)	$I_{e1p}=I_{e3p}/3$	A	0.094		
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.141		
Percentage Resistance (1-phase)	$R_{\%}=kW_{loss}/(10*MVA_{rated})$	%	0.400		
Transformer Base Impedance, 69kV base	$R_{tb}=kV^2/MVA_{rated}$	Ω	423.200		
DC Resistance from 69kV	$R_{dc}=R_{tb} * R_{\%}/100$	Ω	1.693		
69kV Winding Resistance	R_{dc69}	Ω	1.639		See Notes 3 and 4

Equivalent Resistance of 69kV Windings	$R_{KEL}=R_{T1}$	Ω	1.639

Station Grounding Grids

			Resistance		Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5		Assumed
Seal Cove Grounding Grid Resistance	$R_{G\ SCV}$	Ω	0.5		Assumed
Kelligrews Grounding Grid Resistance	$R_{G\ KEL}$	Ω	0.5		

69kV Transmission Lines

			38L (HRD-SCV)	52L (SCV-KEL)	Remarks
Length of Transmission Line	l	km	3.54	8.22	Nalcor input
Total Resistance (pu)	R_{pu}	pu	0.0078796	0.0230975	Nalcor input
Total Resistance	$R_{dc}=R_{pu}*V_H^2/MVA_b$	Ω	0.3751478	1.0996720	

Notes
1. The nominal tap is considered for the calculations.
2. Base MVA is shown in bold.
3. For two-winding transformers, the resistance is based on the square of the voltage ratio; for a 230/138kV transformer split is 60% (mid tap and above) and 40% (from neutral to mid tap).
4. Resistances of Delta windings are ignored for auto transformers.
5. The 69kV transfomer windings connected in Delta are not included in the tables.

Table E-6: 69 kV Transmission Network Simulation Results

69kV Transformer Results
Holyrood Terminal Station

Transformer Designation			**HRD_T5**	**HRD_T10**
69kV Winding Resistance	R_{dc69}	Ω	1.065	1.065
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.188	0.188
Calculated DC Current (1-phase)	I_{dc}	A	0.060	0.060

Stray DC Current at Holyrood	I_{HRD}	A	0.360
Stray DC Current at Holyrood (per phase)	I_{HRD} /3	A	0.120
Equivalent Resistance of 69kV Transformers	$R_{HRD}=R_{T5}\|\|R_{T10}$	Ω	0.532

69kV Transformer Results
Seal Cove

Transformer Designation			**SCV_T1**	**SCV_T2**
69kV Winding Resistance	R_{dc69}	Ω	15.217	1.654
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.031	0.141
Calculated DC Current (1-phase)	I_{dc}	A	0.007	0.064

Stray DC Current at Seal Cove	I_{SCV}	A	0.211
Stray DC Current at Seal Cove (per phase)	I_{SCV} /3	A	0.070
Equivalent Resistance of 69kV Transformers	$R_{SCV}=R_{T1}\|\|R_{T2}$	Ω	1.492

69kV Transformer Results
Kelligrews

Transformer Designation			**KEL_T1**
69kV Winding Resistance	R_{dc69}	Ω	1.639
Acceptable DC Current (1-phase)	$I_{edc}=I_{e1}$ * 1.5	A	0.141
Calculated DC Current (1-phase)	I_{dc}	A	0.050

Stray DC Current at Kelligrews	I_{KEL}	A	0.149
Stray DC Current at Kelligrews (per phase)	I_{KEL} /3	A	0.050
Equivalent Resistance of 69kV Transformers	$R_{KEL}=R_{T1}$	Ω	1.639

Notes:
1. The network was analyzed as a resistive network in the CDEGS software module MALZ.

