prepared for

nalcor energy

DC1500

Electrode Review

CONFIRMATION OF TYPE AND SITE SELECTION

FINAL REPORT

December 2010

H335672-DC1500-RPT-CA01-2501
Rev 0

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HATCH™

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Executive Summary

As part of the Lower Churchill Project, a three terminal, high voltage direct current (HVdc) transmission system between mainland Labrador, the island of Newfoundland and the Maritime provinces is planned. The dc transmission system will be bipolar and will involve three terminal stations, cable and overhead line to connect the terminals stations, HVdc electrodes, and electrode lines between the terminal station neutral buses and the electrode locations. HVdc electrodes are required for the earth return monopolar operation of the system.

Various electrode types and locations for electrode installations were reviewed in the previous studies [1,7,8], considering the electrical interference, corrosion and environmental impacts associated with the construction and operation of an electrode, to select the most suitable electrode installations for the Gull Island and Soldiers Pond terminals. In DC1250 [1], land and lake shoreline pond type electrodes located in mainland Labrador were ruled out as viable options for the Gull Island electrode due to unfavourable soil conditions (high resistivity rock) in the area and the expected impacts of the electrode on the surrounding infrastructure. For the Soldiers Pond terminal, the analysis concluded a shoreline pond electrode at Dowden's Point in Conception Bay as a viable site. It was recommended that a similar shoreline pond electrode along the North shoreline of the Strait of Belle Isle (SOBI) be investigated for the Gull Island electrode; a desktop review identified L'Anse-au-Diable (LAD) as a candidate site. Also, the next steps [1] to qualify the assumptions and to further analyze the design of the Dowden's Point shoreline pond electrode were suggested.

Based on the suggested next steps in the DC1250 report, NE-LCP decided to undertake a more detailed study to select a suitable location along the shoreline of the SOBI for the Gull Island electrode, to confirm the analysis [1] of the Soldiers Pond electrode impacts and to develop conceptual design of the electrode installations for better defining the electrode installations and facilitating the land procurement and environmental impact assessment tasks. NE-LCP retained Hatch to lead the study, and work with a panel of experts in HVdc electrodes, electrode lines, marine structures, and local geology and geophysics. The panel participants and their specific areas of expertise are as follows:

Donald Gordon, Teshmont Consultants LP – HVdc electrodes;

Terry Treasure, Hatch – HVdc electrodes;

Hugh Miller, AMEC – Geophysics;

Calvin Miles, AMEC – Geotechnical;

Joanne Hu and Bruno Bisewski, RBJ Engineering – Electrode lines;

Scott Hancock, Hatch – Marine structures;

Rauf Ahmed and Ben McLeod, Hatch – HVdc electrodes and panel coordinators.

This work was conducted as WTO DC1500 *"Electrode Review – Confirmation of Type and Site Selection"*. The key objectives of the study were as follows:

- Gull Island Shoreline Pond Electrode
    - Undertake a site investigation to select the candidate sites along the shoreline of the SOBI and perform an analysis to pick the most likely site for further analysis.
    - Undertake a literature review to develop the sea and soil model.
    - Perform the electric field study.
    - Review the infrastructure in the vicinity of the electrode, and study electrical interference and corrosion impacts associated with the electrode operation.
    - Develop electrode layout and details, and provide NE-LCP information for land procurement and environmental assessment.
    - Review electrode line fault detection and protection.
    - Develop cost estimate of electrode installations with NE-LCP inputs.
- Soldiers Pond Shoreline Pond Electrode
    - Undertake a literature review for improving the sea and soil model.
    - Perform the electric field study based on revised sea and soil model and refined electrode model.
    - Revisit the electrical interference and corrosion impact analysis and suggest additional mitigation measures if required.
    - Develop electrode layout and details, and provide NE-LCP information for land procurement and environmental assessment.
    - Develop cost estimate of electrode installations with NE-LCP inputs.

The key findings of the reviews and analyses completed under WTO DC1500 are:

- Gull Island Shoreline Pond Electrode
    - The cove at L'Anse-au-Diable (LAD) North is viable for a shoreline pond electrode. The bathymetry of the cove requires extending the middle section of the breakwater approximately 75 m into the sea to achieve the required low tide depth of 4 m at the toe of the breakwater.
    - The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode exceed the permissible dc stray current values that will consume 50% of the ground electrode material (a typical acceptable consumption of ground electrode material) over the life of the project. Corrosion of grounding poles is not a significant concern and the issue can be addressed through regular inspection and replacement as required.
    - Based on the theoretical analysis, corrosion impact on the HVdc submarine cable resulting from the electrode operation is minimal and is not of concern. However, corrosion of the submarine cable is a complex phenomenon that is a function of geomagnetic induced current, chemistry of the sea environment and land fall installation, dc stray current

associated with an electrode operation and should be studied during the detail engineering stage.

- The impact of the electrode operation on the marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 2.6 km into the SOBI, and it is not of concern.
- Reliable fault detection on a long electrode line like the one from the Gull Island converter station to the LAD North electrode location is a difficult technical problem. It may not be possible to achieve reliable fault detection; therefore the line insulation should be designed to ensure that any arcing will be self-extinguishing and diverted away from the insulators. Undetected faults such as trees falling against the line and dropped conductors are the main safety concerns. If a sensitive detection is not possible then the risks shall be mitigated by other means such as greater emphasis on tree cutting in the right of way, safe and rugged electrode line design and more frequent line patrols.
- The engineering, procurement and construction (EPC) cost of the shoreline pond development at LAD North electrode (Option 1) for the Gull Island converter station is expected to be $ million CAD.

- Soldiers Pond Shoreline Pond Electrode
  - The literature review suggests a worst case seawater resistivity of 0.38 Ωm, which is higher than the 0.2 Ωm used in the DC1250 analysis. Consequently, higher GPR values at the locations of interest were observed.
  - The analysis of the additional infrastructure information provided by NE-LCP shows that the effect of the higher GPR values were not significant. The actual grounding impedances are far higher than the conservative estimates used in DC1250 (approximately by a factor of 10 to 30). The calculated dc stray currents through the transformer windings, transmission line pole foundations, guywire anchors, and pole grounding systems are less than the calculated acceptable limits.
  - The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode do not exceed the permissible dc stray current values that will consume 50% of the ground electrode material, a typical acceptable consumption of ground electrode material. There may be situations where the dc stray current through a pole grounding 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. Corrosion of pole grounding rods can be addressed through regular inspection and replacement as required.
  - The impact of the electrode operation on the marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 1.5 km into Conception Bay, and it is not of concern.
  - The construction of the shoreline pond and breakwater without requiring excavation of the seabed will result in extending the structure approximately 130 m into the sea. In case the development in the sea is not feasible, a pond can be developed at the shoreline and this

will require excavating the seabed to achieve a depth of 4 m at the shoreline and subsequently implement a maintenance plan to monitor and maintain the depth.

- The engineering, procurement and construction (EPC) cost of the shoreline pond development (Option 1) at Dowden's Point is expected to be $ million CAD.

A conservative approach was adopted for the electrical field study, electrical interference and corrosion impacts based on best information and analysis technique available. The body of work in this report confirms the adequacy for the application of the electrode at LAD North for Gull Island and at Dowden's Point for Soldiers Pond, and provides information required for the land procurement to apply for environmental assessment.

The actual electrical interference and corrosion impact values may be different from those calculated in this study since dc stray currents from natural sources like inhomogeneous soil chemistry, telluric currents and other industrial operations are not considered. Also, the civil/structural designs are based on assumed geotechnical information and area topography. Moreover, the auxiliary systems proposed for the electrode installations do not take into account NE-LCP's operation and maintenance practices or integration into overall HVdc system. In order to mitigate risks associated with the assumed parameters and to have a sound understanding of the impact of a shoreline pond electrode, the following next steps should be considered:

- Undertake an environmental assessment of the proposed installations including the electrode lines to qualify the locations and designs. Adjust the locations or designs if required (a minor adjustment in location maintaining the same electrode design parameters will not require reassessment).
- Review the auxiliary systems proposed for each electrode location taking into account operation and maintenance practices of NE-LCP and integration into overall HVdc system. Adjust the auxiliary systems as required.
- Identify the shoreline and inland topographic survey requirements and undertake a field program to collect the information required to better define the civil/structural design.
- Identify the geotechnical investigation, wind and wave study requirements, and undertake a field program to collect the data to further the civil/structural design.
- Measure current during the electrode commissioning tests in large transformer grounded neutral leads, transmission line and distribution line ground leads, and rotating machine grounded neutral leads.
- Assess the corrosion potentials for pipeline, large storage tanks and other major metallic structures in the area during the electrode commissioning tests.

1. Introduction

As part of the Lower Churchill Project, a three terminal, high voltage direct current (HVdc) transmission system between mainland Labrador, the island of Newfoundland and the Maritime provinces is planned. The dc transmission system will be bipolar and will involve three terminal stations, cable and overhead line to connect the terminals stations, HVdc electrodes for earth return in monopolar operation, and electrode lines between the terminal station neutral buses and the electrode locations. 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 Salisbury terminal in New Brunswick is optional. The proposed HVdc system is conceptually shown in Figure 1-1

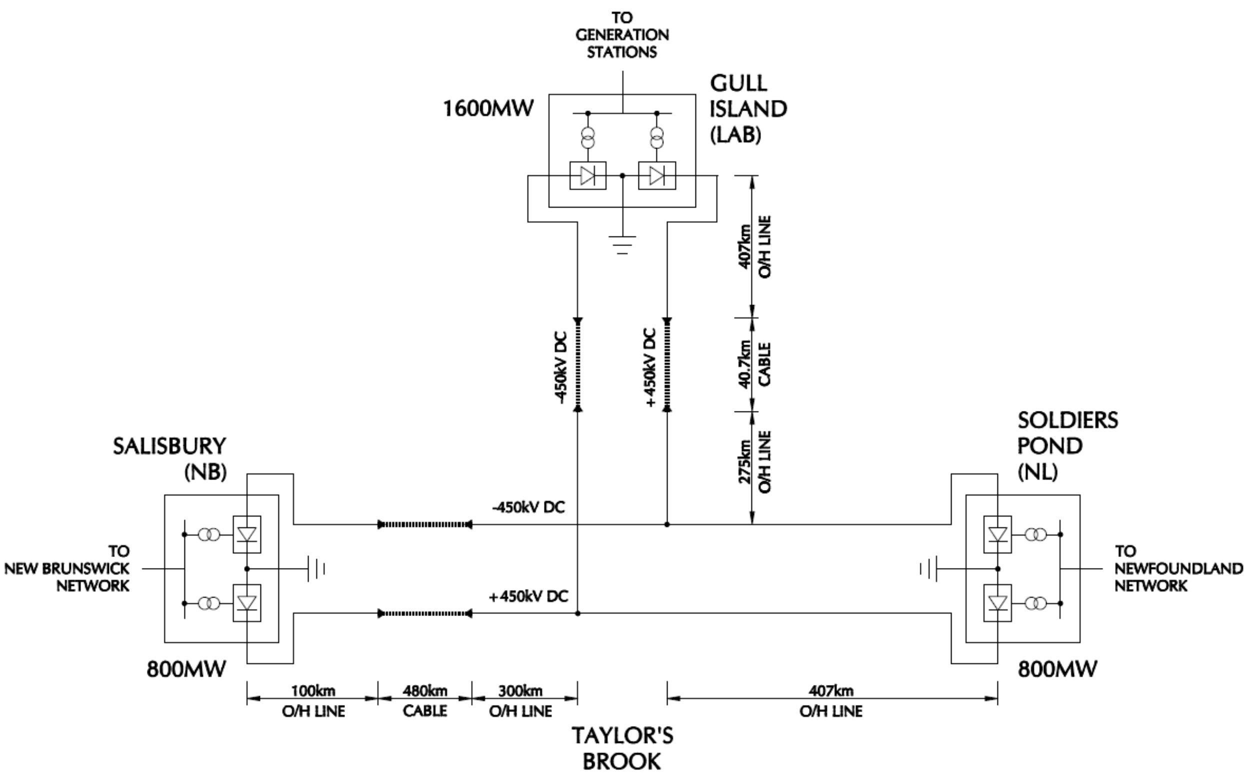

Figure 1-1: Proposed Lower Churchill Multi-Terminal HVdc System

Figure 1-2 shows the location of the Gull Island and Soldiers terminals and the associated electrodes. The shoreline pond electrode on the North shoreline of the SOBI requires an electrode line of approximately 407 km for connection to the Gull Island converter station neutral bus while a short length of approximately 11 km is required for connection between the Soldiers Pond converter station and the proposed Dowden’s Point electrode. The electrode line between the Gull Island terminal station and the electrode on the North shoreline of SOBI will be within the HVdc line right of way (ROW) supported on separate structures, and would require its own ROW for the approach to the shoreline pond electrode. The electrode line from Soldiers Pond to Dowden’s Point will have its own ROW.

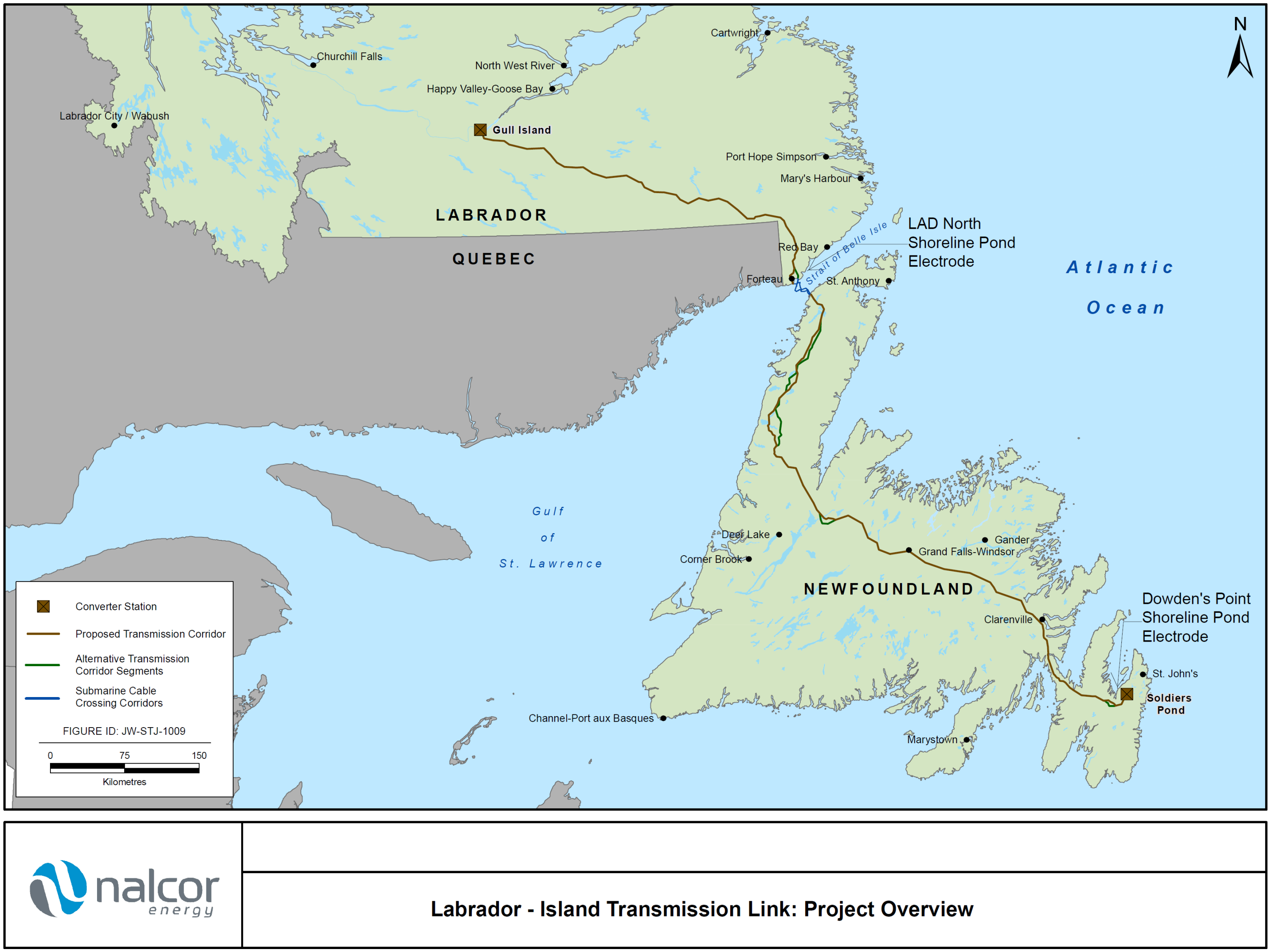

Figure 1-2: Proposed HVdc Transmission Link

2. Terms of Reference

The main objectives of the body of work were to identify and qualify a shoreline pond electrode location along the North shore of the SOBI; reconfirm the electrical field, electrical interference and corrosion impact analyses completed in DC1250 at Dowden's Point based on additional information and investigations; develop the conceptual design of the electrode installations; and estimate the costs of the electrode installations. Originally, the electrode line costs were to be included in the cost estimate for DC1500 with inputs from NE-LCP; however, it was subsequently decided to exclude the electrode line costs from the estimate.

A high-level review of potential impacts on the environment including the production of gases in the shoreline pond review was undertaken to assist NE-LCP in its environmental impact statement (EIS) process.

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

Donald Gordon, Teshmont Consultants LP – HVdc electrodes;

Terry Treasure, Hatch – HVdc electrodes;

Hugh Miller, AMEC – Geophysics;

Calvin Miles, AMEC – Geotechnical;

Joanne Hu and Bruno Bisewski, RBJ Engineering – Electrode lines;

Scott Hancock, Hatch – Marine structures;

Rauf Ahmed and Ben McLeod, Hatch – HVdc electrodes and panel coordinators.

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

- Gull Island Shoreline Pond Electrode
  - Identify candidate sites, rank candidate sites according to site selection criteria, and select the most likely site for further analysis.
  - Size the electrode and perform electrical field study and sensitivity analysis.
  - Identify the surrounding infrastructure and the data of the infrastructure with NE-LCP's help, and perform electrical interference and corrosion impact analysis.
  - Develop design requirements of a shoreline pond electrode's structures and electrical systems, develop conceptual design of the electrode installations, and provide NE-LCP information on the layouts.
  - Review the electrode line fault detection and protection requirements.
  - Estimate engineering, procurement and construction budget for the electrode installations with NE-LCP inputs.

- Soldiers Pond Shoreline Pond Electrode
  - Review the electrode and infrastructure model assumptions in DC1250, establish goals to improve the models, identify steps and/or literature review, and undertake literature review.
  - Revise sea and soil model and perform electrode electrical field study and sensitivity analysis.
  - Reaffirm assessment of electrical interference and corrosion impacts considering the revised electrode electrical field study results and infrastructure models.
  - Develop design requirements of a shoreline pond electrode's structures and electrical systems, reconfirm the number of electrode elements required, develop conceptual design of the electrode installations, and provide NE-LCP information on the layouts.
  - Estimate engineering, procurement and construction budget for the electrode installations with NE-LCP inputs.
- Prepare a report with recommendations including the next steps required to mitigate design risks and present the report findings.

3. Review of Previous Electrode Studies

Various planning and design studies [1,7,8] were undertaken to define the electrodes' functional requirements and the suitable designs to meet the HVdc system needs with acceptable impacts on the infrastructure in the vicinity of the electrode and environment.

In 2009, NE-LCP commissioned a study DC1250 *"Electrode Review, Types and Location"*[1] to study the various types of electrodes and installation locations for application to the LCP. A shoreline pond electrode along the North shoreline of SOBI was identified as suitable location for the Gull Island electrode and a shoreline pond electrode at Dowden's Pont as viable electrode for Soldiers Pond. Land electrodes, preferred by NE-LCP, were found not suitable because of high resistivities of geological units in the area.

In 2007, NE-LCP undertook a high level study DC1110 *"Electrode Review – Gull Island and Soldiers Pond"*[2] to assess the viability of HVdc electrodes for the converter stations. The 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 "*Engineering Review and Update of Capital Cost Estimate*", completed by Teshmont in 1998. 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

[1] NE-LCP assembled a panel of experts to review the available options and select the suitable electrode types and locations.

[2] 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.