Appendix F

Distribution Neutrals Impact Assessment

12.47 kV

Model, Data and Results

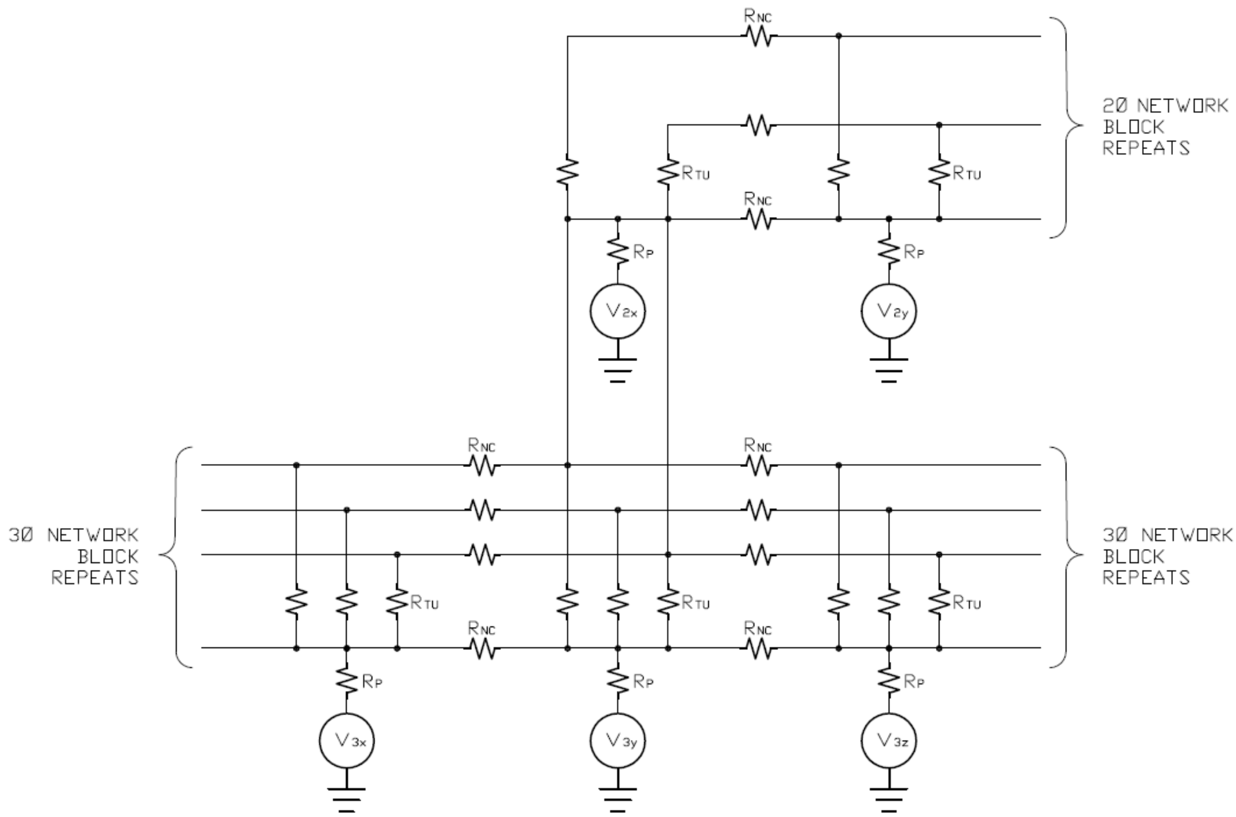


Figure F-1: 12.47 kV Distribution Network Model

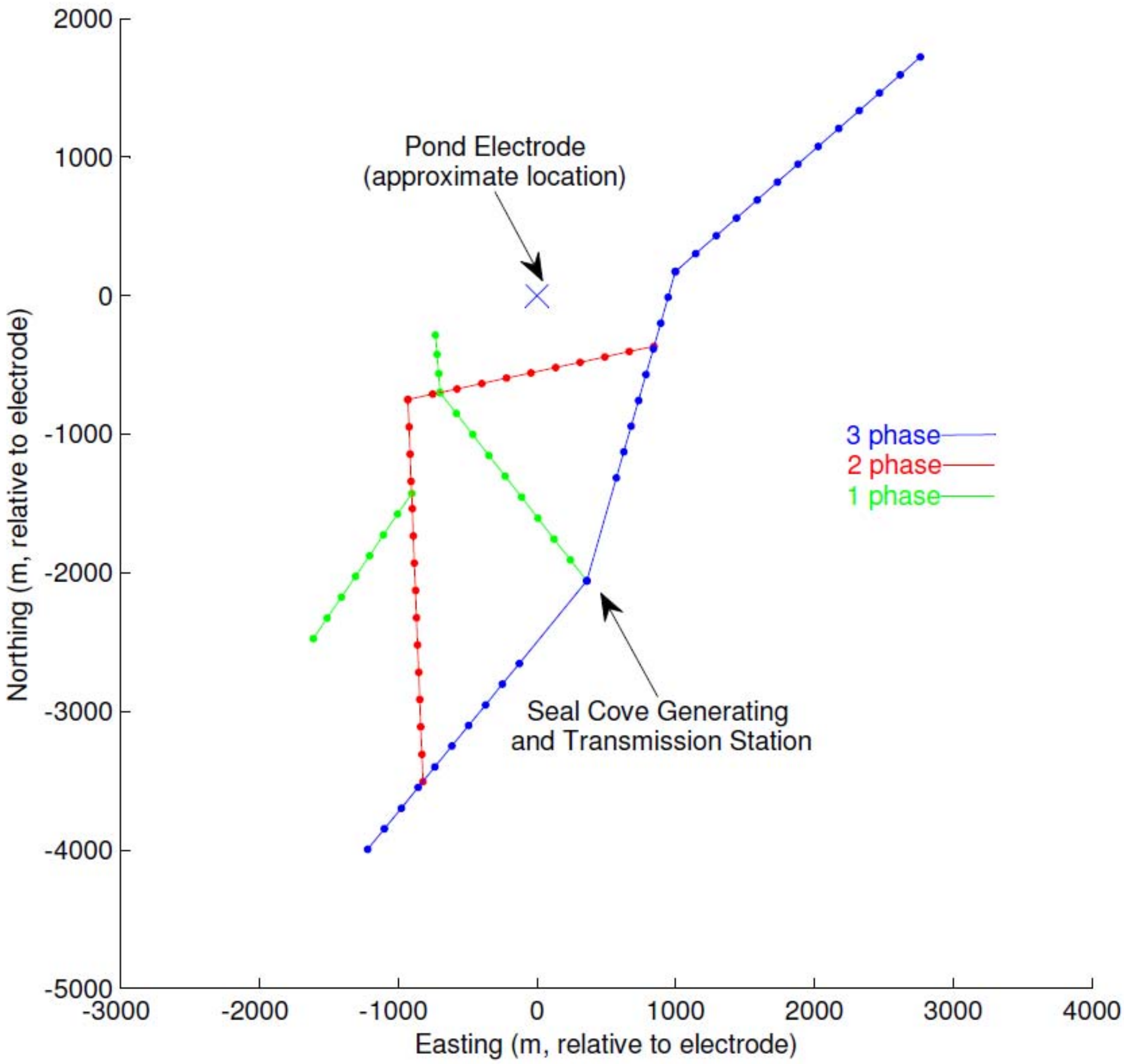


Figure F-2: Plan of 12.47 kV Distribution Network Model

HATCH™

Table F-1: 12.47V Distribution Network Data

Station Grounding Grids				**Remarks**	
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	0.5	(Assumed)	
Pole Grounding Resistance					
Pole Grounding Resistance	R_P	Ω	15	(Assumed)	
Distribution Transformers					
Utility Distribution Transformer	kVA_{TU}	kVA	25	(Assumed)	
Utility Distribution Transformer Resistance	R_{TU}	Ω	186.6		
Seal Cove Station Distribution Transformer	MVA_{SCVdis}	MVA	5	(Assumed)	
Seal Cove Station Distribution Transformer Resistance	R_{SCVdis}	Ω	0.187		
Line Resistances					
Span of Spacing of Distribution Transformers	l	m	200		
DC Resistance of Phase Conductor (2/0 ACSR)	R_{cond}	Ω/km	0.4255		
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.0851		
DC Resistance of Neutral Conductor (1/0 ACSR)	R_{cond}	Ω/km	0.5364		
Resistance of Transmission Line	$R_{sw}=l*R_{cond}$	Ω	0.10728		

Notes:
1. All utility transformers are assumed to be 1Ø.
2. Transformer spacing and pole grounding spacing is assumed the same for 1Ø, 2Ø and 3Ø circuits (200m).
3. Zero 3Ø utility transformers are assumed for the first 600m away from Seal Cove.

Table F-2: 12.47V Distribution Network Results

Pole Designation	GPR (V)	Calculated Current through Distribution Pole	Permissible Current through Copper Rods	Calculated Current through Transfomer Windings			Permissible Current through Transformer Windings
				AØ	BØ	CØ	
Seal Cove	4.000	-0.8779	0.1243	0.0657	0.0566	0.0670	0.7802
Closest Pole in 1Ø Line	6.250	0.0580	0.1243	N/A	0.0018	N/A	0.0232
Closest Pole in 2Ø Line	6.090	0.0491	0.1243	0.0020	N/A	0.0020	0.0232
Closest Pole in 3Ø Line	6.500	0.0627	0.1243	0.0023	0.0024	0.0023	0.0232

Notes
1. The polarity of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into pole; -ve from pole into ground.

Appendix G

Permissible Material Loss

Data and Calculations

Table G-1: Corrosion Data and Calculations for Permissible Material Loss and dc Stray Currents

HATCH™

Table G-1: Corrosion Data and Calculations for Permissible Material Loss and dc Stray Currents

Steel Foundation				***Remarks***
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	1	%	Assumed
Total Weight	m_{tot}	600000	g	Assumed
Electrode Duty (as Anode)	Ah_{duty}	18400000	A.h	
	=	2100.457	A.yr	
Ah to cause one molar mass loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Iron	$m_{Fe,mol}$	27.925	g	Molar mass divided by valence number
Allowable material Loss	$m_{loss}=m_{tot}*m_{\%}$	6000.000	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	5758.681	A.h	
Permissible Current through Steel Foundation	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.419	A	
Steel Guywire Anchors (two assumed)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	10	%	Assumed
Guywire Anchor Diameter	d	0.022	m	Assumed
Guywire Anchor Length	l	6	m	Assumed, Two anchors each 3 m long
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	17790.211	g	
Electrode Duty (as Anode)	Ah_{duty}	18400000	A.h	
	=	2100.457	A.yr	
Ah to cause one molar mass loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Iron	$m_{Fe,mol}$	27.925	g	Molar mass divided by valence number
Allowable material Loss	$m_{loss}=m_{tot}*m_{\%}$	1779.021	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	1707.469	A.h	
Permissible Current through Anchors	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.124	A	
Copper Grounding Rods (two assumed)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	50	%	Assumed
Grounding Rod Diameter	d	0.019	m	Assumed
Grounding Rod Length	l	6	m	Assumed, Two rods each 3 m long
Copper Density	w	8900000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	15140.435	g	
Electrode Duty (as Anode)	=	18400000	A.h	
	=	2100.457	A.yr	
Ah to cause one Molar Mass Loss	Ah_f	26.802	A.h	Faraday's Law
Molar Mass of Copper	$m_{Cu,mol}$	31.790	g	Molar mass divided by valence number
Allowable Material Loss	$m_{loss}=m_{tot}*m_{\%}$	7570.217	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Cu,mol}$	6382.382	A.h	
Permissible Current through Rods	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.465	A	

Appendix H

Geological Soil Data

Modeling Scenarios

Table H-1: Soil Modeling Scenarios

HATCH™

Table H-1: Soil Modeling Scenarios

Modeling Scenarios September 2009

Unit		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Conception Bay	Resistivity (Ohm-m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Thickness (meters)	100	100	100	100	100	100	100	100	100	100	100	100
Seal Cove Pond	Resistivity (Ohm-m)	100	100	100	100	100	100	100	100	100	100	100	100
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Lance Cove Pond	Resistivity (Ohm-m)	10	10	10	10	10	10	10	10	10	10	10	10
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Indian Cove Pond	Resistivity (Ohm-m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Surficial	Resistivity (Ohm-m)	1000	5000	10000	1000	5000	10000	1000	5000	10000	1000	5000	10000
Glacio-marine Top	Thickness (meters)	4	4	4	4	4	4	4	4	4	4	4	4
Surficial	Resistivity (Ohm-m)	100	300	500	100	300	500	100	300	500	100	300	500
Glacio-marine Middle	Thickness (meters)	3	3	3	3	3	3	3	3	3	3	3	3
Surficial	Resistivity (Ohm-m)	3000	5000	10000	3000	5000	10000	3000	5000	10000	3000	5000	10000
Glacio-marineLower	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5
Surficial	Resistivity (Ohm-m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Till Undifferentiated	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5
Surficial	Resistivity (Ohm-m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Poor Till	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5
Cambro-Ordovician	Resistivity (Ohm-m)	500	500	500	2000	2000	2000	500	500	500	2000	2000	2000
	Thickness (meters)	500	500	500	500	500	500	500	500	500	500	500	500
Granitoid-Volcanics	Resistivity (Ohm-m)	5000	5000	5000	5000	5000	5000	10000	10000	10000	10000	10000	10000
	Thickness (meters)	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth

Appendix N

Labrador Electrode Sites

Ground Potential Simulation

Suggested Models

Labrador Electrode Sites
Ground Potential Simulation
Suggested Models

Hugh G. Miller, P.Geo.