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

In conjunction with the DC1250 work, more field work was carried out at Dowden's Point in 2009 by AMEC [6]. Three resistivity soundings were recorded, test pits were dug at seven locations and there were two boreholes. Three samples from test pits were submitted for thermal property measurements. The results of this field work was used for assigning resistivities for the 2009 modeling, as well as for the modeling under this body of work.

4. Methodology

4.1 Gull Island

The tasks for the Gull Island electrode scope of work included selecting a viable site along the North shoreline of the SOBI; developing a sea and soil model, and electrode design; performing an electric field study; reviewing impact of electrode operation on the infrastructure; developing conceptual design of electrode installations; reviewing electrode line fault detection and protection; and developing an order of magnitude cost for the electrode installations.

The candidate sites identified, using large scale hydrographic charts and site selection criteria developed by the panel members, were reviewed for their suitability for the application, and most likely sites were selected. Subsequently the sites were flown over in a helicopter and the most likely sites were visited to collect field data for further evaluations. The candidate sites were ranked based on known information, data collected during site visit, and manual electrical field calculations in accordance with site selection criteria. The highest ranked sites were further reviewed to select the most suitable site for a detailed assessment.

The SOBI seawater salinity was studied, considering seasonal and geographic variations, to predict the seawater resistivities. Also, a literature review was undertaken to identify the geological units in the area and to assign resistivities to these units. Accordingly, a sea and soil modeling scenario document was developed to provide the basis of the electrical field study.

The electrode size, number of the electrode elements and sea exposure required, were studied based on the seawater resistivity, the proposed breakwater construction, and the selected site location. These aspects provided inputs to the electrical field study.

The electrical field study was based on the worst case sea and soil modeling scenario with a maximum current injection of 2320 A considered. GRELEC (**GR**ound **ELEC**trode program), a software developed by Teshmont, was used for the electric field simulations.

The electrical interference and corrosion impact analysis was based on infrastructure information provided by NE-LCP and the GPR values at the locations of interest established in electric field simulations. 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.) was used to assess the impact of ground potentials on the surrounding infrastructure. Some of the impacts (e.g. compass deviation) were calculated analytically. Conservative assumptions were made where information was not available. The effect of dc stray current from natural sources such as inhomogeneous soil chemistry, telluric currents and geomagnetic activities are not factored in the analysis.

The civil/structural design was developed based on experience with similar structures in the area, without any geotechnical investigation, bathymetric survey, or land survey. Typical wave heights were assumed to propose armour stone for the breakwater.

The electrode line fault detection and protection review was based on limited available information, and included mainly review of various schemes, limitations of the schemes and the functional requirements for the project.

The engineering, procurement and construction budget was established based on a material take-off; conceptual designs; and guidance provided by NE-LCP on the Owner's management and environment assessment costs.

4.2 Soldiers Pond

The tasks for the Soldiers Pond electrode scope of work included undertaking a literature review to improve the sea and soil model used in the DC1250 study; reaffirming the electrical field study, electrical interference and corrosion impacts completed as part of DC1250; developing conceptual designs of the electrode installations; and developing electrode installation costs.

The Conception Bay seawater salinity was studied, considering seasonal variations and layers, to predict the seawater resistivities. The land geological units identified in the DC1250 study were used for the soil model. Accordingly, the sea and soil modeling scenario document developed for DC1250 work was revised to provide the basis of the electrical field study.

The electrode size, number of the electrode elements and sea exposure required were analyzed based on the revised seawater resistivity, the proposed breakwater construction and the exact location of the electrode. The findings of this analysis were used as inputs to the electrical field study and civil structural design.

The electrical field study was based on the worst case sea and soil modeling scenario with a maximum injection current of 1340 A. The current injection was simulated as multiple point sources. GRELEC was used for the electric field simulations.

The electrical interference and corrosion impact analysis was based on additional information provided by NE-LCP and the revised GPR values at the locations of interest established in electric field simulations. The CDEGS models used in DC1250 were revised based on the new information available and the impact of ground potentials on the surrounding infrastructure was reassessed. Some of the impacts (e.g. compass deviation) were calculated analytically. Conservative assumptions were made where information was not available. The effect of dc stray current from natural sources such as inhomogeneous soil chemistry, telluric currents and geomagnetic activities are not factored in the analysis.

The civil/structural design was developed based on experience with similar structures in the area, without any geotechnical investigation or land survey. A bathymetric survey was conducted to better define the extension of infrastructure development into the sea. Typical wave heights were assumed to propose armour stone for the breakwater. Two breakwater designs were considered; one extending into the sea that does not require excavating the sea bed, and the other with the pond formed by excavating the shoreline, avoiding a footprint in the sea.

The engineering, procurement and construction budget was established based on a material take-off; conceptual designs; and guidance provided by NE-LCP on Owner's management and environment assessment costs.

5. Gull Island

Ideally, the Gull Island electrode should be located near the Gull Island converter station to minimize the length of the electrode line required. However, in DC1250 [1] it was concluded that land and lake shoreline pond type electrodes located near the Gull Island converter station are not viable options for the Gull Island electrode; this is mainly due to unfavourable soil conditions (high resistivity rock) present in the area resulting in higher electrode GPRs and the anticipated negative electrical interference and corrosion impacts on the infrastructure. Also, a desktop review in the DC1250 study identified L'Anse-au-Diable on the north shore of the Strait of Belle Isle as a potential shoreline pond electrode site for the Gull Island converter station due to its favourably high exposure to the sea and expected small zone of influence. A further study was recommended to identify other candidate sites and to select a suitable site. A detailed investigation – including site selection, electric field analysis and infrastructure impact assessment – was performed, and the analysis and findings are presented in the following sections.

5.1 Site Selection

The site selection process consisted of three major tasks:

- Identification of the candidate sites based on site selection criteria and selection of the most likely sites,
- Collection of site data, ranking of the candidate sites based on known information, site visit observations and refinement of ranking, and manual electrical field calculations in accordance with site selection criteria
- Further review of highest rank sites to select the most viable site for further assessment.

This section summarizes the site selection process and key findings; full details are recorded in AMEC's report [5].

The first step in the site selection process was to define a search area along the Strait of Belle Isle (SOBI) for candidate shoreline pond electrode sites; Figure 5-1 illustrates the search area considered. The HVdc transmission line right of way (ROW) is shown shaded in grey. The electrode line will share the same ROW until it diverges to the electrode site. The red arc is drawn about the yellow point at the top of the figure where the transmission line turns south near the Quebec border, with a radius equal to the distance from that point to the cable landing site. The sites examined lie within this arc along the coast of the SOBI. The pink circle shows the area outside of which the electrode line would be longer than the distance to the cable landing site from the eastern most point of the transmission ROW.

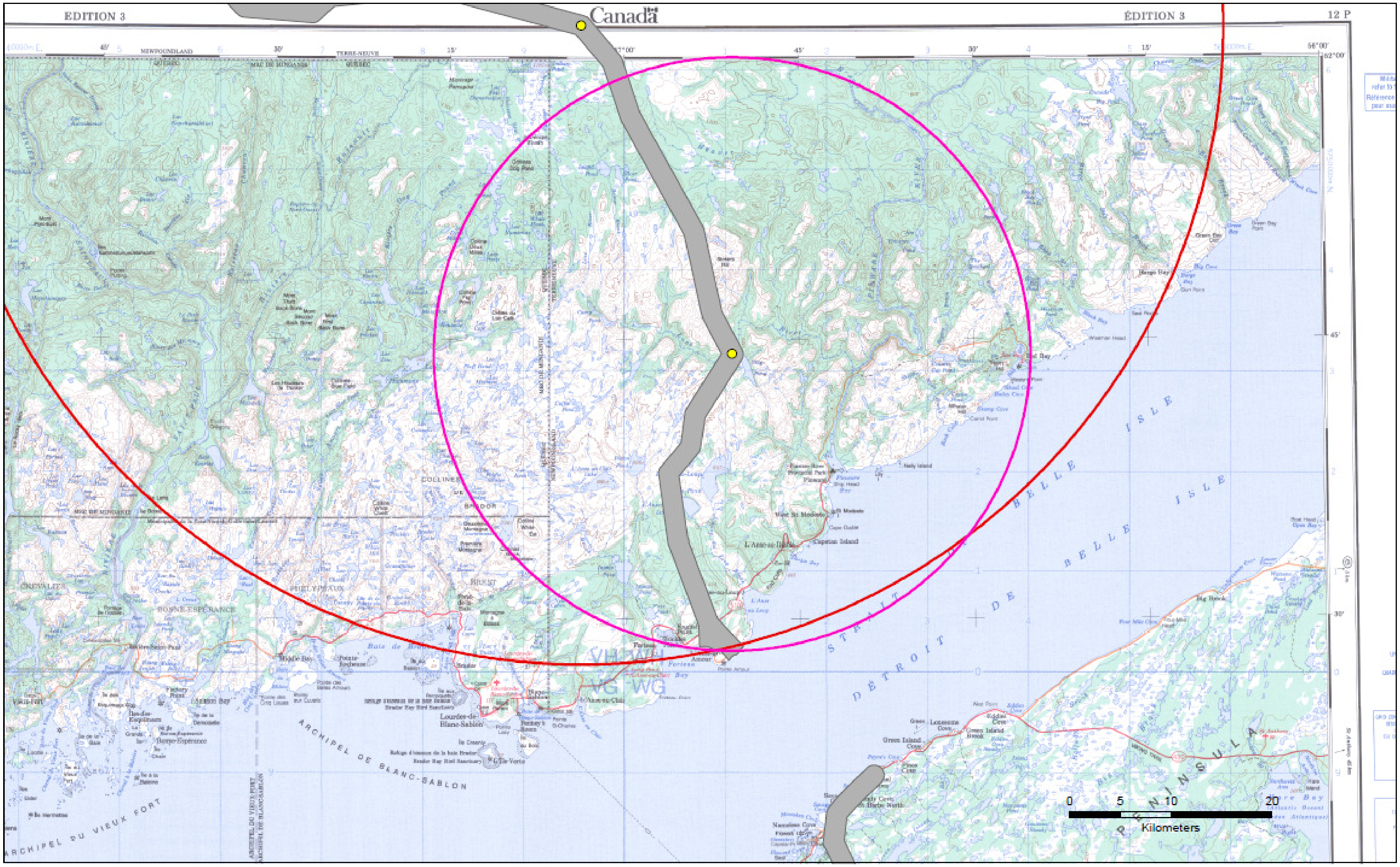

Figure 5-1: Gull Island Electrode Site Search Area

Within the search area along the shore of SOBI, AMEC identified fourteen candidate sites. The candidate sites were ranked according to the site selection criteria prepared by the panel included in AMEC's report [5]; the sites and their preliminary rankings are listed in Table 5-1.

Table 5-1: Preliminary Ranking of Gull Island Electrode Candidate Sites

Candidate Site	Distance from Cable Landing	Distance from Population Centre	Fresh Water Inflow	Accessibility	Wave Action	Water Runoff	Total	Rank
L'Anse-au-Diable North	10	10	5	7	8	8	48	**1**
Kelpy Cove (Red Bay)	10	2	10	10	8	8	48	**1**
Capstan Cove (Red Bay)	10	3	10	8	8	9	48	**1**
Buckle Cove (Red Bay)	10	8	3	7	10	9	47	**2**
Wiseman's Cove (Black Bay)	10	10	8	2	5	10	45	**3**
West St. Modeste	10	1	10	10	1	10	42	**4**
Carrol Point Back Cove	10	10	5	1	8	8	42	**4**
Carrol Point Cove	10	10	5	1	6	10	42	**4**
Little Capstan Cove (Red Bay)	10	2	10	8	5	7	42	**4**
Pinware South	10	7	10	7	1	6	41	**5**
Red Bay Steamer Cove	10	2	5	10	5	8	40	**6**
L'Anse-au-Diable Main	10	10	1	7	2	5	35	**7**
L'Anse-au-Loup Schooner Cove	5	7	1	6	3	10	32	**8**
Black Bay	10	10	1	2	2	5	30	**9**

Notes:
1- The sites at a distance >10 km are assigned a score of 10 for the criteria item "Distance from Cable Landing".

On June 17, 2010, NE-LCP and AMEC flew over all fourteen sites by helicopter, and examined on foot five sites: L'Anse-au-Diable North, Capstan Cove, Little Capstan Cove, Buckle Cove, and Wiseman's Cove (during the site visit, Little Capstan Cove appeared more suitable than indicated in the preliminary ranking). Kelpy Cove, one of the top ranked sites, was not visited and was reviewed based on the available information in selecting the most likely sites.

Based on the observations made during the site visit, known information of the area and electrical field calculations, three sites were shortlisted as the most likely locations for a shoreline pond electrode. The relative pros and cons relating to the performance of an electrode and its impacts on the surrounding infrastructure for each site are summarized below:

- L'Anse-au-Diable North:
    - Population located ~1 km NE (a few houses on north side of Route 510, not a population centre).
    - Marine service centre located ~0.6 km WSW.
    - Fur farm located ~1 km WNW.
    - ~10 m depth at mouth of cove.
    - Ditch from quarry drains into the western side of the cove. Catchment area draining into cove is estimated to be less than 1 km^2. Effect of the drainage water on the resistivity within the cove is anticipated to be minimal.
    - Area around the cove is semi-industrialized.
    - To accommodate breakwater area requirements, the breakwater may need to be constructed on either side of the shoal on east side of cove.
- Buckle Cove, Red Bay:
    - Population located ~2.5 km N (across from the cove, along the shoreline). A higher GPR is expected at the location of houses on the other side of the bay.
    - ~10 m depth at mouth of cove.
    - Wide opening across the cove (~300 m at mouth). Considerably longer breakwater would be required, resulting in higher construction costs.
    - Exposure to the SOBI is less than the other sites (north-facing cove).
- Little Capstan Cove, Red Bay:
    - Population located ~1.5 km W.
    - ~10 m depth at mouth of cove.
    - A small brook connects cove with an adjacent pond (~300 m N). Observed to be full and flowing rapidly.
    - Width of cove ~100 m at mouth.

The three shortlisted sites were reviewed further and ranked based on a detailed set of criteria; the results are included in Table 5-2.

Table 5-2: Review of the Most Likely Gull Island Electrode Sites Based on Site Visit Information

No.	Criteria	Suitability of the Site 1-best, 2-average, 3-worst			Remarks
		L'Anse-au-Diable North	Buckle Cove, Red Bay	Little Capstan Cove, Red Bay	
1	Located 10 km or more from the HVdc cable landing	1	1	1	LAD North, Buckle Cove and Little Capstan Cove are located at distances of roughly 13 km, 38 km and 42 km respectively from the cable landing location and all meet the criteria of being located 10 km away from the cable landing point. The electrode operation, at any of the locations, will have minor impact on the dc submarine cable.
2	Located approximately 3 km or more from any significant population centre or major infrastructure	1	3	2	LAD North does not have any significant infrastructure or population centre in the vicinity; the impact on the marine centre located 600 m away, the fur farm at 1 km and a few houses at 1.5 km will be minor. Red Bay area locations are close to the Red Bay community and marine infrastructure and will have a higher impact.
3	Located away from fresh water inlets, and such that minimum mitigation is required against run-off water from rain and snow melt	2	1	3	Buckle Cove does not have any fresh water inflow. Drainage from the nearby quarry flows into LAD North but will not impact the cove salinity significantly. Little Capstan Cove has significant inflow that may increase the cove water resistivity by up to 30%. All sites can be developed to mitigate run-off water.
4	Located in a shoreline pond of adequate depth to ensure satisfactory performance considering sea tide.	1	1	1	The depths at the mouths of all coves were estimated to be 10 m which can provide satisfactory electrode performance.
5	Easily accessible with minimal infrastructure development	1	3	2	LAD North is located closest to the provincial highway.

No.	Criteria	Suitability of the Site 1-best, 2-average, 3-worst			Remarks
		L'Anse-au-Diable North	Buckle Cove, Red Bay	Little Capstan Cove, Red Bay	
6	Located away from potential rock slides	-	-	-	Rock slides are not a factor for any site and therefore rankings are not assigned to this criterion.
7	Viable for connections to the electrode line	1	2	3	LAD North will require the smallest independent ROW for the electrode line. Red Bay area locations will require longer independent ROWs and will also have to cross the Pinware River and other geophysical anomalies.
8	Sheltered from high wave action	2	1	3	Buckle Cove is a well-protected cove with its mouth opening towards the North-East. The LAD North cove opens South with a rock extension on the east side. Little Capstan Cove opens South. The attached sketches show the cove details.
9	Located such that minimum mitigation is required from sea ice pushing against the pond and electrode structures	1	1	1	All sites will be impacted in a similar fashion from sea ice and pond ice. Sea ice will not have significant impact and pond infrastructure needs to be protected against ice movement with sea tide for all locations. It is assumed similar electrode installations can be arranged for all locations.
10	Civil/structural/infrastructure design challenge	-	-	-	This criterion is closely related to the items covered under criteria items 3 and 8 and hence a ranking is not assigned to this criterion.
11	CAPEX and OPEX Cost				

No.	Criteria	Suitability of the Site 1-best, 2-average, 3-worst			Remarks
		L'Anse-au-Diable North	Buckle Cove, Red Bay	Little Capstan Cove, Red Bay	
a	Civil/structural and infrastructure capital and operational cost	1	3	2	LAD North is located closest to the provincial highway and requires the shortest access road. The breakwater length for LAD North Little Capstan Cove will be roughly of the same length. Buckle Cove will require the longest breakwater structure.
b	Electrode line capital and operational cost	1	2	3	LAD North requires shortest independent ROW for the electrode line and the Red Bay locations require river crossing.
c	Electrode installation and operational cost	-	-	-	The costs are assumed to be same since the electrode size will be the same and the access is not considered a major factor. Therefore, this criterion is not weighted in the ranking.
d	Mitigation cost	1	3	2	LAD North has the least infrastructure and the installations in the vicinity are of limited expanse. Red Bay locations are close to the Red Bay community and will have higher impact and consequently higher mitigation costs. The Buckle Cove is farther from houses than Little Capstan Cove, however infrastructure is located on the other side of the bay and a higher GPR transfer is expected.
	TOTAL	**13**	**21**	**23**	

The site selection process concluded that the L'Anse-au-Diable (LAD) North is the most viable site for a shoreline pond electrode for the Gull Island converter station. The site is well suited for the interfacing with the electrode line, has minor infrastructure in the vicinity, and requires minimum infrastructure development to access and construct the breakwater.

The LAD North site is shown in Figure 5-2 and the site was evaluated further for its suitability for the application by undertaking an electrical field study, and by analyzing the electrical interference and corrosion impacts.

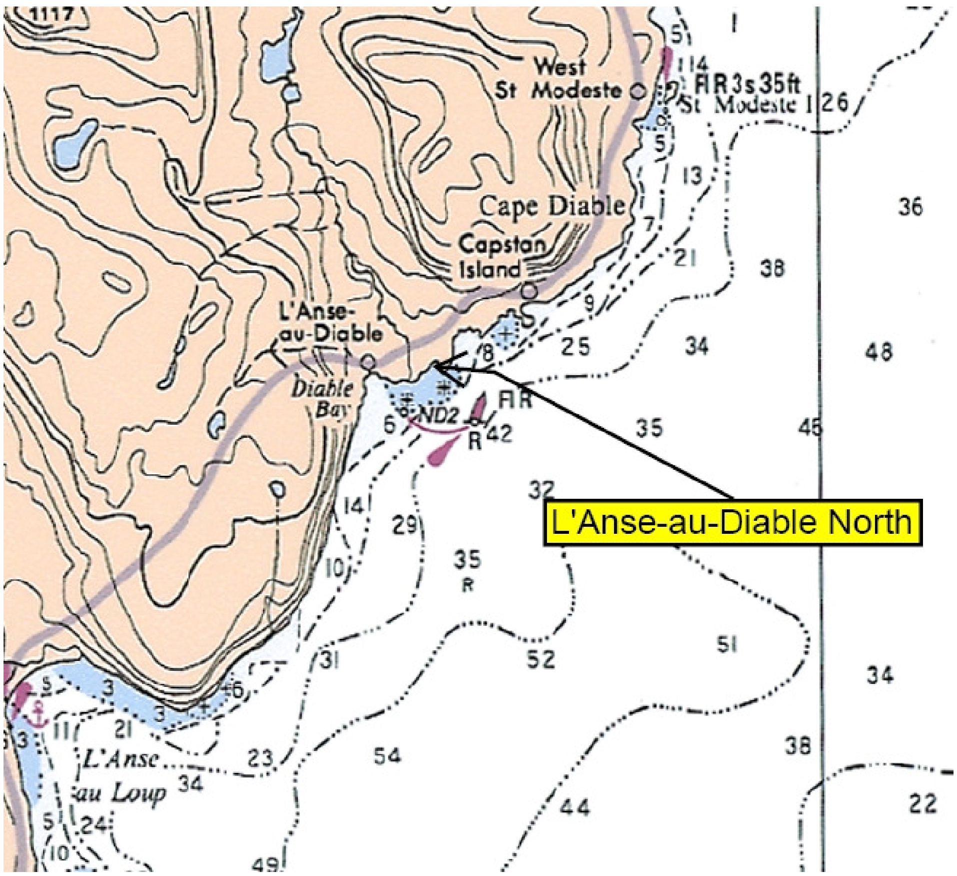

Figure 5-2: LAD North Electrode Location
(The values shown in the sea are the depths in fathoms at the lowest normal tide)

5.2 Electrode Design Criteria and Electrode Installations

The electrode must meet the electrical performance requirements, which include the current carrying requirements and duties for the Gull Island electrode; these values are summarized in Table 5-3 and Table 5-4, and full details are included in the DC1250 study [1].

Table 5-3: Gull Island Station Monopolar Current Duties

Nominal current, I_{nom} (A)	1780
Maximum continuos current, I_{max}, cont. (A)	2320
Maximum 10-minute overload, I_{max}, 10min. (A)	2760

Table 5-4: Gull Island Electrode Duties over 40 Year Life Cycle

Description	Anodic Operation Duty (Ah)	Remarks
Scheduled outages	2,845,248	$I_{max, cont.}$ *0.5%*70%*8760 h/y*40 y
Forced outages	4,835,520	$I_{max, 10min.}$*0.5%*8760 h/y*40 y
Continuous imbalance	8,760,000	I_{nom}*1%*8760 h/y*40 y
Cable outage (one year)	20,323,200	$I_{max, cont.}$ *8760 h/y*1 y
Total Duty (40 years)	**36,763,968**	**Ampere hours**

The maximum continuous current of 2320 A is considered for determining the minimum number of electrode elements required for the electrode. The electrode element currents need to be such that they will allow for continuous monopolar operation without replacement for a duration of more than one year (in the event of submarine cable damage in the Strait of Belle Isle). A design margin will be considered to address any imbalances in current sharing, electrode element design tolerances and condition of the electrode at the start of the worst case monopolar operation. Additional elements are considered to ensure electrode performance during maintenance. The impact on the surrounding infrastructure is evaluated for a 36,763,968 Ah duty that is based on a very pessimistic operation of HVdc link. 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.

The dimensions of the shoreline pond and breakwater are a function of the electrode element types, electrode element installations, seawater resistivity, tide changes, ice formation during winter, and safe GPR gradients required on the sea side. When installed along the side of the breakwater, the shoreline pond must be deep enough to fully contain the electrode elements, and in addition account for tide changes and ice. From an operational perspective, the electrode installations should facilitate maintenance. Regular inspection of electrode elements should be achieved from the top of the breakwater, without the need of a diving team.

The design of electrode supporting infrastructure (such as the electrode control room, the electrode line towers, the electrode site fence, etc.) should take into consideration the impacts of the electrode's operation, interfacing with the electrode elements, operation and maintenance requirements, and integration with the overall HVdc system. The security fence should be split into isolated sections or be of insulated design to minimize the impact of dc stray currents. Grounding and bonding connections to the area distribution system should be avoided.

5.2.1 Civil/Structural Design Criteria

The breakwater shall be designed to withstand the expected worst case site conditions, including wave action, tidal effects, pack ice and freezing inside the shoreline pond.

The depth of the shoreline pond required at the land side toe line must account for the electrode element installations in the shoreline pond, changes in the water level due to tides and ice formation within the shoreline pond. The depth shall be such that the electrode elements are fully immersed in the water below the ice under various tide conditions. Also, a depth on the sea side shall be such as to meet the safety criteria explained below.

The size of the breakwater, its composition and its location relative to the shoreline will depend on the electrical performance requirements, structural integrity and operational and maintenance needs. The crest width will be selected to satisfy operations requirements and meet minimum requirements for construction. A layer of uniform size rock with an increased void ratio is required to conduct the electrode current through the breakwater and into the SOBI and to maintain the salinity of water in the shoreline pond which is critical for the performance of the electrode. Public access to the electrode site must be restricted from the land side. In case the access from the sea side is a concern, the fence will be installed on the sea side of the breakwater crest.

The installation of the electrode elements should be arranged to provide mechanical protection against the floating ice and consideration should be given to mitigating the formation of ice in the raceways housing the electrode elements and the electrode leads.

5.2.2 Safety Design Criteria

The contact area between the breakwater and the sea is driven by safety considerations; a minimum contact area between the shoreline pond and the breakwater must be achieved to ensure a safe voltage gradient on the sea side of the breakwater.

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 seawater. A value of 1.25 V/m is selected as safe design value [10,15,16] for large fish and humans.

5.3 Proposed Design

The electrode arrangement and the monitoring requirements are based on the analysis performed part of this study and a typical electrode facility monitoring practices.

5.3.1 Electrode Installations

The proposed electrode installation considers an array of tubular, high-silicon chromium chill cast iron (HSCI) electrode elements arranged in the shoreline pond along the side of the breakwater. The elements are divided into six subsections, as shown in Figure 5-3. Considering a total electrode current of 2320 A (corresponding to the 10 minute continuous maximum current), a current dissipation of 35.2 A per element for normal operation (less than manufacturer's recommended current value and electrode consumption time period of more than two years) and a contingency of one subsection (for maintenance), the Gull Island electrode requires 66 elements (i.e. 6 subsections of 11 elements).

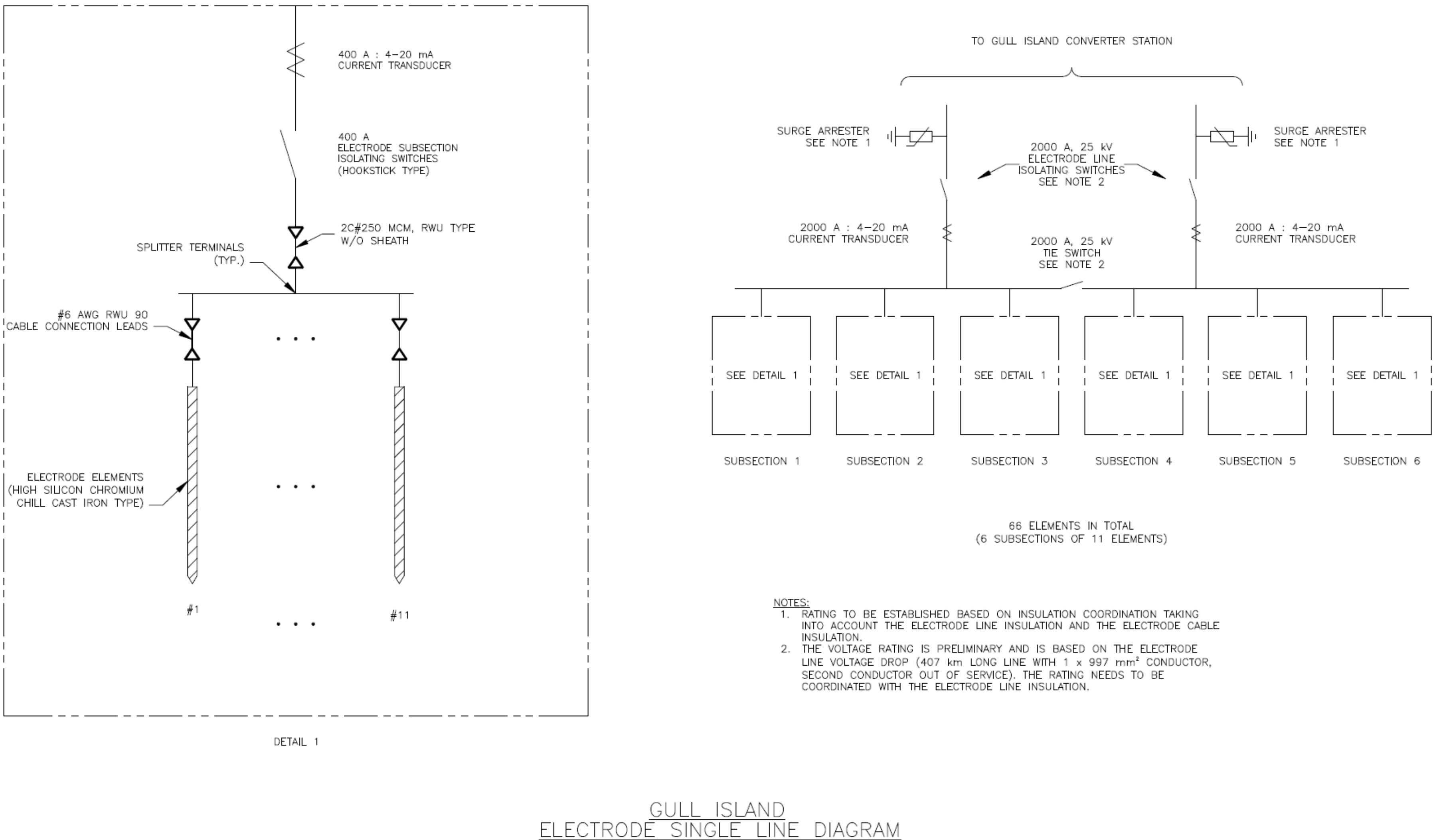

Figure 5-3: Gull Island Electrode Single Line Diagram

Assuming a discharge of 100% of the electrode current into the sea through the breakwater, the dimensions of the breakwater required to ensure a safe gradient of less than 1.25 V/m at the interface of the breakwater and the sea can be calculated. The required contact area is approximately 724 m^2, which translates to a breakwater approaching 100 m in length. Details for calculating the number of electrode elements and breakwater size are included in Appendix A.

A sensitivity analysis was carried out to examine the effect of different element arrangements in the pond on the element current density. It is known that when equally spaced, elements on the extremities of a linear array will carry higher currents than those in the middle. The analysis determined that a 'quasi-uniform array' spacing would provide a fairly uniform current distribution among the elements and would be feasible from a constructability standpoint. The 'quasi-uniform array' consists of a 1.75 m equal spacing for all elements in the middle of the array, with tapering in steps of 1.5 m and 0.75 m towards both ends of the array. Figure 5-4 shows the even current dissipation among elements. The details of the sensitivity analysis are included in Appendix B.

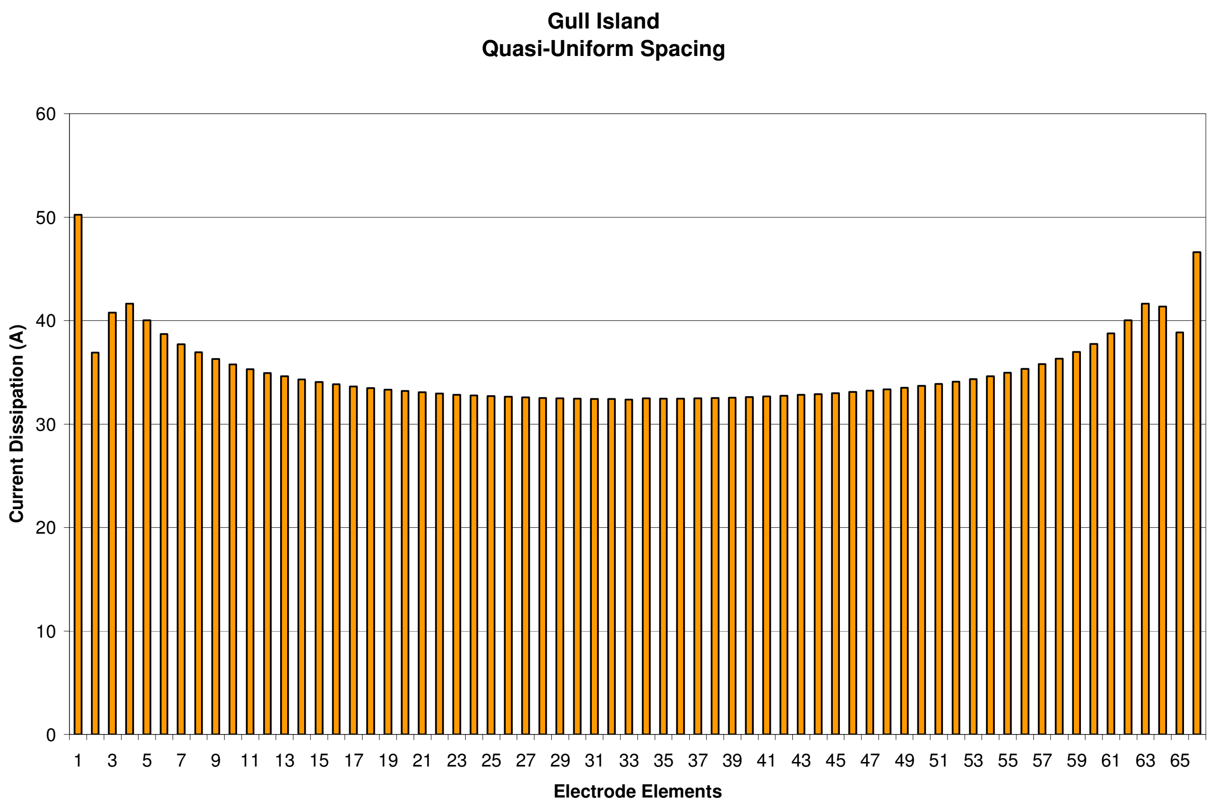

Figure 5-4: Gull Island Current Dissipation, Quasi-Uniform Spacing

Significant wave height in the range of 6-8 m is expected along the SOBI requiring a significant breakwater structure and armour.

It is anticipated that the breakwater would be a rubble mound structure consisting of embankment materials obtained from nearby quarries in bedrock. The majority of the structure will be random materials from blasting in the quarry. Larger sizes will be selected from the quarry to be used as the armour stone placed on the sea side slope to protect the main body of the mound from destruction by storm waves. A further selection will be made to form the embankment which is required to be permeable so that a flushing and transfer of saltwater can be achieved naturally through the embankment. Any potential for landslides at the eroded shoreline fill at LAD North will be mitigated by slope flattening and revetment with riprap stone. Selected coarser rock will be selected to form a pavement on the pond side slope in the tide and ice range of movement.

Access roads to the site will be constructed to link with existing local roads. The site will be fenced by chain link fencing to prevent public access from the land side to the pond.

Approximate significant parameters for the rubble mound structure and pond are indicated in Table 5-5 below:

Table 5-5: LAD North Shoreline Pond and Breakwater Design Summary

Description	Unit	Value
Pond length Note 1	m	100
Pond width	m	Varies
Pond depth at pond side toe, low tide	m	4, minimum
Water depth at sea side toe	m	Not confirmed
Assumed shore slope	H: 1V	1.5
Crest width	m	9.5
Sea side mound slope	H: 1V	1.5
Shore side mound slope	H: 1V	1.5
Approximate CL height	m	15.5
Tide height	m	1.5
Crest above low water	m	9.5
Low water level on shoreline	el. m	0
Armour weight (mass)	Tonnes	4 & 12
Permeable core size	m	0.5 to 1.0

Notes:
1. Length of breakwater section where depth at sea side toe is 4 m or more.

A conservative void ratio of 19.3% is considered for the calculation; a higher void ratio will permit a shorter length of breakwater. The average size of rock in the permeable zone is assumed to be 0.5 m to 1 m in diameter. A crest width of 5 m (excluding the armour stone) on the top of the breakwater is expected, based on a high level review. A slope of 1.5 H in 1 V is foreseen for the breakwater based on experience in the area.

A wind and wave study will have to be undertaken to confirm the design wave height. The design wave in conjunction with anticipated economical armour size available near the site will determine the final embankment slopes and protective layer arrangement and thicknesses. The catchment area should be developed to minimize or prevent drainage of run-off water from precipitation and snow melt into the pond.

The layout and section of the shoreline pond electrode, breakwater and associated installations are shown in Figure 5-5 and Figure 5-6 respectively; this design is referred to as Option 1. The breakwater extends beyond the mouth of the cove into the SOBI such that, at the land side toe of the breakwater where the elements are installed, a natural low-tide sea depth of 4 m is achieved (i.e. no excavation of the seabed).

During the site visits in June 2010, the water depth at the mouth of LAD North was visually estimated to be of the order of 10 m. However, the bathymetric survey of LAD North provided by NE-LCP (Appendix L) revealed the depths were shallower than previously observed the natural depth of 4 m occurred farther into the SOBI than initially anticipated. The result was a large footprint of breakwater.

Minimizing the footprint of the breakwater is desirable to reduce issues in the environmental and regulatory processes. Therefore, an alternative shoreline pond electrode was designed at LAD North; the layout and section for Option 2 are shown in Figure 5-7 and Figure 5-8, respectively. The crest of the breakwater aligns with the top of the existing bank and the sea side toe line coincides with the existing low tide shoreline. A channel would be excavated to a depth of 4 m from the inside of the shoreline pond outward to the natural depth of 4 m in the SOBI. The seabed is anticipated to be bedrock, which may require blasting in the area to be excavated. The excavated area on the sea side of the breakwater may be in the shape of a wedge, increasing the electrode’s exposure to the sea. A regular excavation program may be required to maintain the seabed depth requirement of 4 m to ensure the electrical resistance of the electrode does not increase significantly and the breakwater’s permeable zone is not clogged. The installation will require optimization of electrode element spacing to accommodate the elements.

Option 1 is the preferred technical solution.

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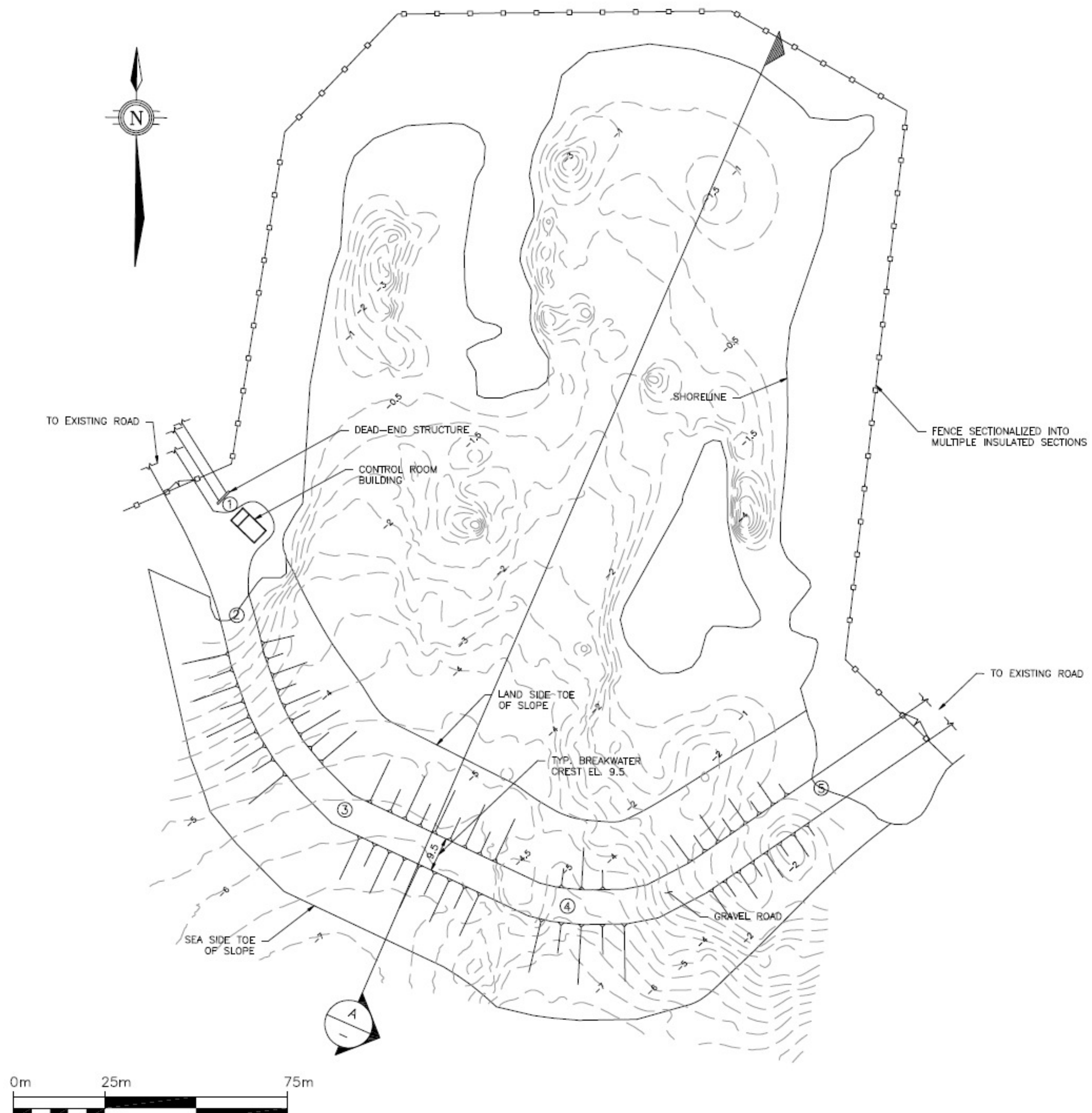

SCALE: 1:1250

PLAN VIEW
L'ANSE-AU-DIABLE NORTH-OPTION 1

NOTES:

1. ELECTRODE ELEMENTS AND ASSOCIATED RACEWAYS ARE NOT SHOWN.
2. THE SHORELINE AND BATHYMETRY CONTOURS ARE BASED ON THE BATHYMETRIC SURVEY DRAWING PROVIDED BY NALCOR.
3. THE COORDINATES OF POINTS 1–5 ARE BASED ON THE BATHYMETRY CHART PROVIDED BY NALCOR AND SHOULD BE VERIFIED.
4. CREST OF BREAKWATER: EL. 9.5m.
5. HIGH WATER LEVEL: EL. 1.5m.
6. LOW WATER LEVEL: EL. 0.0m
7. BREAKWATER SLOPES ASSUMED TO BE 1.5H:1V.