July 2009

Objective

To calculate the Ground Potential readings (GPR) which would be expected to occur at the Lower Churchill Power sites from the passage of DC current into electrodes located at various possible sites.

Required Input

A model of the crustal electrical structure based on the known geology and the expected ground electrical resistivities.

Input Data

Geology

The principal components of the geology which will have an influence on the calculated potentials are:

- The Surficial sediments. The surficial sediments consist, in the Lower Churchill River valley, primarily of glaciofluvial and glaciofluvial marine sediments in which there can be clay and silt layers of varying thickness. The actual thickness varies from place to place.
- Bedrock sediments. The bedrock sediments in the area under consideration consist of arkoses and conglomerates of the Double Mer Formation. The thickness of these sediments is unknown.
- Granitoid rocks which occupy most of the area. Elsewhere, there are numerous faults cutting to unknown depths in the granitoid rocks
- The Double Mer formation is present in a fault bounded graben. Gower (pers. Comm., 2009) suggests that thickness of 2000 – 3000 m may be the best estimate.

Electrical Resistivity

There is very little information on the electrical resistivity of the geological units in the study area. Resistivity sounding at sites associated with the LCP conducted by AMEC in 2007 revealed that the overlying surficial cover could have resistivities of the order of 1500 - 2000 ohm-m for dry sands, 50 ohm-m for inferred clays, and in the bedrock resistivities > 5000 ohm-m. These investigations sampled depths up to 40 m.

Magnetotelluric (MT) investigations in Labrador have been confined to deep investigations (Kurtz and Garland, 1976) conducted along the Quebec North Shore relatively distant from the present study area. Shallower audio-magnetotelluric (AMT) work has been conducted as part of exploration programs in Central and Northern Labrador (NL Natural Resources Exploration files). The Kurtz and Garland investigation was undertaken without any correction for the presence of induced currents in the nearby salt water in the Gulf of St. Lawrence. More modern MT studies (McNeice, 1998) have shown that these corrections are essential and influence the inferred resistivity structure, especially at periods typical of deep crustal penetration. Taken as a whole the Kurtz and Garland study provides weak evidence for the nature of the deep crust, and does not contradict the inference that the resistivities are most likely > 10 000 ohm-m to depths of the order of 50 km. Beyond that the evidence is less compelling, although there is a hint of a low resistivity layer, <50 ohm-m, at great depths >150km. The exploration reports typically report resistivities >10 000 ohm-m extending from surface to depths up to 2 km. Locally there are zones having resistivities with resistivities <1000 ohm-m, but their size is very small relative to the scale of investigation being undertaken in the current study.

The Statnet simulation presented in the Hatch Final Report DC110 Electrode Review uses resistivities in the 1000 – 5000 ohm-m for the Granitoid-Normal Crust. This is consistent with the values deduced by McNeice (1998) in the thesis studying the MT response in Newfoundland which investigated sites on the Island of Newfoundland. Since the Hatch study was investigating electrodes in the ocean with return current through Newfoundland geology, these values are consistent for their study. However, the preponderance of the Labrador data suggests it is appropriate to use larger resistivities there.

In summary for modeling the following resistivities are recommended:

- Surficial sediments - 50 ohm-m;
- Double Mer formation – 2000 -3000 ohm-m;
- Granitoid rocks 10000 ohm-m;
- Very deep resistivity 100 ohm-m;
- Resistivity for Lake Melville to be that for sea water.

The Models

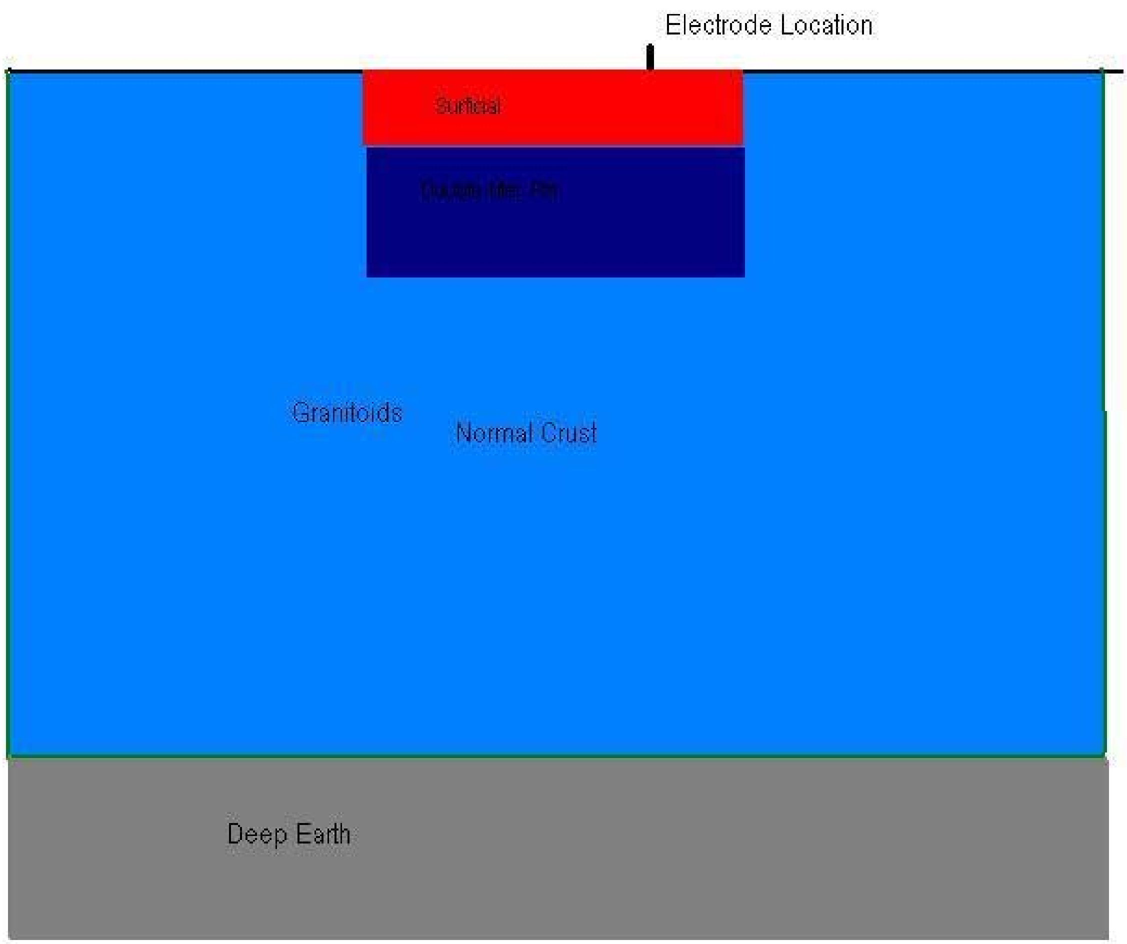
The spatial extent of the various geological units have been extracted for a provincial digital geology file and presented as a series of polygons for each feature. The X-Y coordinates of each unit are presented in the accompanying ASCII files (Text files) which should be able to be easily input into any computer program. The coordinates are the Easting and Northing in meters in UTM Zone 20 Datum NAD 83. Most of the area lies within Zone 20, portions within Zone 21 were converted to Zone 20 coordinates. The major decision to be made is the thickness of each unit. The files are:

- Lake Melville giving the shoreline of Lake Melville. The depth of the lake is not known, but a maximum of 100m could be used. The lake is probably underlain by the Surficial sediments and the Double Mer formation, but its low resistivity will probably mean these have little effect in that area.
- Surficial Sediments. These comprise the glacial marine sediments which contain the clays. The thicknesses to be used are given in the Scenario Table.
- Double Mer Formation which underlies the glacial marine sediments. The thicknesses to be used are presented in the Scenario Table
- The Electrode Location coordinates based on the selected sites from the Workshop priority table.
- Electrode file gives Electrode #, Electrode Name, Xcoord and Y coord
- File format for Lake Melville, Surficial and Double Mer files
    - Unit Name
    - Xcoord(Easting), Y coord(Northing)- coordinates in meters
    - Polygon # 1
    - Coords of point 1
    - Coords of point
    - Last point coordinate is same as first to close polygon
    - Polygon #3
    - Coords of point 1
    - Coords of point
    - Last point coordinate is same as first to close polygon
    - Repeat for each polygon in file

There should be a series of models run encompassing several scenarios as follows.