COORDINATES IN UTM ZONE 21, NAD 83.		
POINT	NORTHING	EASTING
1	5712186	517279
2	5712156	517279
3	5712103	517370
4	5712077	517370
5	5712110	517439

PRELIMINARY

DATE: DECEMBER 1, 2010

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Figure 5-5: Gull Island Shoreline Pond and Breakwater Layout (Option 1)

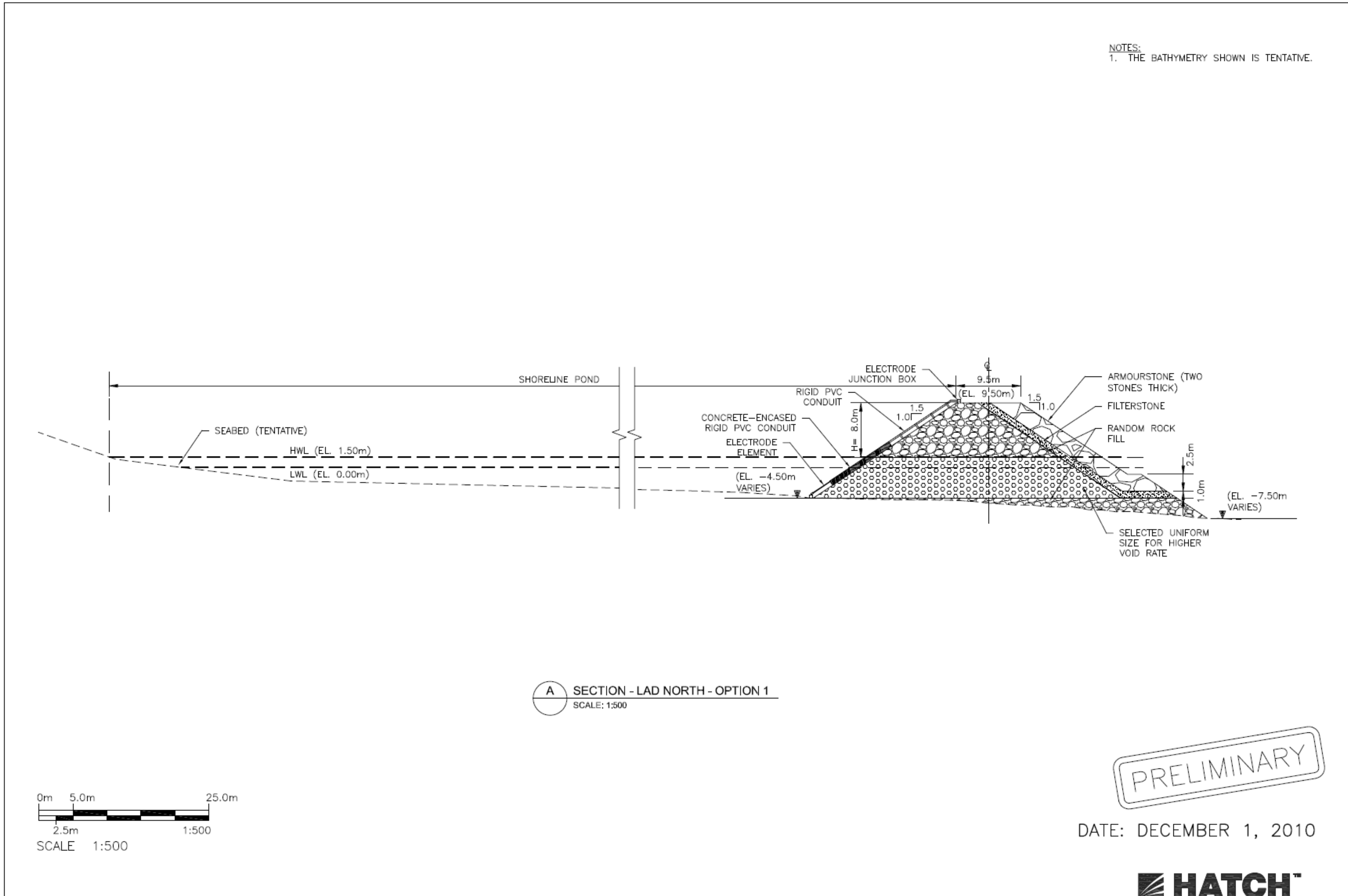

Figure 5-6: Gull Island Shoreline Pond and Breakwater Section (Option 1)

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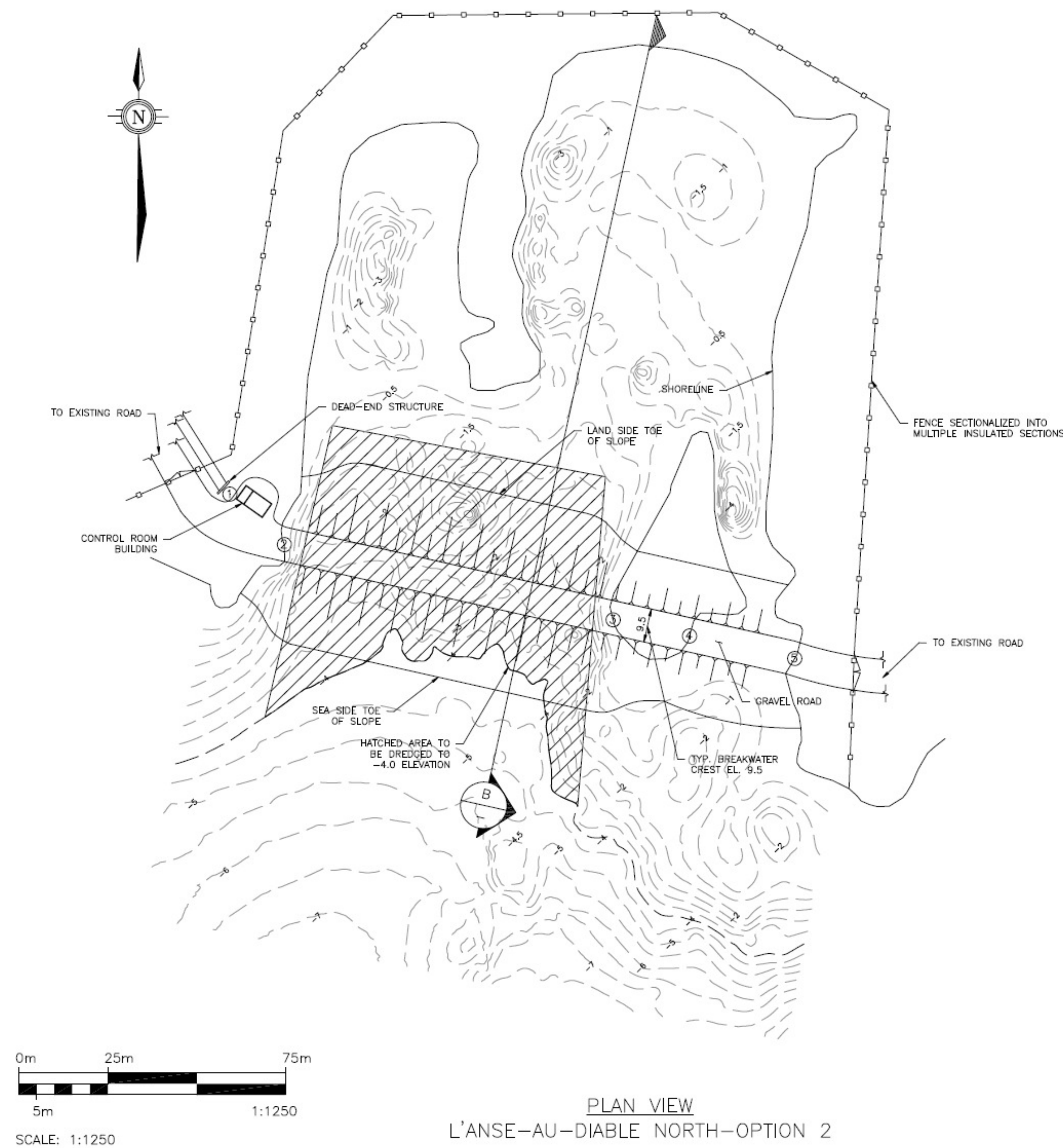

NOTES:

1. ELECTRODE ELEMENTS AND ASSOCIATED RACEWAYS ARE NOT SHOWN.
2. THE SHORELINE AND BATHYMETRY CONTOURS ARE BASED ON THE BATHYMETRIC SURVEY DRAWING PROVIDED BY NALCOR.
3. THE COORDINATES OF POINTS 1–5 ARE BASED ON THE BATHYMETRY CHART PROVIDED BY NALCOR AND SHOULD BE VERIFIED.
4. CREST OF BREAKWATER: EL. 9.5m.
5. HIGH WATER LEVEL: EL. 1.5m.
6. LOW WATER LEVEL: EL. 0.0m
7. BREAKWATER SLOPES ASSUMED TO BE 1.5H:1V.

COORDINATES IN UTM ZONE 21, NAD 83.		
POINT	NORTHING	EASTING
1	5712186	517279
2	5712172	517292
3	5712152	517385
4	5712148	517407
5	5712142	517436

PRELIMINARY

DATE: DECEMBER 1, 2010

HATCH™

Figure 5-7: Gull Island Shoreline Pond and Breakwater Layout (Option 2)

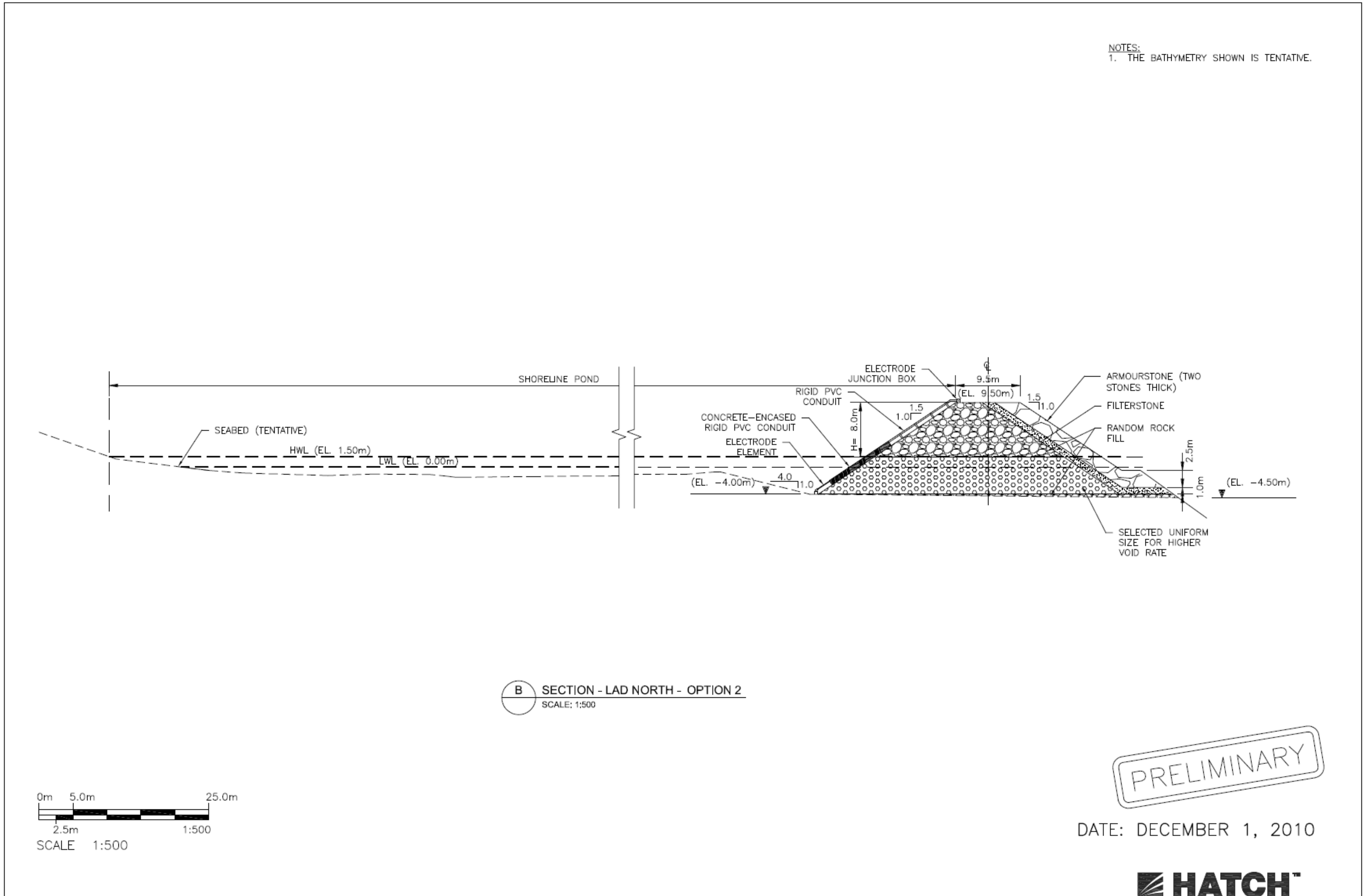

Figure 5-8: Gull Island Shoreline Pond and Breakwater Section (Option 2)

5.3.2 Surge Protection, Isolating Switches, Monitoring Requirements and Auxiliary Systems

Remote monitoring, electrode line instrumentation and protection, and an ac power supply fed from the local area distribution capable of supporting the site operation should be provided to maintain reliable operation of the HVdc system. The relatively remote electrode site location and the need for protection equipment for the long electrode line would require a dc auxiliary system.

The single line diagram of the proposed electrode configuration is shown in Figure 5-3. The main electrode line conductor switches and tie switch at the electrode location are manually operated and are required for isolation of the electrode installations from the electrode line and for reconfiguration of the electrode. Individual sections are provided with hookstick operated disconnect switches to facilitate inspection and maintenance of the electrode sections. Distribution class surge arresters at the electrode line termination points are required to protect the electrode site cables and instruments from transient and lightning surges. The surge arrester rating will be a function of the electrode line insulation, the voltage rating of the cables and the voltage ratings of the equipment, and the surge arrester rating needs to be determined as part of the electrode line insulation coordination study.

In normal operation, the two line switches will be closed, and the tie switch will be open. If a neutral line fault is detected on one electrode line conductor or reconfiguration of the electrode is required for maintenance, the switches at the converter station and at the electrode site will be manually operated by staff.

There will be eight dc current transducers located at site. Two will measure the electrode line currents for an electrode line differential current protection system and will require continuous transmission of current measurements from the electrode site to the converter station. The requirement of the electrode line differential current protection along with the communication equipment is assumed and needs to be confirmed as part of the electrode line fault detection and protection scheme and the electrode line design integration study. Six dc current transducers will measure the current in each electrode subsection and the data will be logged for interrogation from the converter station upon request. Relative changes in the measured current values over time between the electrode subsections could detect a loss of electrode elements, indicate the development of a high resistance connection or an excessive consumption of the electrode elements.

The electrode elements are installed below the expected freezing level of the shoreline pond, supported in conduit guides (typically PVC) with pull-out provisions for inspection from the top of the breakwater. Typical installation arrangements are shown in Figure 5-6. The selection of conduit materials and installation design shall be such as to minimize the probability of freezing in conduits. A heat tracing system is not considered and an inspection program would be required during the first winter after commissioning to identify any freezing issues in the conduits.

The auxiliary power supply shall consist of a reliable 125 Vdc supply for the monitoring and electrode line protection systems, and a 600 V or 208/120 Vac supply to support the dc supply and to feed heating, ventilation and other auxiliaries. The capacity of the dc supply shall be such that it should be able to sustain for a duration of probable distribution supply interruption; a back-up diesel generator set could be considered if a longer outage period on the local area distribution system is expected. Figure 5-9 is the proposed single line diagram of the proposed auxiliary supply.

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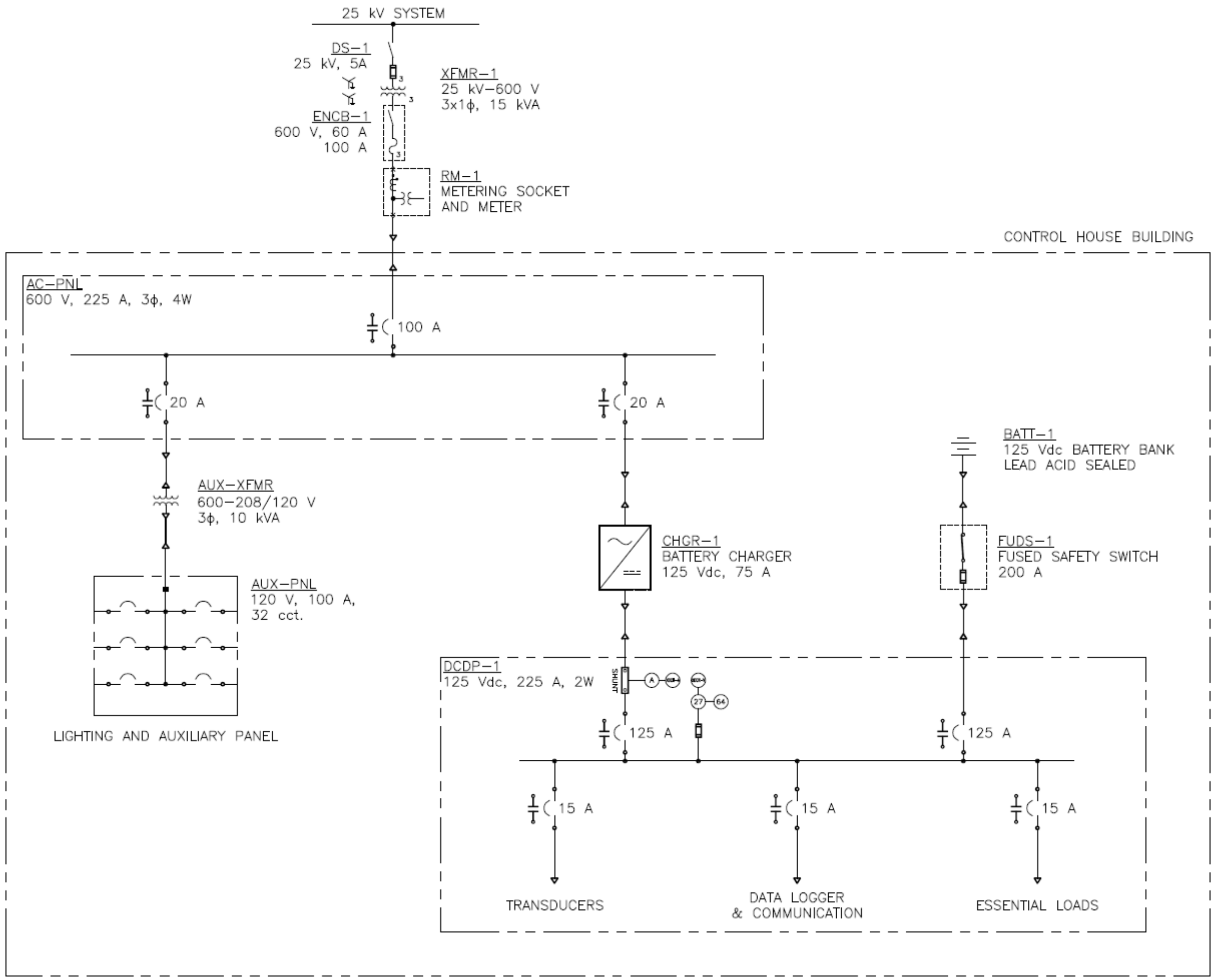

NOTES
1. ALL RATINGS ARE PRELIMINARY.
2. A DIESEL GENERATOR SET CAN BE INCLUDED IF AN EXTENDED OUTAGE ON THE 25 kV DISTRIBUTION SYSTEM IS PROBABLE (I.E. IF THE SYSTEM CANNOT BE SERVICED WITHIN 12 HRS, THE BATTERY DISCHARGE TIME).