- Surficial sediments 50 m thick with resistivity 50 ohm-m underlain by Double Mer formation 2000 m thick with resistivity 2000 ohm-m. The rest of the area would have a resistivity of 10000 ohm-m down to whatever maximum depth is necessary for the construction of the model. This resistivity would extend from surface to the maximum depth everywhere outside the Surficial Sediments/Double Mer area, and from the bottom of the Double Mer to the maximum depth beneath the area covered by Surficial Sediments overlying Double Mer. (see sketch below).
- Same resistivities and thicknesses for the Surficial sediments and Double Mer Formation and for the rest of the area a resistivity of 10 000 ohm-m to a depth of 150 000 m (150 km), then a resistivity of 50 ohm-m for all depths below 150 000m (ie 150 km). The same comments apply regarding the area where the 10 000 ohm-m resistivity is to be applied.
- To assess the effect of variation in the thickness of the surficial sediments, two more scenarios should be run using the resistivities given for the surficial sediments and Double Mer, but using a Surficial Sediment thickness of 20m for one run and 100 m for the other. These two scenarios should be run for each of the deep resistivity scenarios.
- Consideration should be given to whether or not these scenarios all need to be run for each of the proposed electrode locations as the electrode will be closer to the boundaries of the various units in the proposed different locations. Once the basic geological/resistivity models have been loaded, it should be simple to vary the electrode locations to see the effect of that variation.

Schematic Cross-section (either N-S or E-W) illustration of disposition of various geological units to be used in model simulation (not to scale)



Lake Melville will overlie the surficial sediments in areas where it is present.

The scenarios to be modeled are presented in the following table:

Modelling Scenarios							
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Geological Unit							
Surficial	Resistivity (Ohm-m)	50	50	50	50	50	50
	Thickness (meters)	50	20	100	50	50	50
Double Mer	Resistivity (Ohm-m)	2000	2000	2000	2000	2000	2000
	Thickness (meters)	2000	2000	2000	2000	3000	2000
Granitoid	Resistivity (Ohm-m)	10000	10000	10000	10000	10000	5000
Normal Crust	Thickness (meters)	To max depth	To max depth	To max depth	150000	To max depth	To max depth
Deep Earth	Resistivity (Ohm-m)	N/A	N/A	N/A	50	N/A	N/A
	Thickness (meters)	N/A	N/A	N/A	To max depth	N/A	N/A

Notes on Scenarios

Comparison of the output from Scenarios 1, 2 &3 will enable the effect of variation of the surficial layer to be examined.

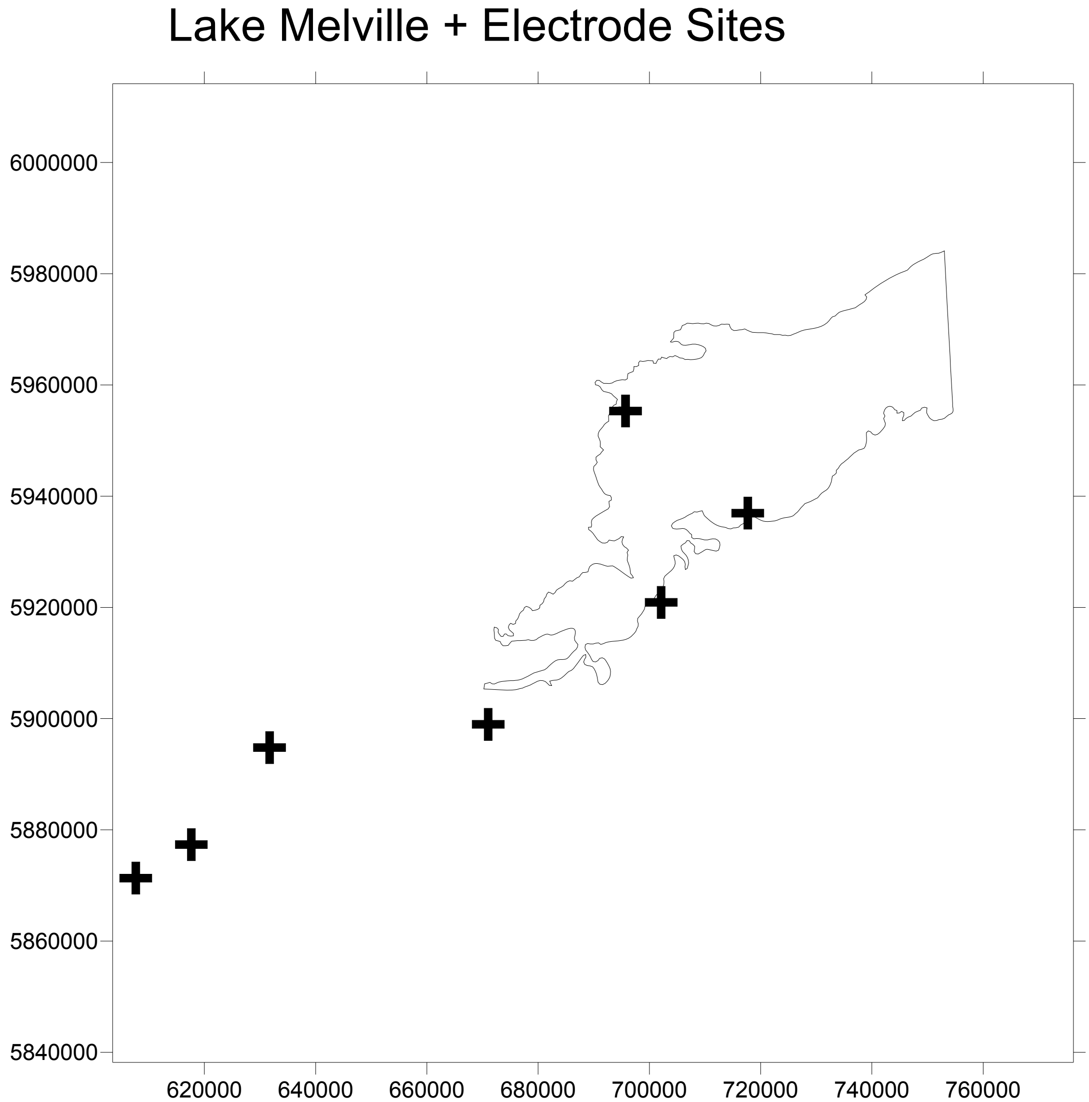
Comparison of Scenarios 1&4 will enable the effect of including the Deep Earth layer to be assessed.

Comparison of Scenarios 1&5 will enable the effect of varying the Double Mer Formation thickness to be assessed.

Comparison of Scenarios 1&6 will enable the effect of changing the Granitoid resistivity to be assessed. These scenarios should be run for various Electrode Site locations within the surficial unit as defined by the priority assessment table distributed with the Workshop Summary. The electrode coordinates are presented in the Electrode file.