GULL ISLAND
AUXILIARY POWER SUPPLY
SINGLE LINE DIAGRAM

Figure 5-9: Gull Island Electrode Site Auxiliary System, Single Line Diagram

WorkingTogether SAFELY

The preferred transformer configuration for the ac supply is wye-grounded/wye-grounded to avoid ferroresonance on the distribution system from a single fuse blowing. The HV and LV grounds will be independent and a spark gap will bridge the two grounds to eliminate the possibility of dc current injection into the distribution neutral from the electrode location.

A control building will be required to house the communications and control equipment, battery, battery charger, etc. Typical alarms would include: entry, power failure, high and low room temperature, battery charger failure, low battery voltage, etc.

A voice channel for telephone connection to the HVdc control room should be provided as well.

The minimum communications and monitoring requirements for the electrode site are:

- two channels to the converter station for continuous current telemetry for differential neutral line protection.
- control building alarms (ac power failure, dc battery system, high and low room temperature, data logger, communication equipment).
- telephone voice channel to HVdc control room.

Figure 5-10 is the block diagram of the monitoring and communication infrastructure foreseen. A further review taking into account NE-LCP's operational philosophy, maintenance practices, site accessibility, and integration with the overall HVdc system will be required to finalize the above foreseen auxiliary supply, and monitoring and communication systems.

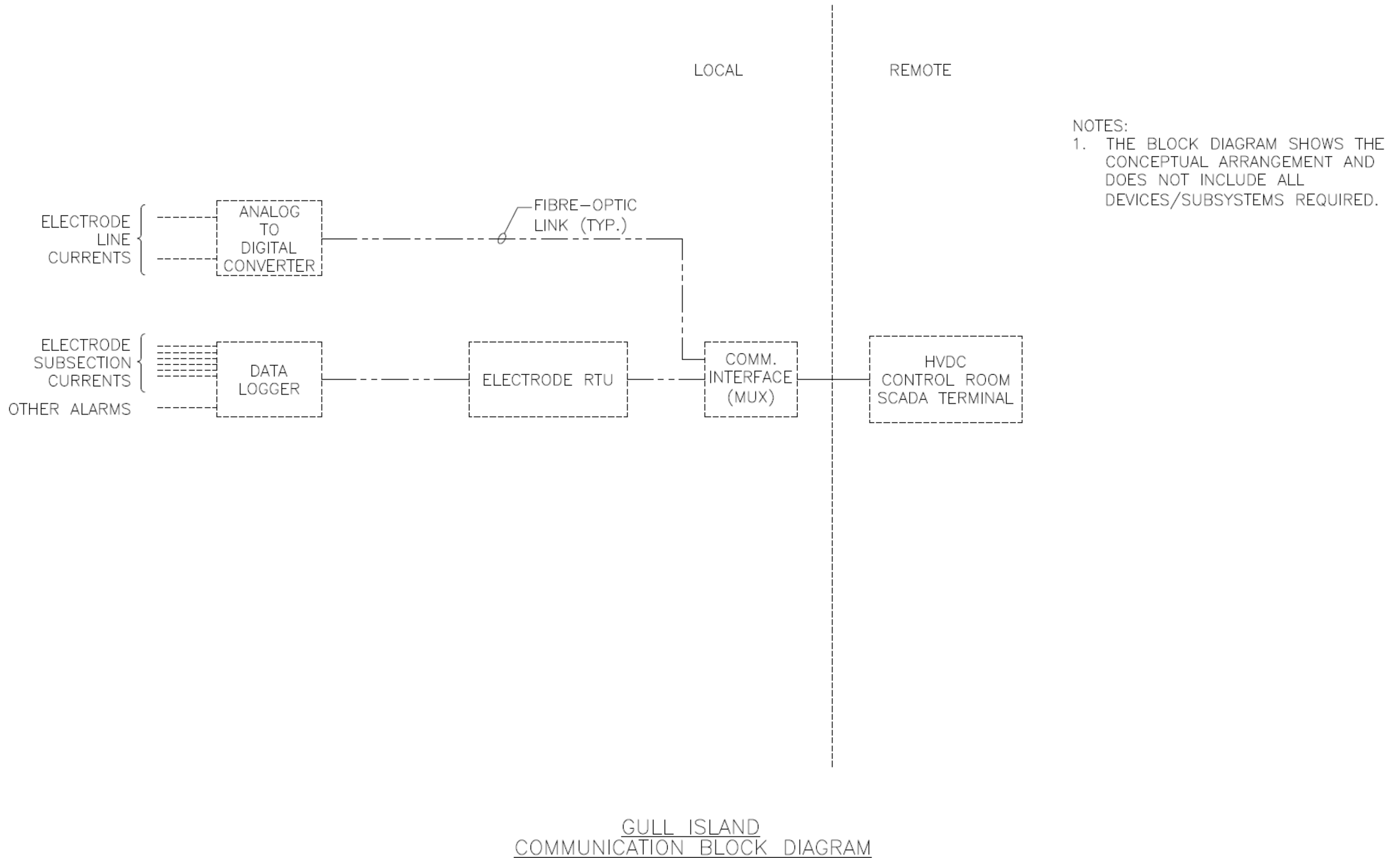

Figure 5-10: Gull Island Electrode Site Auxiliary System, Communication Block Diagram

5.4 Electrode Electrical Field Simulation Model

A literature review was undertaken to identify the properties of the geological units along the SOBI including their spatial extents and resistivities, and to establish seawater resistivities based on published salinity and seawater temperature data. Two modeling scenarios were developed based on this review.

The sea and soil model, the bathymetry of the SOBI, the electrode design, and the worst case continuous current were used to develop the electrode model to establish the GPR distribution of the electrode in anodic operation, using Teshmont's GRELEC simulation program.

5.4.1 Soil and Sea Model

Two modeling scenarios were identified: the "most likely" scenario and the "worst case" scenario. The suggested seawater resistivities considered the salinities and temperatures in the SOBI, and the worst case resistivity is used in the suggested models. Table 5-6 describes the two modeling scenarios.

Table 5-6: Gull Island Suggested Soil and Sea Modeling Scenarios

Unit Descriptions	Parameter Descriptions	Most Likely	Worst Case
Labrador sediments	Thickness (m)	150	50
	Resistivity (Ωm)	1000	300
Labrador Basement	Thickness (m)	infinite	infinite
	Resistivity (Ωm)	5000	10000
SOBI Water	Thickness (m)	Per bathymetry	Per bathymetry
	Resistivity (Ωm)	0.39	0.39
SOBI Sediments	Thickness (m)	300	500
	Resistivity (Ωm)	300	1000
SOBI Basement	Thickness (m)	infinite	infinite
	Resistivity (Ωm)	5000	10000
NL Carbonates	Thickness (m)	500	1000
	Resistivity (Ωm)	300	1000
NL Dunnage	Thickness (m)	2000	5000
	Resistivity (Ωm)	2000	5000
NL Basement	Thickness (m)	infinite	infinite
	Resistivity (Ωm)	5000	10000

The details of various geological units in Table 5-6 and their spatial extents are given in Appendix G. The sea depths considered in the model are low tide depths as shown in bathymetric charts [13]; the low resistivity mud or sediment at the seabed is not considered in the model as a conservative design measure.

5.4.2 *Electrode, Shoreline Pond and Breakwater Model*

The GRELEC program divides the soil into layers, rings and sectors, and calculates the self- and mutual-resistances of each element. The spatial extents and resistivities were based on:

- The sea and soil model summarized in Section 5.4.1,
- The bathymetric data of the SOBI [13], and
- The shoreline pond electrode design (void ratio of 19.3% of uniform size rock, resistivity of 2 Ωm for the breakwater and 0.01 Ωm resistivity for the shoreline pond water volumes containing electrode elements were assumed).

A cylindrical volume of 600 km in radius and 50 km in depth was modeled; volumes outside the modeled mass will not have significant impact on the simulation results. The sea and soil model used in the electrical field study is included in Appendix I.

Figure 5-11 shows the top layer of the model in close proximity to the electrode. Figure 5-12 shows the partial view of surficial geology and water bodies; rings with radii greater than 40 km are omitted.

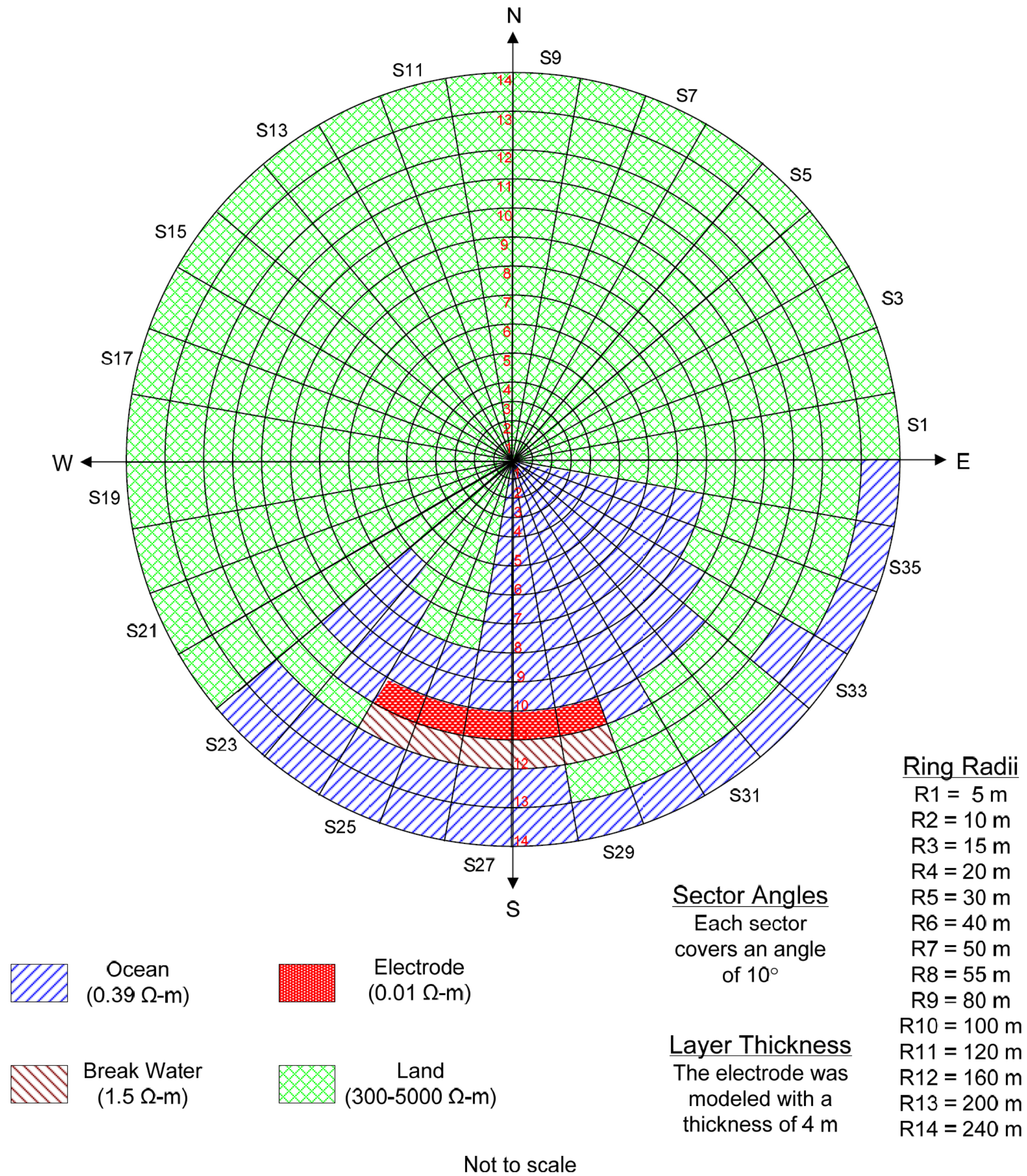

Figure 5-11: LAD North Shoreline Pond and Breakwater Model

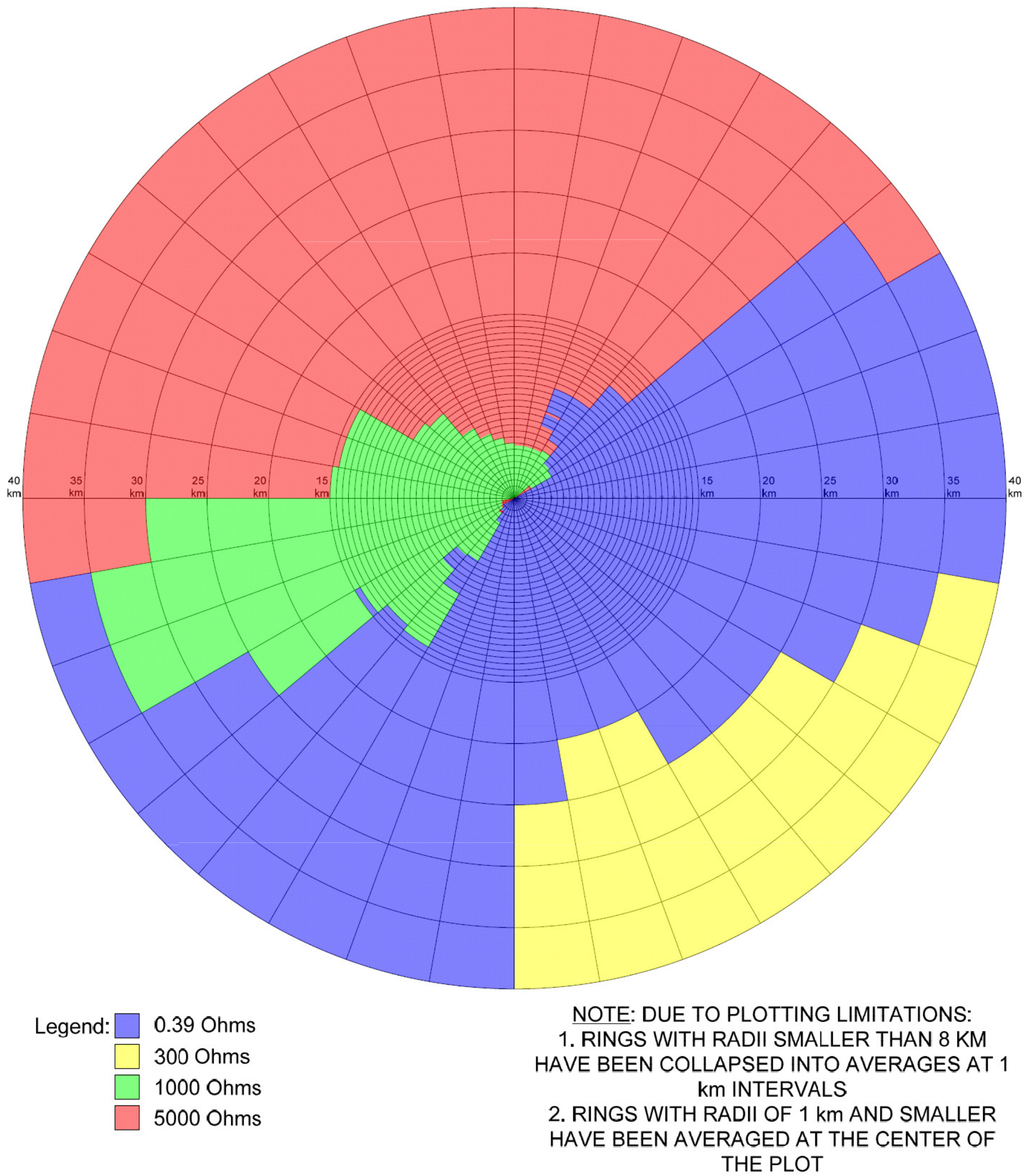

Figure 5-12: LAD North Top Layer of Sea and Soil Model

5.4.3 Electric Field Simulation Results

A current of 2320 A, the maximum continuous electrode current, was injected at the LAD North location (5712200N, 517350E in UTM 21). The current injected into the GRELEC model was distributed among the low resistivity volumes representing the electrode (the area shown in red in Figure 5-11). This approach will produce a more realistic representation of the GPR distribution in the near vicinity of the shoreline pond compared to a single point source current injection method.

The volumes containing electrode elements were assigned a low resistivity of 0.01 Ωm to approximate the actual resistance of the electrode element array.

Figure 5-13 shows the GPR contours in the vicinity of the electrode based on the "Most Likely" soil modeling scenario that uses the worst case seawater resistivity; as a conservative approach, these are the results used in the infrastructure impact assessment. The "Worst Case" scenario with higher soil resistivities will have an insignificant impact on the GPR values; rather, the higher soil resistivities will skew the GPR distribution to reduce the zone of influence inland.