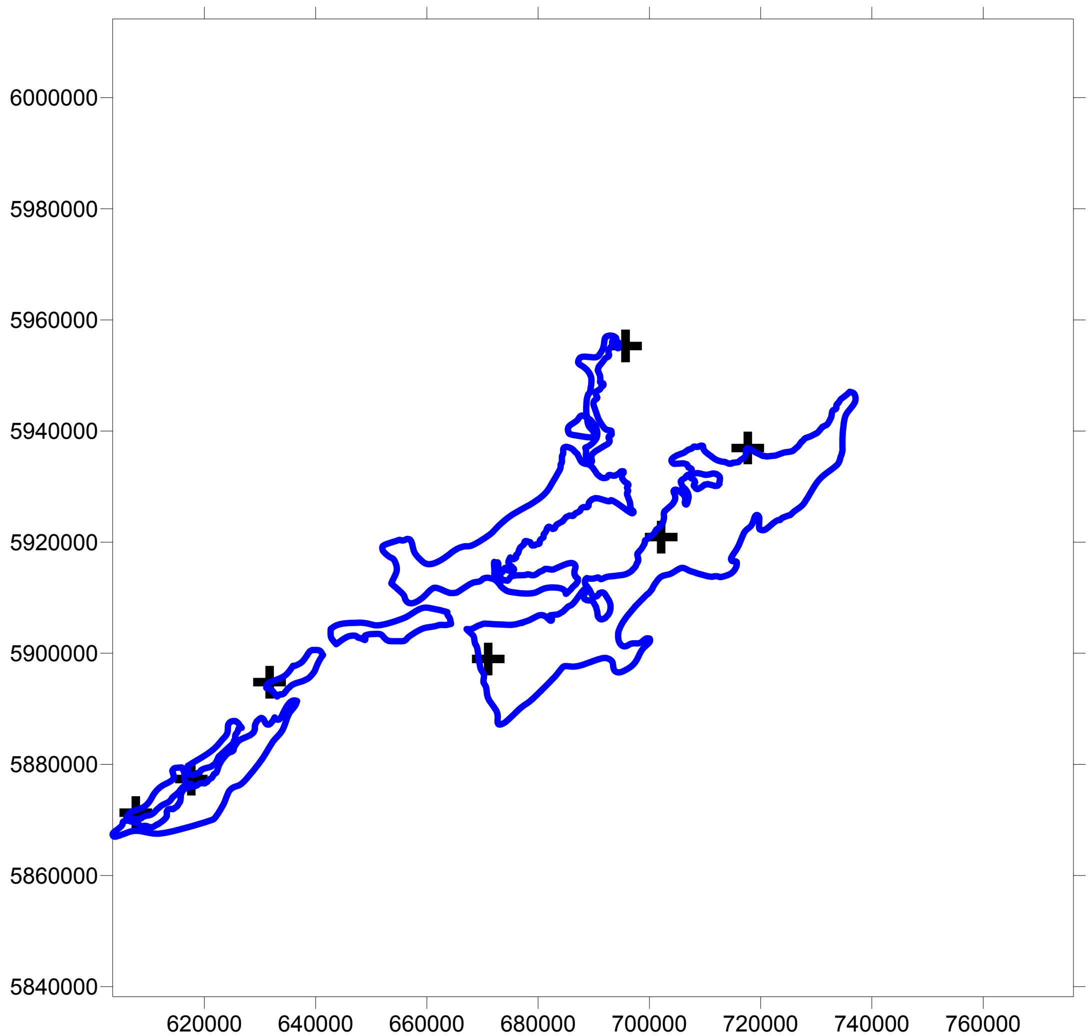
It is recommended that Scenario 1 be re-run with the 5000 ohm-m resistivity for the Granitoid –Normal Crust layer (presented as Scenario 6). This will provide information on the sensitivity of the results to variations in the resistivity of the major geological unit. Additional scenarios to be considered would be to keep the Surficial at 50/50, the Double Mer at 2000/2000 and vary the Granitoid –Normal Crust Resistivity to 5000 ohm-m and to 20000 ohm-m for each of the Normal Crust and Deep Earth Scenarios (Scenarios 1 and 4).

Plot of Electrode Locations and Lake Melville



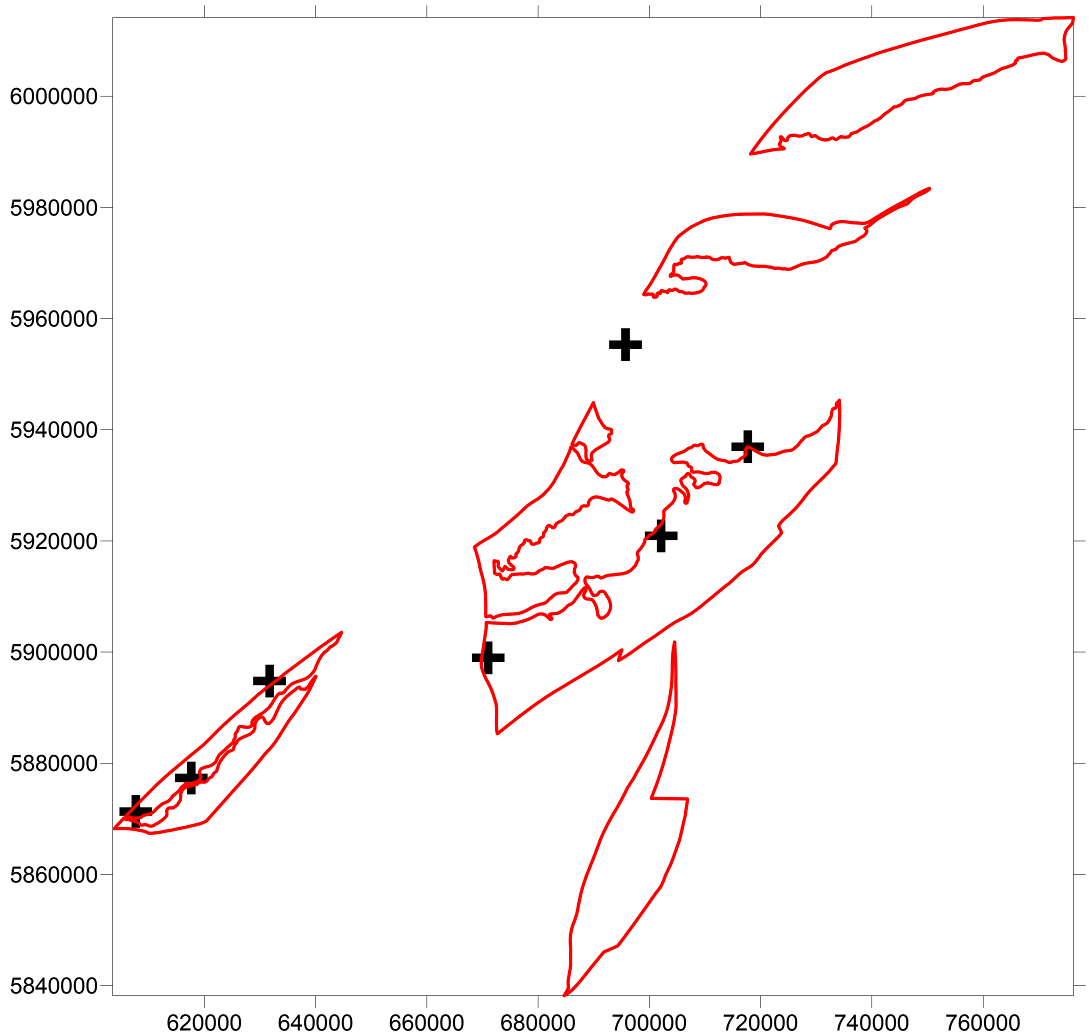
Plot of Electrode Locations and Surficial Unit

Surficial Geology + Electrode Sites



Plot of Electrode Locations and Double Mer Formation

DoubleMer Formation + Electrode Sites



NOTE: The southernmost and the most northerly polygon can probably be eliminated from the simulations.

Appendix O

Dowden's Point Electrode

Ground Potential Simulation

Suggested Models

Dowden's Point Electrode
Ground Potential Simulation
Suggested Models

Hugh G. Miller, P.Geo.

September 2009

Objective

To calculate the Ground Potential readings (GPR) which would be expected to occur at the Holyrood generation site and in the surrounding area from the passage of DC current into an electrodes located at the Dowden's Point location.
Required input

A model of the crustal electrical structure based on the known geology and the expected ground electrical resistivities.
Input Data

Based on the geology within a circle of 3.5 km radius centered on the proposed electrode location. This radius chosen to encompass the Holyrood generation site.

Thermal Data

Thermal data consisting of the thermal conductivity and thermal capacity were obtained from three fine grain samples taken from three separate test pits excavated as part of the field work conducted at Dowden's Point in September. The results are summarized below:

Dowden's Point
Thermal Data

Sample #	Test Pit	Schlumberger Site	Thermal Conductivity (W/mK)	Standard Deviation (W/mK)	Thermal Capacity (MJ/m^{3}K)	Standard Deviation (MJ/m3K)
1	7		1.87	0.03	2.12	0.12
2	3	4	1.98	0.17	2.14	0.07
3	5	1	1.34	0.01	1.63	0.14
		Average	1.73		1.96	

Geology

The principal components of the geology which will have an influence on the calculated potentials are:

- The Surficial sediments. The surficial sediments consist, in the Seal Cover area, primarily of glaciomarine and marine sediments in which there can be clay and silt layers of varying thickness, undifferentiated thin till veneer and poor drift as described by Liverman, 1990. The thickness of each unit in the area is unknown.
- Bedrock sediments. The bedrock sediments in the area under consideration are the Cambro-Ordivician Manuels River Formation comprising black shale and lenses of limestone, mafic and pillow lavas and pyroclastics underlain by the Chamberlains Brook Formation consisting of green and red

shale and slate, thin limestone beds, a thin manganiferous bed near the base, and spillite cherty pillow lavas. The thickness of these sediments is unknown.