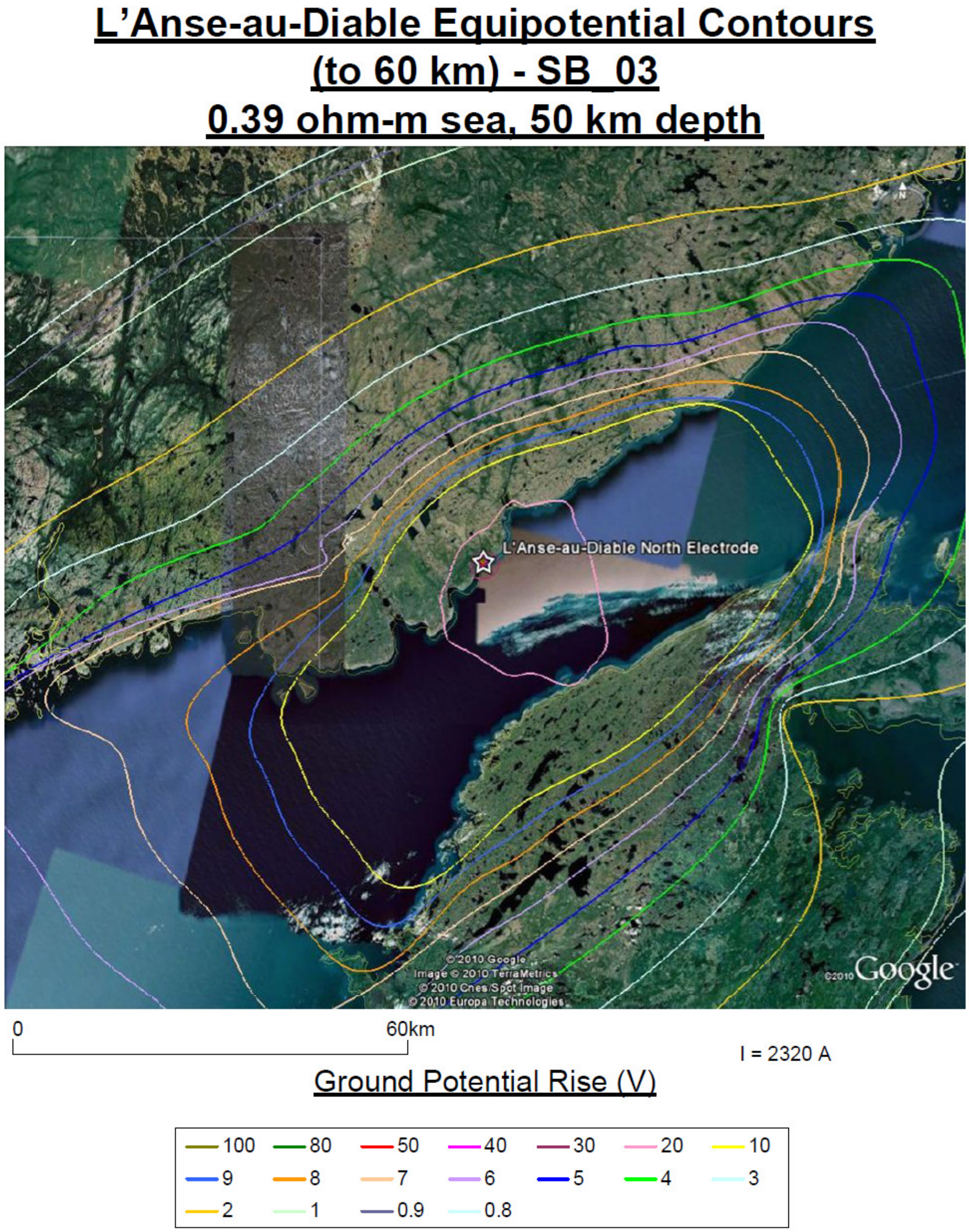

Figure 5-13: GPR Contours in Vicinity of LAD North

The maximum GPR difference between any two points along the distribution line, assumed along the Trans-Labrador Highway (Hwy 510), does not exceed 20 V. The GPR at the HVdc cable landing is 20 V; the submarine cable route is tangentially oriented relative to the electrode (i.e. parallel to equipotential GPR contours). Details of the GPR calculations and additional contour plots are included in Appendix I.

5.5 Impact Assessment

The infrastructure in the vicinity of LAD North mainly includes the distribution system, a service marina and the future HVdc submarine cable. The infrastructure models were based on infrastructure data provided by NE-LCP and the electrical simulation results. The data provided by NE-LCP is included in Appendix P. The data provided did not cover all aspects of the above infrastructure and conservative assumptions were made if data was not available. This section presents the models and results of the impact assessment, and the details are contained in the project memo [3] prepared under WTO DC1500.

5.5.1 Land Impacts

5.5.1.1 25 kV Distribution System

A 4.16/25 kV, 5-unit diesel generator station at L'Anse-au-Loup and a substation at Blanc Sablon (in Quebec) supply the communities along the shoreline of the SOBI; the distribution system is shown in the single line diagrams included in Appendix P. The distribution line routing information was not available at the time of the study. The distribution network was modeled assuming the 3-phase line runs along the Trans-Labrador Highway (Hwy 510). Branches from the main line to the service entrances in the communities were not modeled. The distribution line was modeled as a multi-grounded system, with grounds at every pole, spaced 85 m apart. The resistance of each pole ground was assumed to be 5 Ω, based on information from NE-LCP (refer to Appendix P). Single-phase transformers were considered at every fifth pole (spaced 425 m apart). The model considered a total linear span of approximately 8 km with the middle portion of the model nearest to the shoreline pond electrode site. The sizes of the distribution transformers can vary in size (25 kVA, 50 kVA, 75 kVA, or 100 kVA); however, smaller transformers will produce the most pessimistic results given the lower tolerance for dc stray currents through their windings, therefore only 25 kVA transformers were assumed for the distribution network. Figure 5-14 shows the locations of the transformers poles, and Figure 5-15 shows the network model. The details of the distribution network equipment, circuit and grounding data used in the model are included in Appendix C; the data is based on data provided by NE-LCP (Appendix P) and assumed parameters (e.g. transformer losses).

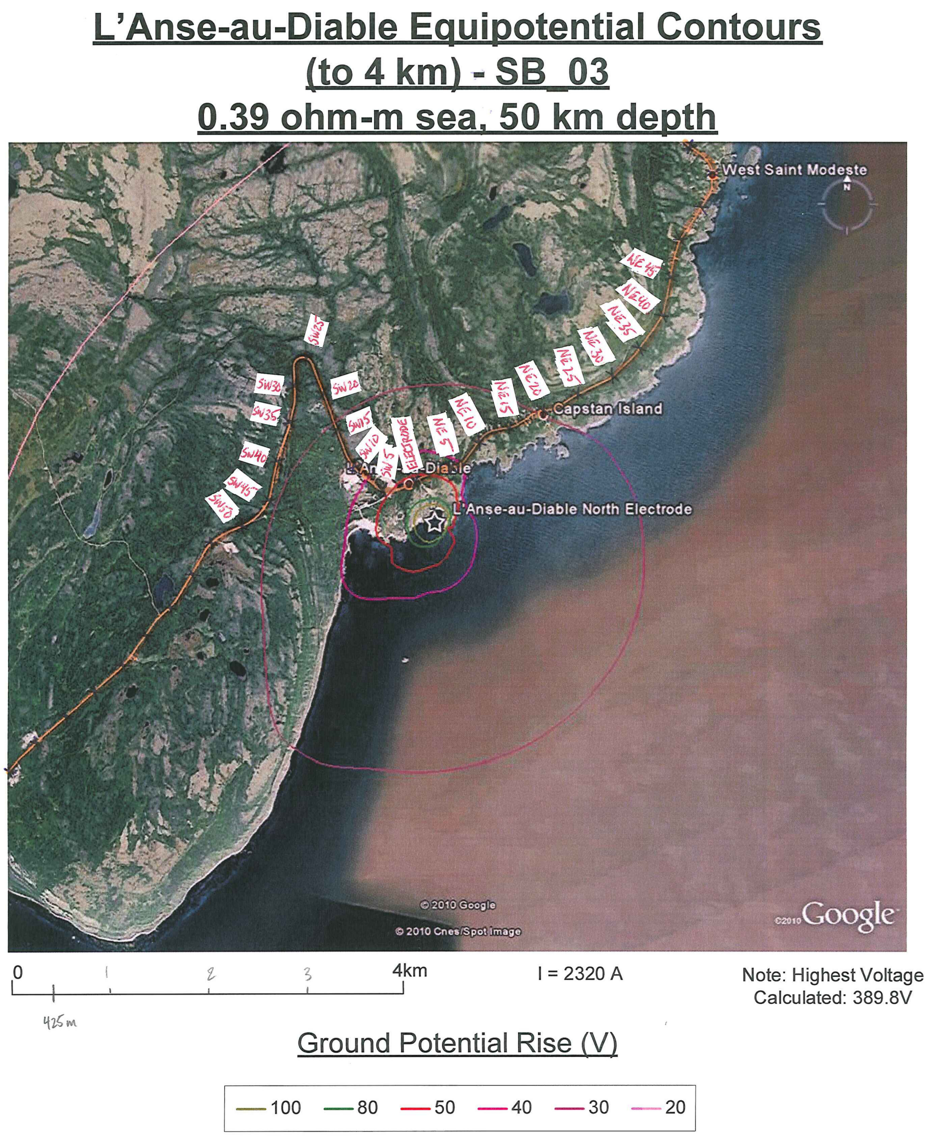

Figure 5-14: 25 kV Distribution Line and Locations of Transformers (LAD North)

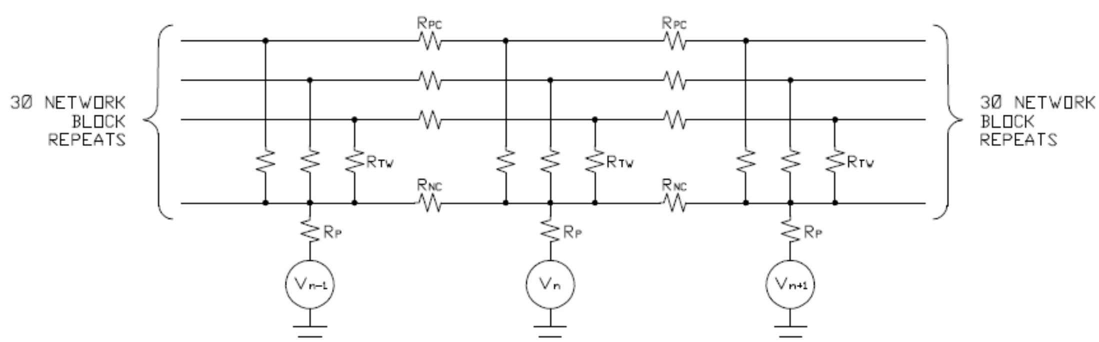

Figure 5-15: 25 kV Distribution Network Model (LAD North)

The CDEGS simulation calculated the stray dc currents through the distribution transformer windings and pole grounds for all poles. Table 5-7 presents only the currents through the poles grounds for poles on which the transformers are installed (i.e. every fifth pole); results for all components including currents through individual pole grounds are included in the Gull Island impact assessment memo [3]. The pole named “ELECTRODE” is the pole located closest to the electrode site (approximately 500 m away), the pole named “SW5” is the fifth closest pole to south-west of the electrode site, the pole named ″NE5″ is the fifth closest pole to north-east of the electrode site, etc.

Table 5-7: 25 kV Distribution Network Results (LAD North)

Pole	GPR (V)	Calculated Current through Pole Ground (A)	Permissible Current through Pole Ground (A)	Calculated Current through Transformer Winding (A)	Permissible Current through Transformer Winding (A)
SW50	29.00	-0.1177	0.4020	0.0168	0.0462
SW45	29.80	-0.0281	0.4020	0.0165	0.0462
SW40	29.50	-0.0758	0.4020	0.0159	0.0462
SW35	29.00	-0.1571	0.4020	0.0148	0.0462
SW30	28.00	-0.3203	0.4020	0.0125	0.0462
SW25	27.50	-0.4655	0.4020	0.0079	0.0462
SW20	29.00	-0.4295	0.4020	0.0001	0.0462
SW15	30.50	-0.4531	0.4020	0.0110	0.0462
SW10	38.00	0.1946	0.4020	0.0247	0.0462
SW5	48.00	1.1735	0.4020	0.0367	0.0462
ELECTRODE	54.00	1.8218	0.4020	0.0406	0.0462
NE5	42.00	0.5141	0.4020	0.0335	0.0462
NE10	35.50	-0.0516	0.4020	0.0218	0.0462
NE15	32.50	-0.1974	0.4020	0.0101	0.0462
NE20	29.80	-0.3348	0.4020	0.0000	0.0462
NE25	29.40	-0.2367	0.4020	0.0080	0.0462
NE30	28.90	-0.1831	0.4020	0.0141	0.0462
NE35	27.80	-0.2271	0.4020	0.0188	0.0462
NE40	27.00	-0.2643	0.4020	0.0220	0.0462
NE45	26.20	-0.3362	0.4020	0.0233	0.0462

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

For all transformers, the currents through the transformer windings are below the permissible limits. The currents through the pole grounds are acceptable for all poles, except for 28 poles (SW15-27, SW1-8, ELECTRODE, and NE1-6) near the electrode site which are above the permissible limits. Higher currents through these pole grounds are not of concern since grounding rods can be inspected and replaced as required. Alternatively, the grounding rods can be replaced with high silicon chromium steel electrodes to mitigate the corrosion impacts.

5.5.1.2 Other Infrastructure

The new infrastructure associated with the electrode installation (e.g. electrode line towers, electrode control room, electrode site fence, etc.) will require special attention in the design stage to ensure the integrity of the installations and the safety of public. The fence limiting public access to the electrode site should be sectionalized using fence isolators to prevent touch potential hazards and accelerated corrosion due to dc stray currents. The material of the fence should be selected to avoid corrosion. Suitable mitigation, if required, can be provided for any new infrastructure and can be reviewed during the detailed design stage.

The potential difference across a typical bridge or structure (e.g. marina located approximately 600 m away from the electrode) 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.

The segregation of HV ground from LV neutral through a spark gap could eliminate some of the operational issues with the distribution circuit. This spark gap isolates the distribution neutrals connected to homes and industrial units 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.

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.

5.5.2 Marine Impacts

The marine life, infrastructure and operations can be impacted by the induced magnetic field from electrode operation and the GPR gradients. The impacts include compass deviation, and corrosion of ships, submarine cable armours and other metallic marine infrastructures. The impact on the marine life of the gas produced at the electrodes and electrical field is not investigated and would require knowledge of the marine ecology; these aspects can be addressed as part of the environmental assessment process. However, the pond electrode installations are designed to have GPR gradients on the sea side lower than the recommended safe values [9,10].

5.5.2.1 Compass Deviation

The analysis of the Gull Island electrode’s impact on marine navigation is analyzed in detail in Appendix D; the findings of the analysis are summarized in this section.

The worst case for compass error occurs along the line from the electrode parallel with the magnetic north, where the earth’s magnetic field and the induced magnetic field from the electrode are orthogonal. A typical value for the horizontal component of the magnetic field intensity due to the earth’s magnetic field is assumed to be 16 A/m [9].

The resultant horizontal magnetic field at the surface of the water along the line parallel with the magnetic north is calculated for the Gull Island electrode in Table 5-8.

Table 5-8: Resultant Magnetic Field Intensity (LAD North)

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)	Magnetic field intensity (earth), H_{earth} (A/m)	Magnetic field intensity (resultant), $H_{res} = [(H_{elec})^2 + (H_{earth})^2]^{0.5}$ (A/m)	Compass error, α (°)
200	1.85	16	16.106	6.579
300	1.23	16	16.047	4.397
400	0.92	16	16.027	3.301
500	0.74	16	16.017	2.642
1000	0.37	16	16.004	1.321
2000	0.18	16	16.001	0.661
3000	0.12	16	16.000	0.441
4000	0.09	16	16.000	0.330
5000	0.07	16	16.000	0.264

An angle of deviation of 0.5° or less is considered acceptable [18]. The annual deviation at L'Anse-au-Diable North is 13.6'/yr (approximately 0.23°/yr) [19].

The actual compass errors at the water surface will be less than the values in Table 5-8 considering the steel hull of a ship acting as a magnetic shield and a compass located above the water level. Nowadays, large ships and vessels use gyro compasses or GPS navigation, and magnetic compasses as back-up. A gyro compass or a GPS navigation system will not be impacted by magnetic fields.

5.5.2.2 Ship and Infrastructure Corrosion

Full details of the corrosion impact analysis are provided in Appendix D; the analysis is summarized in this section.

Most large ships use an impressed current cathodic protection (ICCP) system to suppress natural electro-chemical activity on the hull and prevent corrosion. An ICCP system monitors and controls the electric potential at the interface between the ship's hull and the seawater, making it more effective than a sacrificial anode system.

An ICCP system impresses a low voltage dc output onto the ship hull through an anode attached to but insulated from the hull; a ship will have multiple anodes. The impressed voltage is typically 0.85 V. The reference cells are used to measure the potential on the ship's hull and to feedback the voltages to the controller.

The voltage gradient at a distance of 1500 m or larger from an electrode will be very small and the voltage difference between the two ends of a 200 m long ship will be less than 0.85 V; this will not impact the ICCP system operation. For a smaller yacht or boat, even without cathodic protection, the impact will be insignificant.

An anchored ship connected to the conductive infrastructure (e.g. power system grounding system or pipeline) on land can be impacted negatively. This aspect can be reviewed in detail on a case-by-case basis.

Any ferry terminals or marine structures are assumed to be equipped with cathodic protection and are of limited expanse, and will not be impacted negatively by the electrode operation.

5.5.2.3 HVdc Cable

Two submarine cable runs are proposed for the HVdc transmission line across the SOBI. Based on work carried out under DC1210 *"HVdc Sensitivity Studies Summary Report"*, a mass impregnated cable with steel armour(s) for mechanical protection and strength, and an outer serving of bitumen-bonded polyethylene yarn is considered for the submarine cable. The risk associated with the HVdc cable is the loss of material of the armour due to corrosion; the cable's armour must retain its tensile strength in order to pull out the cable in the event of a repair. Leakage currents are one of the causes of corrosion; other factors that may affect the way in which a cable corrodes include geomagnetically induced currents, chemistry of the seabed in which the cable is buried, resistive discontinuities in the medium in which the cable is laid (e.g. at the cable landing), and mechanical wear.

For the purpose of the impact assessment, a uniform leakage current is assumed around the perimeter of the cable armour. In reality, the leakage currents will be non-uniform, and corrosion effects will be localized and difficult to predict. The analysis is theoretical and considers only GPR associated with the electrode operation for estimating the loss of armour material.

A submarine cable of 135 mm outer diameter with 6 mm thick steel armour is assumed; the actual cable information was not available. Typically, a loss of 0.1 mm of armour (1.667 % of the total thickness) is acceptable over the operational life of the project, based on a conservative approach. The cable is modeled in CDEGS as a ladder network consisting of the longitudinal and leakage resistances of the steel armour. The insulating effect of the bitumen-bonded yarn is not factored in the model, rather the cable armour in direct contact with the low resistivity seawater is considered. The permissible leakage current for the submarine cable steel armour is 20 mA per metre length; the calculations of the permissible leakage current are included in Appendix C. The conductive metallic connection of the armour to the grounding grid at the cable landing site is not factored in the analysis; this will eliminate the higher concentration of leakage current observed the analysis. The worst case average leakage current is 100 mA per metre length near the cable landing on the south side of the SOBI, where the GPR gradients are highest. The current leakage drops below the acceptable limit within 70 m from the end of the cable. The analysis results are included in Table 5-9.

Table 5-9: HVdc Cable Leakage Current Results

Distance from cable landing (m)	Leakage current (A)	Average leakage current per metre (A)
10	1.000	0.100
20	0.800	0.080
30	0.610	0.061
40	0.470	0.047
50	0.360	0.036
60	0.270	0.027
70	0.200	0.020
80	0.160	0.016
90	0.140	0.014
100	0.094	0.009
110	0.052	0.005
120	0.012	0.001

The analysis considers the cable armour directly in contact with the seawater and as a result, the leakage resistance is conservatively low. In reality, the cable armour will be wrapped with a serving of bitumen-bonded polyethylene yarn and buried in a trench in the seabed. The leakage resistance is calculated considering the cable as a steel rod of equivalent diameter in the seawater. Factors including cable burial in the mud and higher resistivities of geological units underneath the cable are not considered, which will result in a higher leakage impedance and consequently lower leakage currents.

The analysis does not consider the detailed routing of the cable; rather a straight line between the two cable landing sites is assumed. The orientation of the cable runs relative to the electrode's electric field is mostly tangential to the GPR contours. This is favourable since the gradients along the cable will be minimal and therefore currents flowing in and out of the cable armour will be minimal. The actual routing of the cable will be determined mainly by the seabed bathymetry and morphology.

5.5.3 *Electrolysis Emissions at Anode and Cathode*

A review was carried out by AMEC to estimate the amount of electrolysis emissions produced during electrode operation, including chlorine and other by-products at the anode, and hydrogen at the cathode. The review also comments on electrode element pitting corrosion. The detailed review is included in Appendix K, and the findings of the review are summarized here.

The primary chemical reactions that produce chemicals of concern are listed below, with the primary products being chlorine gas (Cl_2) and hydrogen gas (H_2) [20].