- Granitoid and volcanic rocks underlie these consolidated sediments throughout the area. These granitic and volcanic rocks also directly underlie the surficial cover in regions where the Cambro-Ordovician sediments are not present.
- The nature of the bedrock geology beneath the Conception Bay portion of the area is inferred from the geology around the nearby regions. The surficial geology at the seabed is also inferred from the adjacent land geology. The geology is summarized in the schematic diagram below.

Electrical Resistivity

There is very little information on the electrical resistivity of the geological units in the study area. Resistivity sounding at the Soldier's Pond site conducted by AMEC in 2007 associated with the LCP indicated very thin cover overlying granitic bedrock at the site. The thin overlying surficial exhibited resistivities < 500 ohm-m and the underlying bedrock had resistivities > 8000 ohm-m. AMEC has measured the resistivity at a variety of other sites on the Avalon Peninsula in other projects, and these indicate resistivities in the 1000 – 4000 ohm-m range for the near surface consolidated sediments similar in age to the Cambro-Ordovician sequences overlying the bedrock granitoids and volcanics.

A major magnetotelluric (MT) investigation on the island of Newfoundland was undertaken by McNeice (1994). This investigation only occupied a few stations in the western Avalon Zone. For these, the upper 10 kilometers of crust exhibited resistivities varying from 1000 – 5000 ohm-m, similar to those reported by the shallower investigations of AMEC further east on the Avalon. McNeice reports low resistivity for the very deep portion of the crust. For the limited area being simulated for the present investigation, this deep resistivity is not a factor.

In the Dowden's Point simulation area there are four water bodies, the ocean of Conception Bay which is salt water, Lance Cove Pond which is considered to be brackish water, Seal Cove Pond which is fresh water, and Indian Cove Pond which is salt water. These will accordingly have different resistivities.

The Statnet simulation presented in the Hatch Final Report DC110 Electrode Review uses resistivities in the 1000 – 5000 ohm-m for the Granitoid-Normal Crust. This is consistent with the values deduced by McNeice (1998) in the thesis studying the MT response in Newfoundland which investigated sites on the Island of Newfoundland. Since the Hatch study was investigating electrodes in the ocean with return current through Newfoundland geology, these values are consistent for their study.

Field work associated with the present project was conducted in September 2009. This work involved three Schlumberger soundings to ascertain the vertical resistivity structure along with test pits and boreholes to provide stratigraphic information. Thermal tests were conducted on three samples from the test pits. A complete report on the field investigation is being submitted to NALCOR.

For modeling in the present simulations, the area has been divided into several areas, the lateral coordinates for which are presented in the attached files discussed below. The recommended scenarios are summarized in the spreadsheet presented later. The following notes pertain to the specific properties assigned to the various units in the modeling:

- Surficial sediments

- o The surficial sediments are divided into four basic model units – the glaciomarine unit on land and beneath Conception Bay. This unit exists in the Seal Cove valley.
- o The Poor Drift Till and the Till Undifferentiated.
- o The variation in resistivity is assigned to the Glacio-marine sediments based on the field investigation.

- Cambro-Ordovician rocks which are found beneath the surficial sediments throughout the whole area being modeled. For modeling these are assigned a relatively low resistivity of 500 ohm-m and a higher resistivity of 2000 ohm-m in various scenarios.
- Combined granitoid rocks and /or volcanic rocks which underlie the Cambro-Ordovician and are assigned resistivities of 5000 ohm-m or 10,000 ohm-m.
- Resistivities for the various water bodies are assigned in accord with the type of water in each.

The Models

The lateral spatial extent of the various geological units has been extracted from a provincial digital geology file and presented as a polygon for each feature. The vertical extent is determined from the field work for the Glacio-marine unit and estimated from geological information for the other units. The X-Y coordinates of each unit are presented in the accompanying ASCII files (Text files) which should be able to be easily input into any computer program. The coordinates are the Easting and Northing in meters in UTM Zone 22 Datum NAD 83. The major decision to be made is the thickness of each unit. All edges of the polygons are assumed to have vertical boundaries, so the coordinates can be used as the boundaries at all depths. The files are:

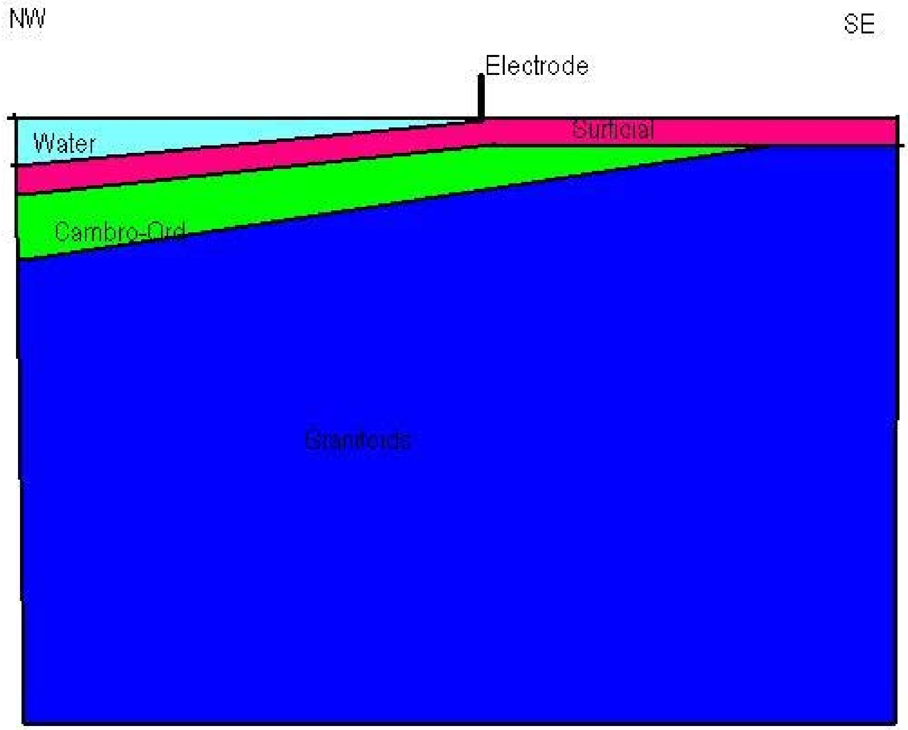
- The Electrode Location coordinates based on the selected site. Two electrode locations are provided, the first located on the shoreline would simulate a Shore or Pond electrode located at the interface between the sea and the land; the second is located on the inland side of the berm in the old pit and would provide information on the effect of a land electrode.
- The Electrode file gives Electrode Name, Xcoord and Y coord
- Dowden's Point Water Update giving the boundaries of Conception Bay, Seal Cove Pond, Indian Cove Pond and Lance Cove Pond. The depth of the ponds is not known, but a maximum of 10m could be used. The depth of water in Conception Bay varies up to approximately 100m at the outer limits of the scenario area; hence an average depth of 50m may be appropriate.
- Surficial Sediments: This file contains the units which comprise the unconsolidated sediments. The glacio-marine has been divided into three units, a Top, Middle and Lower Unit. The thickness and resistivity of each is presented in the Scenario table given below. The Glacio-marine unit has been divided into polygons, the portion on land and the inferred portion comprising the seabed in Conception Bay. The same vertical subdivision for the glacio-marine should be used both on land and beneath the sea. So in modeling there will be six glacio marine units, three on land and three subsea. Each of the land units will have the same lateral coordinates and be stacked top-middle-bottom. The subsea glacio-marine units will be similarly stacked. The other units are Till Undifferentiated and Poor Drift. The thicknesses and resistivities for these are given in the Scenario Table.
- Solid Rocks: Cambro-Ordovician sediments which underlie the surficial sediments and overlie granitoid-volcanic bedrock. The thickness and resistivities to be used are given are presented in the Scenario Table. The thickness has been kept fixed and the resistivity varied for the simulation scenarios. Dip shown on diagram is 6^0 to 10^0 to the northwest.
- File format for Water, Surficial and Solid Rock files

- o Unit Name
- o Xcoord(Easting), Y coord(Northing)- coordinates in meters
- o Coords of point 1
- o Coords of point
- o Last point coordinate is same as first to close polygon
- o Unit Name for next unit
- o Coords of point 1
- o Coords of point
- o Last point coordinate is same as first to close polygon
- o Repeat for each polygon in file

There should be a series of models run encompassing several scenarios as follows:

- The depth of Conception Bay should be kept constant based on the digitized bathymetry. The depth of the three ponds should be kept constant at 10 m.
- The thickness of the Till Undifferentiated and Poor Drift units should be kept constant at 5m with resistivity kept at 2000 ohm-m.
- The resistivity and thickness of the various layers of the Glacio-marine unit have been determined from the field work. The various scenarios allow for simulations to assess the sensitivity to these variations
- The Cambro-Ordovician unit should be given a thickness of 500 m based on the outcrop width and the known dip (between 6^0 and 10^0). The resistivity of the unit should be varied using 500 ohm-m and 2000 ohm-m as indicated in the scenarios, again to assess the sensitivity to the variation.
- The bedrock Granitoids and volcanics are considered to have the same resistivity. This unit should be extended in depth to the limit used in modeling and the resistivity varied using 5000 ohm-m and 10000 ohm-m as indicated in the scenarios

  Schematic Cross-section (NW-SE) illustrating the disposition of various geological units to be used in model simulation (not to scale). The Surficial unit present (Glacio-marine, Till Undifferentiated or Poor Drift) used depends on where cross-section intersects shoreline.


NW
SE
Electrode
Water
Surficial
Cambro-Ord
Granitoids

The scenarios to be modeled are presented in the following table:

Modeling Scenarios September 2009													
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Unit													
Conception Bay	Resistivity (Ohm-m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Thickness (meters)	100	100	100	100	100	100	100	100	100	100	100	100
Seal Cove Pond	Resistivity (Ohm-m)	100	100	100	100	100	100	100	100	100	100	100	100
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Lance Cove Pond	Resistivity (Ohm-m)	10	10	10	10	10	10	10	10	10	10	10	10
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Indian Cove Pond	Resistivity (Ohm-m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Thickness (meters)	10	10	10	10	10	10	10	10	10	10	10	10
Surficial	Resistivity (Ohm-m)	1000	5000	10000	1000	5000	10000	1000	5000	10000	1000	5000	10000
Glacio-marine Top	Thickness (meters)	4	4	4	4	4	4	4	4	4	4	4	4
Surficial	Resistivity (Ohm-m)	100	300	500	100	300	500	100	300	500	100	300	500
Glacio-marine Middle	Thickness (meters)	3	3	3	3	3	3	3	3	3	3	3	3
Surficial	Resistivity (Ohm-m)	3000	5000	10000	3000	5000	10000	3000	5000	10000	3000	5000	10000
Glacio-marineLower	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5
Surficial	Resistivity (Ohm-m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Till Undifferentiated	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5

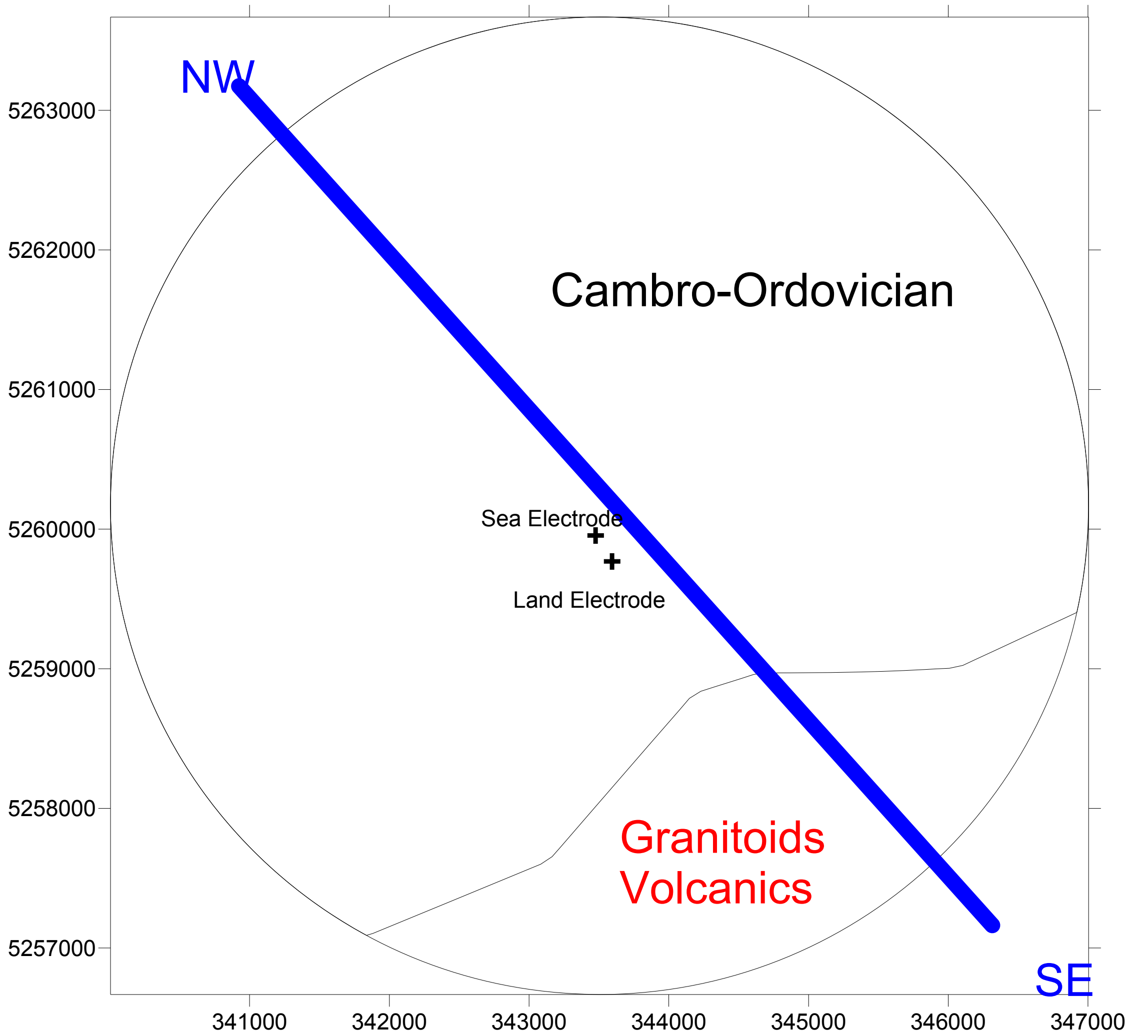
		Modeling Scenarios September 2009											
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Surficial	Resistivity (Ohm-m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Poor Till	Thickness (meters)	5	5	5	5	5	5	5	5	5	5	5	5
Cambro-Ordovician	Resistivity (Ohm-m)	500	500	500	2000	2000	2000	500	500	500	2000	2000	2000
	Thickness (meters)	500	500	500	500	500	500	500	500	500	500	500	500
Granitoid-Volcanics	Resistivity (Ohm-m)	5000	5000	5000	5000	5000	5000	10000	10000	10000	10000	10000	10000
	Thickness (meters)	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth	To max depth