Anode Reaction

$2H_2O \rightarrow 4H^+ + O_2(g) + 4e^-$ (1)

$2Cl^- \rightarrow Cl_2(g) + 2e^-$ (2)

Cathode Reaction

$2H_2O + 2e^- \rightarrow 2OH^- + H_2(g)$ (3)

The concentrations of products from reactions (2) and (3) have been estimated based on Faraday's Law (4) and maximum yields of 30% for Cl_2 and of 100% for H_2 are assumed [20].

$$n = \frac{(T * I)}{(z * F)} \quad (4)$$

where:

T = Operating time (s)

I = Total current (A)

z = Stoichiometric number of electrons transferred from anodic or cathodic reaction

F = Faraday constant (96485 C/mol)

n = products evolved (mol/s)

Table 5-10: Calculations of Cl_2 and H_2 Yield based on Faraday's Law (Gull Island)

Variable	Unit	Gull Island (Anode)	Gull Island (Cathode)
T	seconds	1	1
I	Amps	2320	2320
z	#	2	0.50
F	C/mol	96485	96485
n	mol/s	1.20×10^{-02}	4.81×10^{-02}
n	mol/year	3.79×10^{05}	1.52×10^{06}
Cl_2 (30%)	kg/s	2.56×10^{-04}	-
Cl_2 (30%)	kg/year	8.07×10^{03}	-
H_2 (100%)	kg/s	-	9.62×10^{-05}
H_2 (100%)	kg/year	-	3.03×10^{03}
Pond Length	m	100	100
Pond Width	m	15	15
Pond Depth	m	4	4
Pond Volume	L	6.00×10^{06}	6.00×10^{06}
$[Cl_2]$ one day	g/L	3.68×10^{-03}	-
$[H_2]$ one day	g/L	-	1.39×10^{-03}

It is important to note that these are conservative estimates and do not take into consideration the tidal flushing between the pond water and the ocean (twice per day) and chlorine evaporating from the pond into the atmosphere. In addition, the shoreline pond volume in Table 5-10 is based on the minimum dimensions established in the breakwater sizing and safety limit calculations. The actual shoreline pond volume considered in the design of the Gull Island electrode is larger than the volume stated in Table 5-10. These three factors will further reduce the concentrations of chlorine and hydrogen in the pond as compared to the conservative values presented in Table 5-10. Also, the reaction selectivity at an electrode is a function of water temperature, pH value of the water solution, salinity, light penetration, current density and the organic compound in the sea.

The products of the primary anode and cathode reactions will react with water and minerals in the water in complex ways that are not predictable. The details of secondary and tertiary reactions and by-products formed by these reactions are detailed in Appendix K.

The analysis herein will provide inputs for the environmental impact assessment of electrode installations to be undertaken by NE-LCP.

5.6 Electrode Line Installations, Fault Detection and Protection

An electrode line from the Gull Island converter station to the LAD North electrode location of approximately 407 km in length is planned. The line will have an insulation level equivalent to a 25 kV system line and arcing horns are not foreseen. The line will be routed in the HVdc line corridor with a center-to-center spacing of 25 m between the HVdc and electrode line. The electrode line will diverge from the HVdc ROW near the LAD North shoreline electrode location and will require an independent ROW.

The long electrode line between the Gull Island converter station and the LAD North electrode site presents a unique technical challenge for detecting and protecting faults. A review of the technology and methodology that could be used for the electrode line fault detection and protection was undertaken by RBJ Engineering and is included in Appendix F. The review identifies the issues associated with fault detection for long electrode lines, reviews commonly used schemes for an electrode line fault detection including the limitations of the schemes, and recommends a fault detection scheme for the Gull Island electrode line. The review is summarized in this section.

It is difficult to provide detection of electrode line fault for a number of reasons:

- Electrode lines are connected to ground at the electrode end and thus are in a sense already “faulted”.
- The converter acts as a current source thus there is no increase in total electrode line current even if an electrode line-to-ground fault occurs.
- There is very little electrode line current in the bipolar mode of operation, (typically only 0.5% to 1% of the rated HVdc current). Bipolar mode is the most prevalent mode of operation.

For the long line considered for Gull Island converter, the following factors further complicate the application:

- Large voltage drop at the converter station neutral bus end, resulting in a higher likelihood of sustained arcing faults;

- Large signal levels required for fault detection techniques (e.g. high frequency impedance measuring);
- Increased noise pickup and signal attenuation resulting in decreased sensitivity of fault detection techniques based on time domain reflectometry; and
- Communication from the converter station to the electrode site can be more difficult (e.g. communications repeater stations could be required for a fibre optic communications system).
- High resistivity of the soil that does not provide good conductive path for the current return.

A range of fault detection and protection methodologies including conductor unbalance current fault detection (CUC), end-to-end differential protection (ETED), high frequency current injection method, neutral bus voltage measurement (NBV) and pulse-echo method (PE) were reviewed for application to the Gull Island electrode line. Based on the advantages/disadvantages and availability of each fault detection and protection method, the following techniques are recommended:

- A protection system based on high frequency impedance measurement (HFLI) or high frequency current differential (HFCD) is recommended to use as primary fault detection scheme.
- Neutral bus overvoltage protection (NBV) should always be installed as a primary protection of the neutral bus equipment in the event that both conductors of the electrode become open circuited. Its protective action should be to close a high speed ground switch at the converter station. It would also be necessary to reduce the HVdc converter current or possibly trip the converter.
- Conductor unbalance current (CUC) protection and end-to-end differential (ETED) protections using the HVdc electrode line current should be installed as secondary protections.

In addition, active fault suppression action consisting of either a high speed ground switch at the converter station or a converter temporary block sequence should be specified for clearing of persistent arcing faults on the electrode line that do not self-extinguish. The provision for individually isolating each electrode line conductor should be considered to ensure minimum unavailability of the dc system in the event of maintenance on only one conductor of the electrode line.

Overvoltage protection and insulation coordination of the electrode line should be considered in the overall line and system insulation protection scheme; these aspects were not reviewed. The line insulation should be designed

- to ensure any arcing due to flashovers will be diverted away from the insulators, and
- to ensure any arcing will be self-extinguishing even at the maximum monopolar HVdc converter current and the largest electrode line voltage that is likely to occur at 10 minute overload current rating.

NE-LCP should review the electrode line installations taking into account the above suggested line insulation performance parameters and should analyze the electrode installations with the HVdc systems to qualify the recommended fault detection and protection methodologies.

The primary concern with undetected electrode line faults is the safety of the public and others having access to the transmission line right of way. Undetected faults such as trees falling against the line or dropped conductors where the conductor is not broken are the main concerns. Such faults could pose an electrical hazard or fire risk. If suitably sensitive protections are not available then the risks must be mitigated by other means such as greater emphasis on tree cutting in the right of way and more frequent line patrols to discover dropped conductors.

5.7 Cost Estimate

The engineering, procurement and the construction cost estimate based on the electrode installations foreseen for Option 1 above is of the order of $ million CAD; the cost estimate corresponds to a Level 3 estimate (-20% to +30%) in accordance with AACE. Details of the cost estimate are included in Appendix E.

The following battery limits are considered to develop the estimate:

- Electrode line dead-end termination gantry structure at LAD North. The electrode line and associated instrumentation, controls, and integration of controls into the overall HVdc system are not part of this estimate.
- Fibre connectors at the electrode control building panels. The communication link including communication and SCADA equipment in the HVdc control room.
- The service entrance pole outside the electrode installations, the pole mounted transformer and auxiliaries associated with the transformer are considered part of the estimate. The distribution line from the nearby distribution network to the electrode installation location is not considered in the estimate.

The following assumptions are made to develop the estimate:

- Any mitigations required to address the electrode electrical interference, electrode corrosion impacts or environmental impacts are not considered. It is expected that electrical interference and corrosion impacts will be insignificant. The information on environmental impacts needs to be investigated independently by NE-LCP.
- The construction of the electrode will be a single contract.
- The seabed soil can adequately support the breakwater structure and special measures are not required to improve the soil conditions.
- A diesel generator set is not required to support the electrode facilities for a long duration outage on the distribution system. NE-LCP should review the need of a diesel generator set based on the expected worst case power outage.

5.8 Summary of Findings and Next Steps

The key findings based on the above site selection, electrical field analysis and infrastructure impact assessment are as follows:

- The cove at L'Anse-au-Diable (LAD) North is viable for a shoreline pond electrode. The site meets the electrode performance requirements; is strategically located for access and to interface with electrode line requiring the shortest independent ROW for the electrode line compared with other sites; and is relatively remote from the major infrastructure.

- The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode exceed the permissible dc stray current values that will consume 50% of the ground electrode material (a typical acceptable consumption of ground electrode material) over the life of the project. Corrosion of grounding poles is not a significant concern and the issue can be addressed through regular inspection and replacement as required.
- Based on the theoretical analysis, corrosion impact on the HVdc submarine cable is minimal and is not of concern. However, corrosion of the submarine cable is a complex phenomenon that is a function of geomagnetic induced current, chemistry of the sea environment and land fall installation, dc stray current associated with an electrode operation and should be studied during the detail engineering stage.
- The impact of the electrode operation on marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 2.6 km into the SOBI, and it is not of concern. The voltage gradients in the sea are not large enough to cause corrosion of a ship's hull. The GPR gradients on the sea side of the breakwater are maintained below the published safe level [9,10].
- Reliable fault detection on a long electrode line like the one from the Gull Island converter station to the LAD North electrode location is a difficult technical problem. It may not be possible to achieve reliable fault detection; therefore the line insulation should be designed to ensure that any arcing will be self-extinguishing and diverted away from the insulators. Undetected faults such as trees falling against the line and dropped conductors are the main safety concerns. If sensitive detection is not possible then the risks shall be mitigated by other means such as greater emphasis on tree cutting in the right of way, safe and rugged electrode line design, and more frequent line patrols.
- The engineering, procurement and construction (EPC) cost of the shoreline pond development (Option 1) at LAD North electrode is expected to be $8.27 million CAD.

The actual electrical interference and corrosion impact values may be different from those calculated in this study since dc stray currents from natural sources like inhomogeneous soil chemistry, telluric currents and other industrial operations are not considered. Also, the civil/structural designs are based on assumed geotechnical information and area topography. Moreover, the auxiliary systems proposed for the electrode installations do not take into account NE-LCP's operation and maintenance practices or integration into overall HVdc system.

To increase the confidence level associated with the assumptions made for the proposed design and the resulting impact assessment, the following steps are recommended:

- Undertake an environmental assessment of the proposed installations including the electrode lines to qualify the locations and designs. Adjust the locations or designs if required (a minor adjustment in location maintaining the same electrode design parameters will not require reassessment).

- Identify the shoreline and inland topographic survey requirements and undertake a field program to collect the information required to better define the civil/structural design.
- Identify the geotechnical investigation, wind and wave study requirements, and undertake a field program to collect the data to further the civil/structural design.

The following steps are recommended during the detail engineering and commissioning stages:

- Review the electrode duty to qualify the impact assessment based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation. The electrode duty is based on a very pessimistic operation of the HVdc link.
- Review the auxiliary systems proposed taking into account operation and maintenance practices of NE-LCP and integration into the overall HVdc system. Adjust the auxiliary systems as required.
- Assess the corrosion potentials for any other major metallic structures in the area during the electrode commissioning tests.
- Measure current during the electrode commissioning tests in large transformer grounded neutral leads, transmission line and distribution line ground leads, and rotating machine grounded neutral leads.
- Review the shoreline pond electrode installation costs during the detailed engineering stage.

6. Soldiers Pond

The Dowden's Point site was identified in the DC1250 study as a viable location for a shoreline pond electrode; however, the sea and soil model used for electrical field study and the electrode infrastructure models used for the impact assessment were based on the best information available at that time and assumptions were made where the information was not available. The mandate of this study is to refine the sea and soil model, reaffirm the electrical field study and impact assessment results, reconfirm the Dowden's Point suitability for a shoreline pond installation, and develop a conceptual design of electrode installations.

6.1 Site Description

The site is located on the south shore of Conception Bay, between Seal Cove Pond and Lance Cove Pond. A few operating industrial units are located in the area. Residential infrastructure is located in Seal Cove in the vicinity of Dowden's Point. Seal Cove is a part of the town of Conception Bay South, a larger major population centre that extends 15 km northeast from Seal Cove to Topsail. An abandoned railway running parallel to the shoreline of Conception Bay is currently used as a trail for walkers and for all-terrain vehicles. The key transmission and generation facilities including Holyrood Generating Station, Holyrood 230 kV Terminal Station, Seal Cove Generating Station, and NL Power Distribution Station are located within a 6 km radius from the Dowden's Point electrode location. Figure 6-1 shows the location of Dowden's Point; Appendix O contains site photographs taken at Dowden's Point.

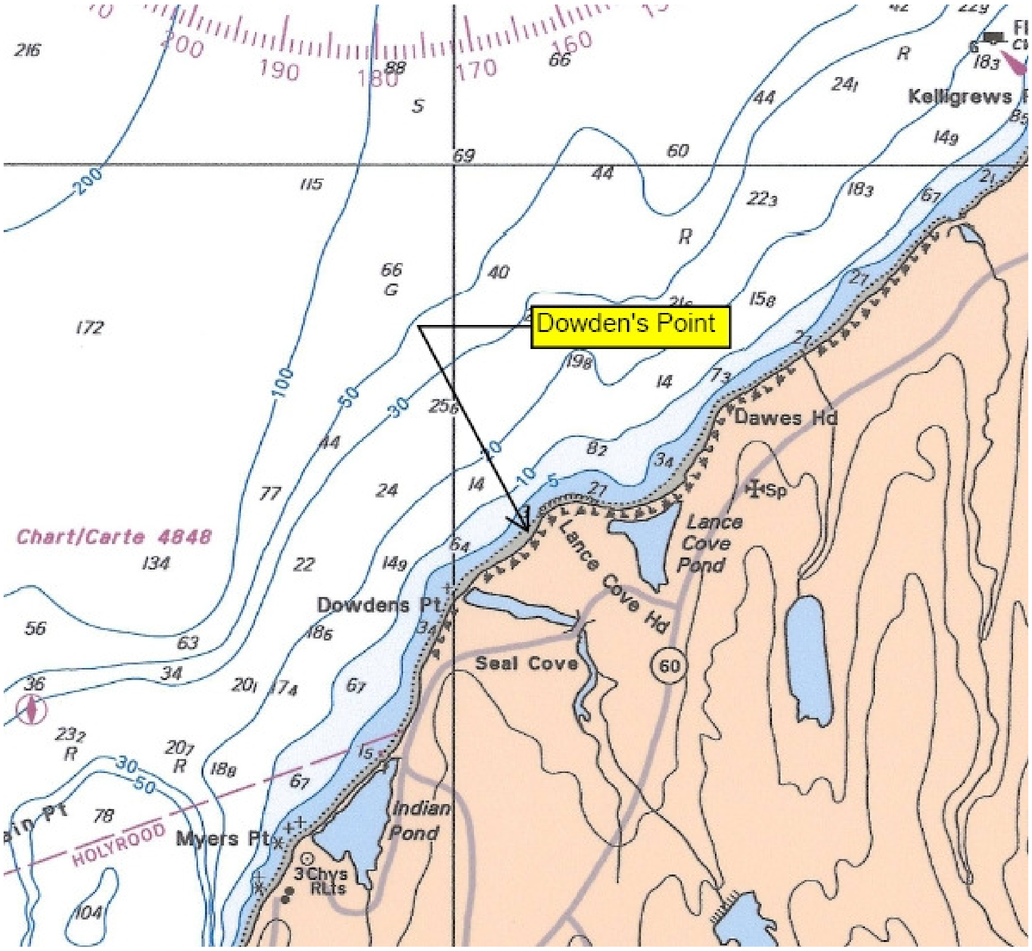

Figure 6-1: Soldiers Pond Electrode Location
(The values shown in the sea are the depths in metres at the lowest normal tide)

6.2 Electrode Design Criteria and Electrode Installations

The primary benefit of a shoreline pond electrode is that the seawater conducts most of the electrode's current (i.e. through the path of lower resistivity), such that the electrode GPR is low and its zone of influence is very limited. Consequently, impact on the land side infrastructure is minimal.

A shoreline pond electrode's performance depends on its exposure to the open sea, therefore the nearby bathymetry impacts the performance of the electrode. The bathymetric chart [14] available from the Canadian Hydrographic Service in the area of Conception Bay is 1:60 000 in scale and does not provide adequate detail for the sea depths in vicinity of Dowden's Point. Consequently, a bathymetric survey was carried out to accurately capture the water depths near the electrode site; the survey is included in Appendix M.

The design of a shoreline pond electrode must satisfy criteria from different vantages – electrical, civil/structural, and safety – all of which are mutually dependent. These criteria form a basis for the design requirements of the shoreline pond, the breakwater and the electrode installations. The following sections summarize the criteria used to develop the design of the Soldiers Pond electrode.

6.2.1 *Electrical Design Criteria*

The electrode must meet the electrical performance requirements, which include the current carrying requirements and duties for the Soldiers Pond electrode; these values are summarized in Table 6-1 and Table 6-2, and full details are included in the DC1250 study [1].

Table 6-1: Soldiers Pond Monopolar Current Duties

Nominal current, I_{nom} (A)	890
Maximum continuous current, $I_{max, cont.}$ (A)	1340
Maximum 10-minute overload, $I_{max, 10min.}$ (A)	1780

Table 6-2: Soldiers Pond Electrode Duties over 40 Year Life Cycle

Description	Anodic Operation Duty (Ah)	Remarks
Scheduled outages	1,643,376	$I_{max, cont.}$ *0.5%*70%*8760 h/y*40 y
Forced outages	3,118,560	$I_{max, 10min.}$*0.5%*8760 h/y*40 y
Continuous imbalance	3,504,000	I_{nom}*1%*8760 h/y*40 y
Cable outage (one year)	11,738,400	$I_{max, cont.}$ *8760 h/y*1 y
Total Duty (40 years)	**20,004,336**	**Ampere hours**

The maximum continuous current of 1340 A is considered for determining the minimum number of electrode elements required for the electrode. The electrode element currents need to be such that they will allow for continuous monopolar operation without replacement for a duration of more than one year (in the event of submarine cable damage in the Strait of Belle Isle). A design margin will be considered to address any imbalances in current sharing, electrode element design tolerances and condition of the electrode at the start of the worst case monopolar operation. Additional elements are considered to ensure electrode performance during maintenance. The impact on the surrounding infrastructure is evaluated for a 20,004,336 Ah duty that is based on a very pessimistic operation of the HVdc link. 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.

The dimensions of the shoreline pond and breakwater are a function of the electrode element types, electrode element installations, seawater resistivity, tide changes, ice formation during winter, and safe GPR gradients required on the sea side. When installed along the side of the breakwater, the shoreline pond must be deep enough to fully contain the electrode elements, and in addition account for tide changes and ice. From an operational perspective, the electrode installations should facilitate maintenance. Regular inspection of electrode elements should be achieved from the top of the breakwater, without the need of a diving team.

The design of electrode supporting infrastructure (such as the electrode control room, the electrode line towers, the electrode site fence, etc.) should take into consideration the impacts of the electrode’s operation, interfacing with the electrode elements, operation and maintenance requirements, and integration with the overall HVdc system. The security fence should be split into isolated sections or be of insulated design to minimize the impact of dc stray currents. Grounding and bonding connections to the area distribution system should be avoided.

6.2.2 *Civil/Structural Design Criteria*

The breakwater shall be designed to withstand the expected worst case site conditions, including wave action, tidal effects, pack ice and freezing inside the shoreline pond.

The depth of the shoreline pond required at the land side toe line must account for the electrode elements installations in the shoreline pond, changes in the water level due to tides and ice formation within the shoreline pond. The depth shall be such that the electrode elements are fully immersed in the water below the ice under various conditions. Also, a depth on the sea side shall be such as to meet the safety criteria explained below.

The size of the breakwater, its composition and its location relative to the shoreline will depend on the electrical performance requirements, structural integrity, and operational and maintenance needs. The crest width will be selected to satisfy operations requirements and meet minimum requirements for construction. A layer of uniform size rock with an increased void ratio is required to conduct the electrode current through the breakwater and into Conception Bay and to maintain the salinity of the water in the shoreline pond which is critical for the performance of the electrode. Public access to the electrode site must be restricted from the land side.

The installation of the electrode elements should be arranged to provide mechanical protection against the floating ice and consideration should be given to mitigating the formation of ice in the raceways housing the electrode elements and the electrode leads.

6.2.3 *Safety Design Criteria*

The contact area between the breakwater and the sea is driven by safety considerations; a minimum contact area between the shoreline pond and the breakwater must be achieved to ensure a safe voltage gradient on the sea side of the breakwater.

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 seawater. A value of 1.25 V/m is selected as safe design value [9,10,11] for large fish and humans.