Notes on Scenarios

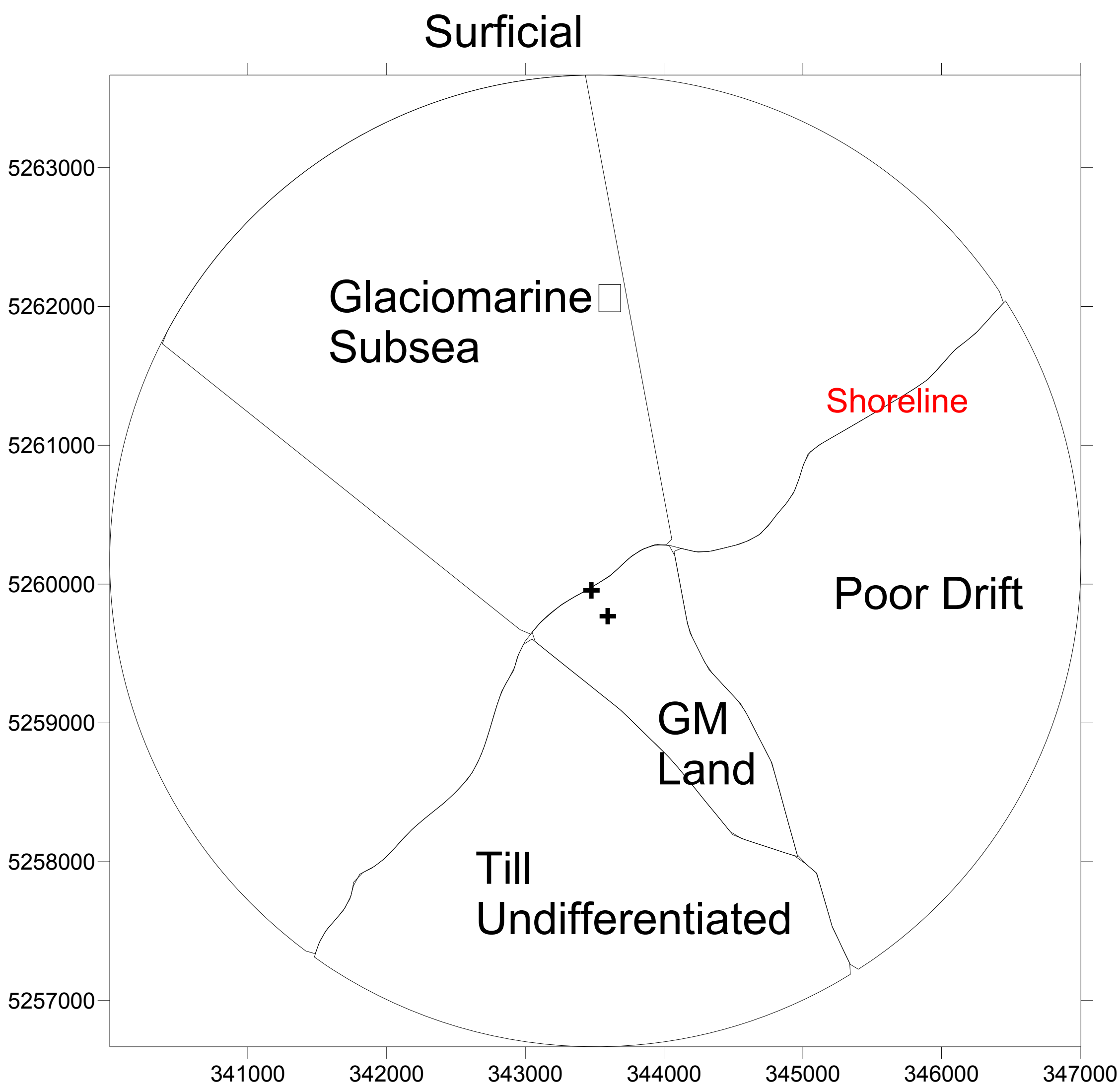
- The Water features are kept constant with the resistivities and thickness as shown for all the simulations
- The Undifferentiated Till and Poor Drift resistivity and thickness are kept constant for all scenarios.
- The thicknesses of the glacio-marine sub-units units are kept constant; the resistivities are varied.
- The thickness of the Cambro-Ordovician unit is kept constant at 500 m and the resistivity varied from 500 ohm-m to 2000 ohm-m.
- The resistivity of the underlying granitoids and volcanics is varied from 5000 ohm-m to 10000 ohm-m.
- The major unit likely to affect the response is the glacio-marine. Accordingly all the first three scenarios for its variation should be run with Scenario 2 being the “Most Likely”. Running this and Scenario 5 will allow the sensitivity to the Cambro Ordovician to be assessed, then running Scenario 8 or 11 will give a sensitivity check on the effect of the Basement Granitoids/Volcanics. Repeating with Scenario 1 or 3 will assess the sensitivity to the least resistive unit in the Glacio-marine.

Plots of various units NW-SE indicates position of illustrative profile

Solid Rock Configuration

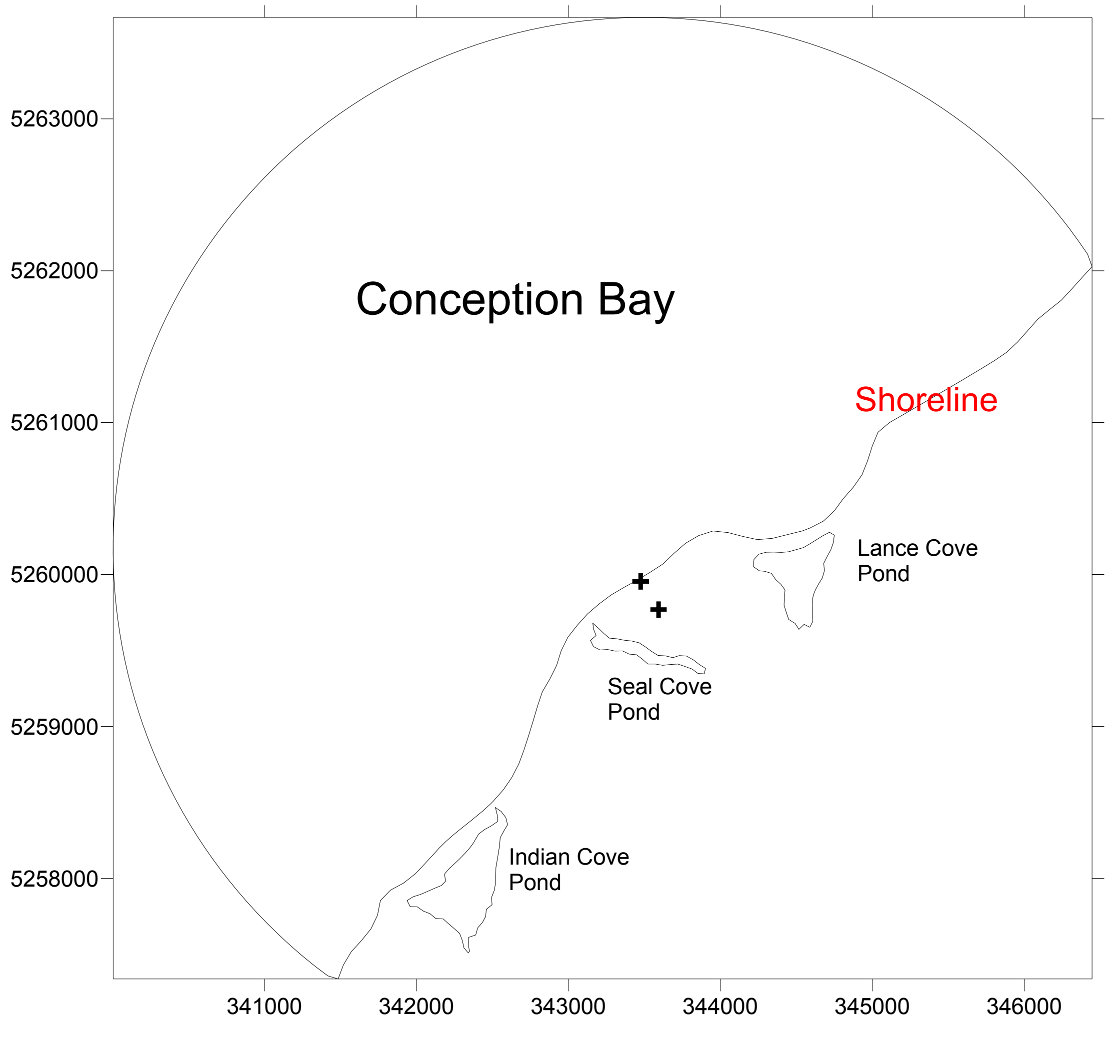


The Granitiods – Volcanics continue throughout the area beneath the Cambro-Ordovician as illustrated in profile



The GM Land unit is the glaciomarine unconsolidated sediments on land. The Undifferentiated Till and Poor Drift do not continue beneath Conception Bay.

Water Bodies



Appendix P

L'Anse-au-Diable

Area Maps and Site Photographs

Figure P-1: Area Map of L'Anse-au-Diable

Figure P-2: Oblique View of L'Anse-au-Diable and Surrounding Topography

Figure P-3: Site Photo at L'Anse-au-Diable, facing South

Figure P-4: Site Photo of Beach at L'Anse-au-Diable, facing South-West