6.3 Proposed Design

The proposed electrode installation considers an array of tubular, high-silicon chromium chill cast iron (HSCI) electrode elements arranged in the shoreline pond along the side of the breakwater. The elements are divided into six subsections, as shown in Figure 6-2. Considering a total electrode current of 1340 A (corresponding to the 10 minute continuous maximum current), a current dissipation of 37.2 A per element for normal operation (less than manufacturer's recommended current value and electrode consumption time period of more than two years) and a contingency of one subsection (for maintenance), the Soldiers Pond electrode requires 36 elements (i.e. 6 subsections of 6 elements).

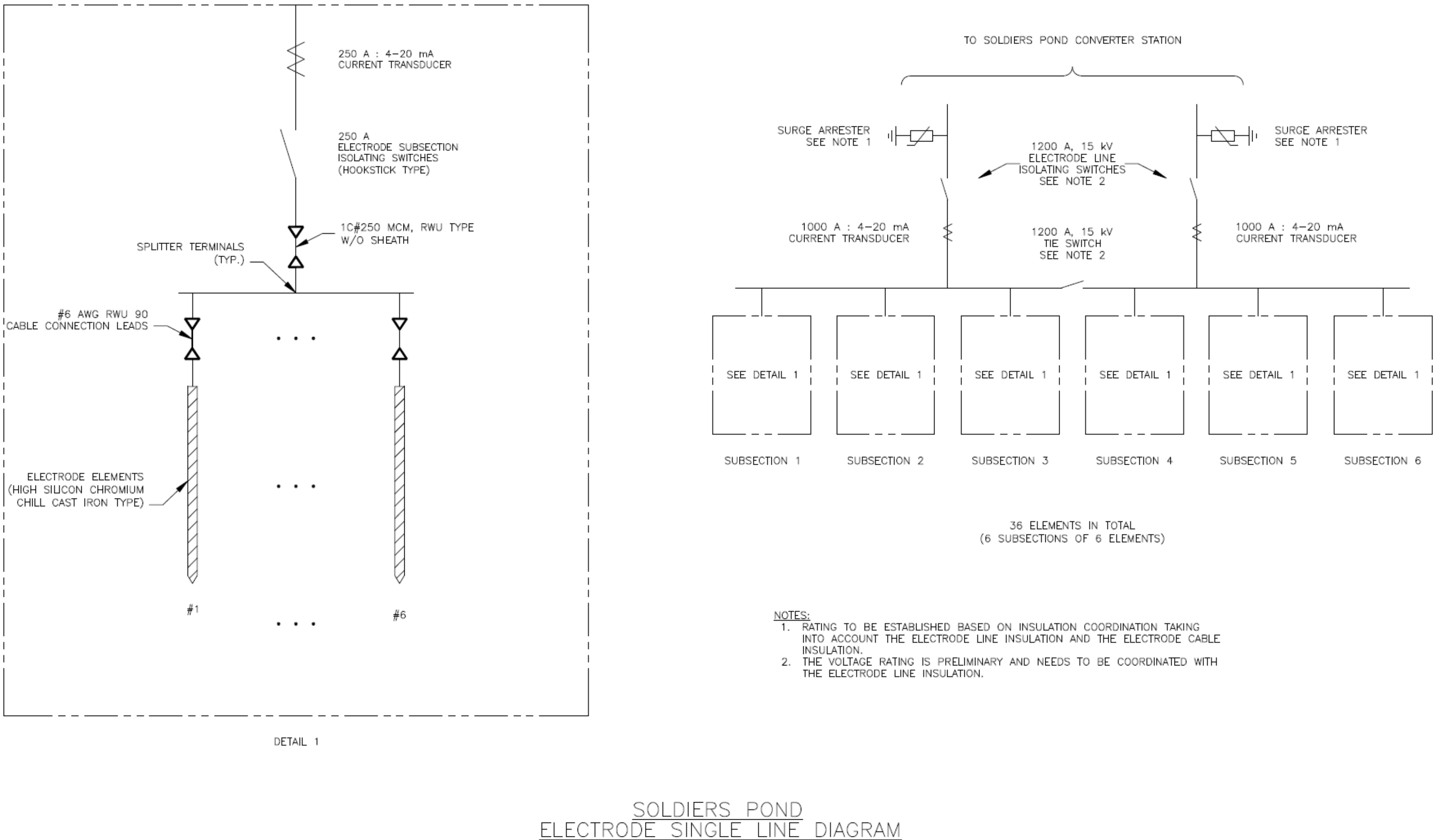

Figure 6-2: Soldiers Pond Electrode Single Line Diagram

Based on the required number of electrode elements, the current density within the shoreline pond can be established. Subsequently, the dimensions of the breakwater required to ensure a safe gradient of less than 1.25 V/m at the interface of the breakwater and the sea can be calculated. The required contact area is approximately 407 m^2, which translates to a breakwater approaching 60 m in length. Details for calculating the number of electrode elements and breakwater size are included in Appendix A.

A sensitivity analysis was carried out to examine the effect of different element arrangements in the pond on the element current density. It is known that when equally spaced, elements on the extremities of a linear array will carry higher currents than those in the middle. The analysis determined that a "quasi-uniform" arrangement would provide a fairly uniform current distribution among the elements and would be feasible from a constructability standpoint. The "quasi-uniform" arrangement consists of a 1.75 m equal spacing for all elements in the middle of the array, with tapering in steps of 1.5 m and 0.75 m towards both ends of the array. Figure 6-3 shows the even current dissipation among elements. The details of the sensitivity analysis are included in Appendix B.

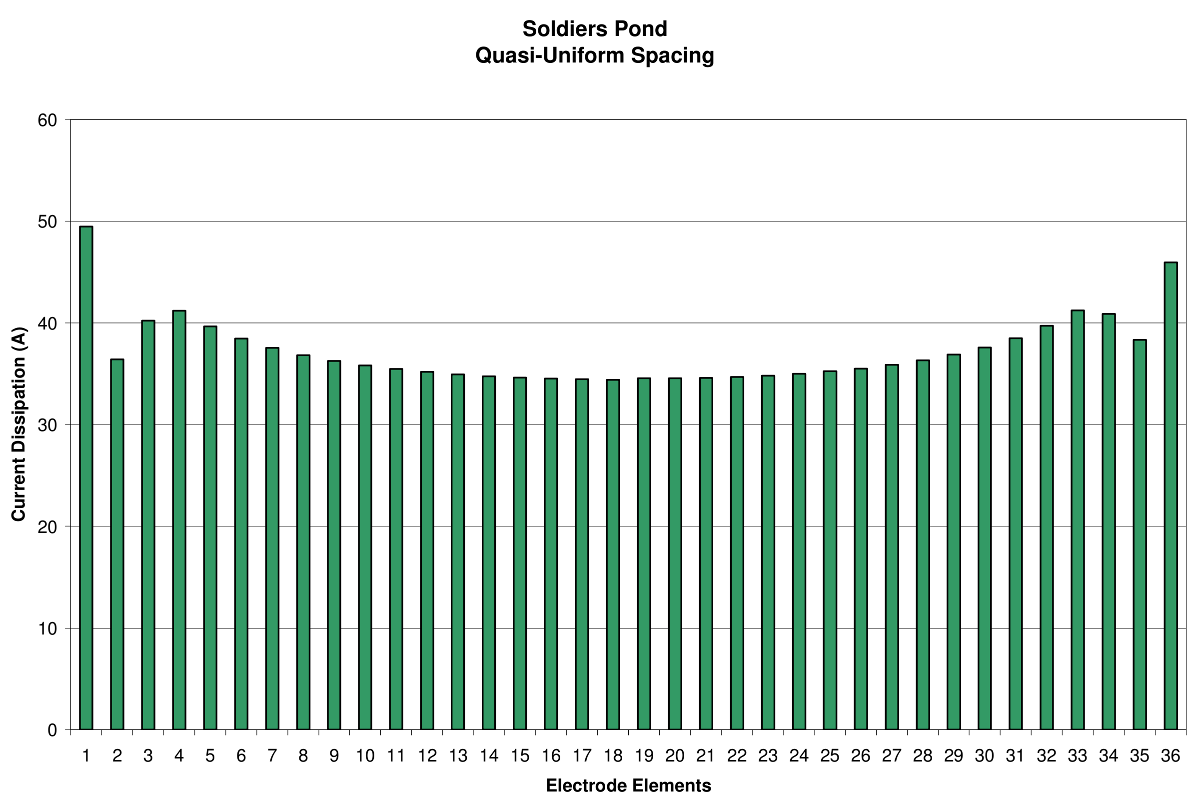

Figure 6-3: Soldiers Pond Current Dissipation

Significant wave height in the range of 6-8 m is expected in Conception Bay requiring a significant breakwater structure.

It is anticipated that the breakwater would be a rubble mound structure consisting of embankment materials obtained from nearby quarries in bedrock. The majority of the structure will be random materials from blasting in the quarry. Larger sizes will be selected from the quarry to be used as the filter and the armour stone placed on the sea side slope to protect the main body of the mound from destruction by storm waves. A further selection will be made to form the embankment which is required to be permeable so that a flushing and transfer of saltwater can be achieved naturally through the embankment. Any potential for landslides at the eroded shoreline fill at Dowden's Point will be mitigated by slope flattening and revetment with riprap stone. Selected coarser rock will be selected to form a pavement on the pond side slope in the tide and ice range of movement.

Access roads to the site will be constructed to link with the existing roads. The site will be fenced by chain link fencing to prevent public access to the pond.

Approximate significant parameters for the rubble mound structure and pond are indicated in Table 6-3 below:

Table 6-3: Dowden's Point Shoreline Pond and Breakwater Design Summary

Description	Unit	Value
Pond length [Note 1]	m	60
Pond width	m	Varies
Pond depth at pond side toe, low tide	m	4, minimum
Water depth at sea side toe	m	Not confirmed
Assumed shore slope	H: 1V	1.5
Crest width	m	9.5
Sea side mound slope	H: 1V	1.5
Shore side mound slope	H: 1V	1.5
Approximate CL height	m	15.5
Tide height	m	1.5
Crest above low water	m	9.5
Low water level on shoreline	el. m	0
Armour weight (mass)	Tonnes	4 & 12
Permeable core size	m	0.5 to 1.0
Notes: 1. Length of breakwater section where depth at sea side toe is 4 m or more.		

A void ratio of 19.3% is considered for the calculation; a higher void ratio will permit a shorter length of breakwater.

The average size of rock in the permeable zone is assumed to be 0.5 m to 1 m in diameter. A crest width of 5 m (excluding armour stone) on the top of the breakwater is expected, based on a high level review. A slope of 1.5 H in 1 V is foreseen for the breakwater based on experience in the area.

A wind and wave study will have to be undertaken to confirm the design wave height. The design wave in conjunction with anticipated economical armour size available near the site will determine the final embankment slopes and protective layer arrangement and thicknesses. The catchment area should be developed to minimize or prevent drainage of run-off water from precipitation, snow melt and storm into the pond.

The layout and section of the shoreline pond electrode, breakwater and associated installations are shown in Figure 6-4 and Figure 6-5 respectively; this design is referred to as Option 1. The breakwater extends into Conception Bay such that, at the land side toe of the breakwater where the elements are installed, a natural low-tide sea depth of 4 m is achieved (i.e. no excavation of the seabed). The land side toe line of the breakwater is approximately 79 m from the shoreline and the sea side toe line is approximately 129 m from the shoreline.

The bathymetric survey at Dowden's Point revealed that the distance into Conception Bay at which a natural depth of 4 m occurs was greater than initially anticipated. The result was a large footprint of breakwater.

Minimizing the footprint of the breakwater is desirable to reduce issues in the environmental and regulatory processes. Therefore, an alternative shoreline pond electrode was designed at Dowden's Point; the layout and section for Option 2 are shown in Figure 6-6 and Figure 6-7, respectively. The crest of the breakwater aligns with the top of the existing bank and the sea side toe line coincides with the existing low tide shoreline. A channel would be excavated to a depth of 4 m from the inside of the shoreline pond outward to the natural depth of 4 m in Conception Bay. The depth of the soil above the bedrock at Dowden's Point is anticipated to be approximately 30 m, which would permit excavation without the need to blast away rock. The excavated area on the sea side of the breakwater may be in the shape of a wedge, increasing the electrode's exposure to the sea. A regular excavation program may be required to maintain the seabed depth requirement of 4 m to ensure the electrical resistance of the electrode does not increase significantly and the breakwater's permeable zone is not clogged.

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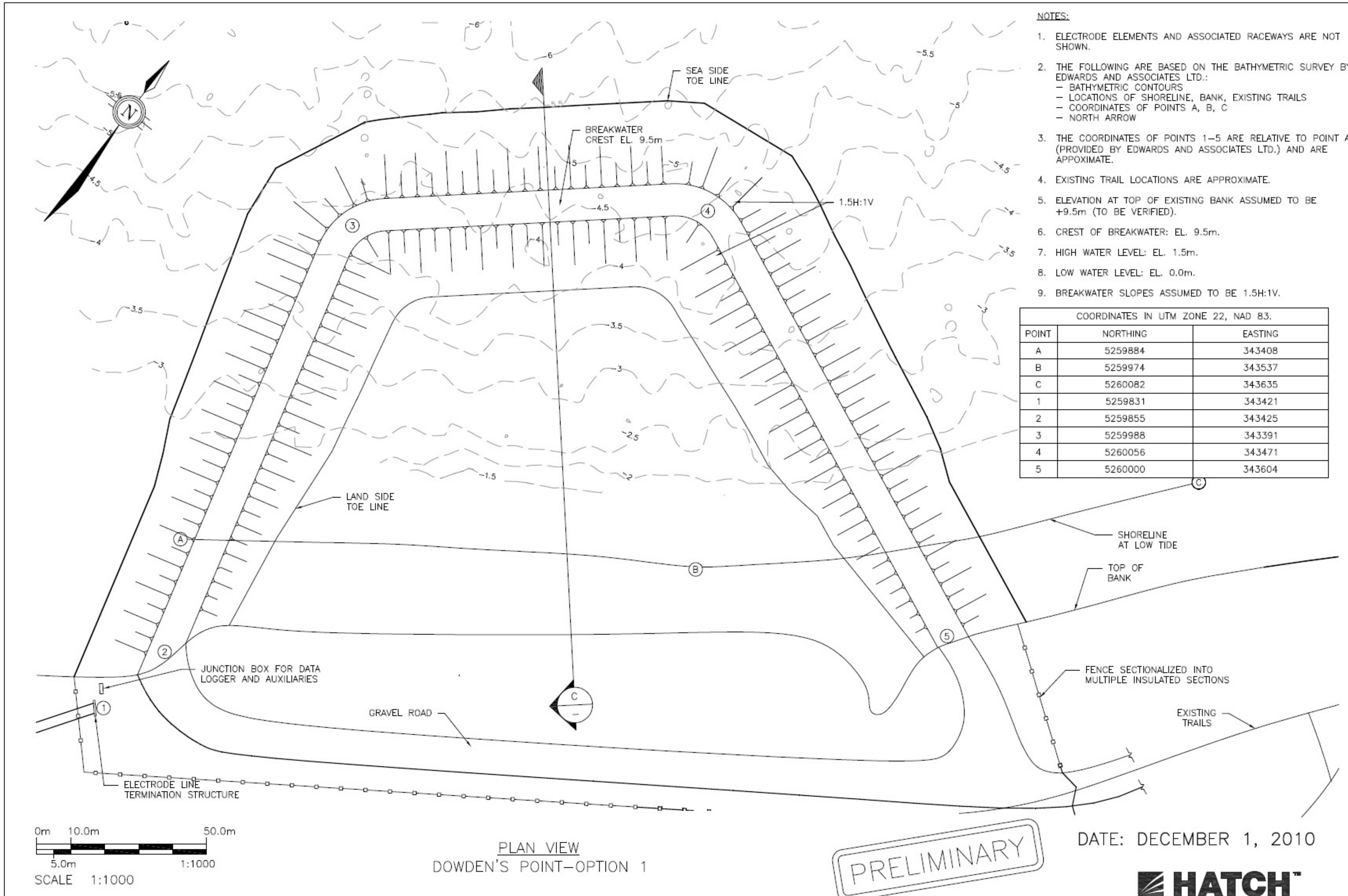

COORDINATES IN UTM ZONE 22, NAD 83.

POINT	NORTHING	EASTING
A	5259884	343408
B	5259974	343537
C	5260082	343635
1	5259831	343421
2	5259855	343425
3	5259988	343391
4	5260056	343471
5	5260000	343604

Figure 6-4: Soldiers Pond Shoreline Pond and Breakwater Layout (Option 1)

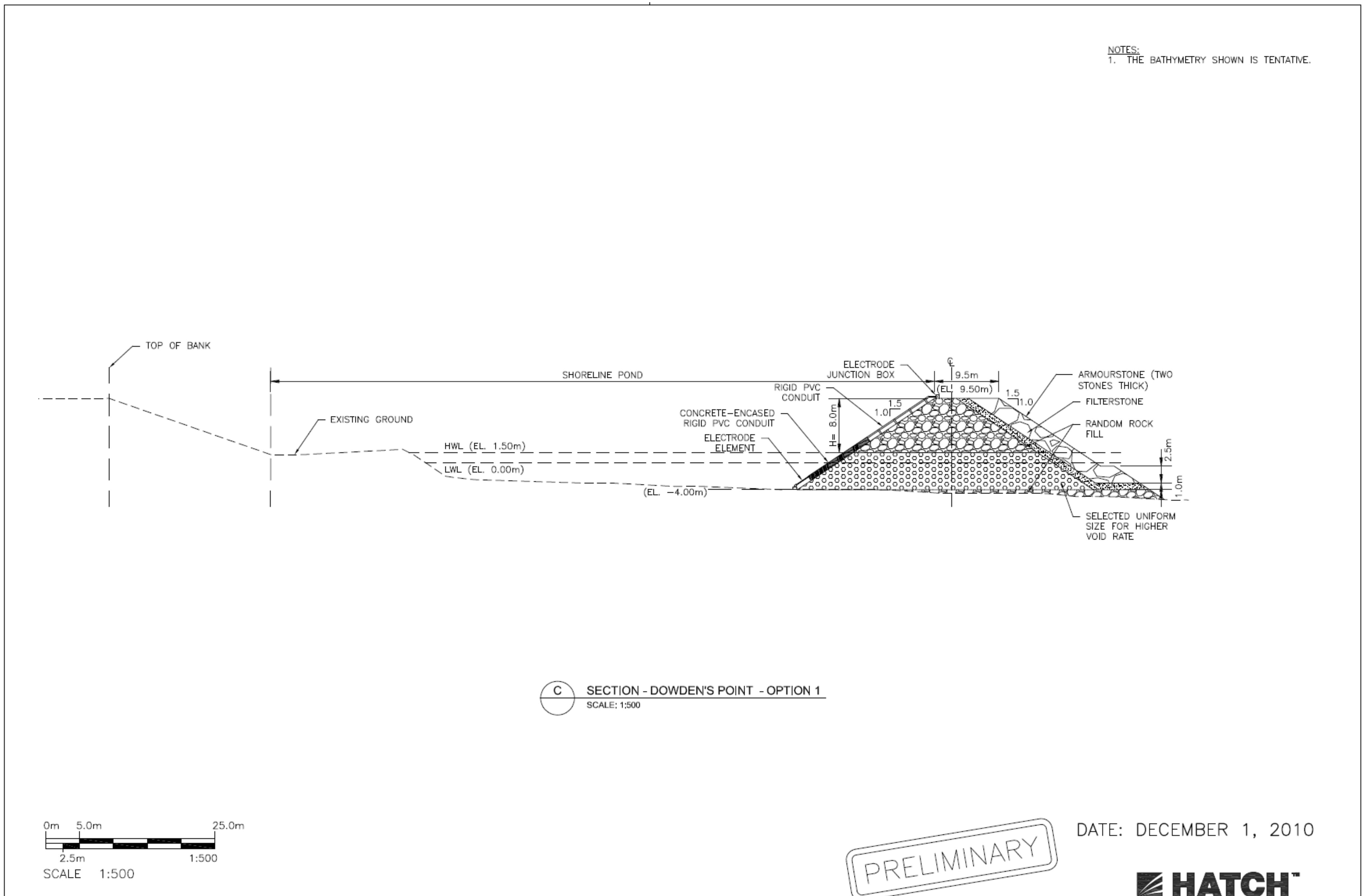

Figure 6-5: Soldiers Pond Shoreline Pond and Breakwater Section (Option 1)

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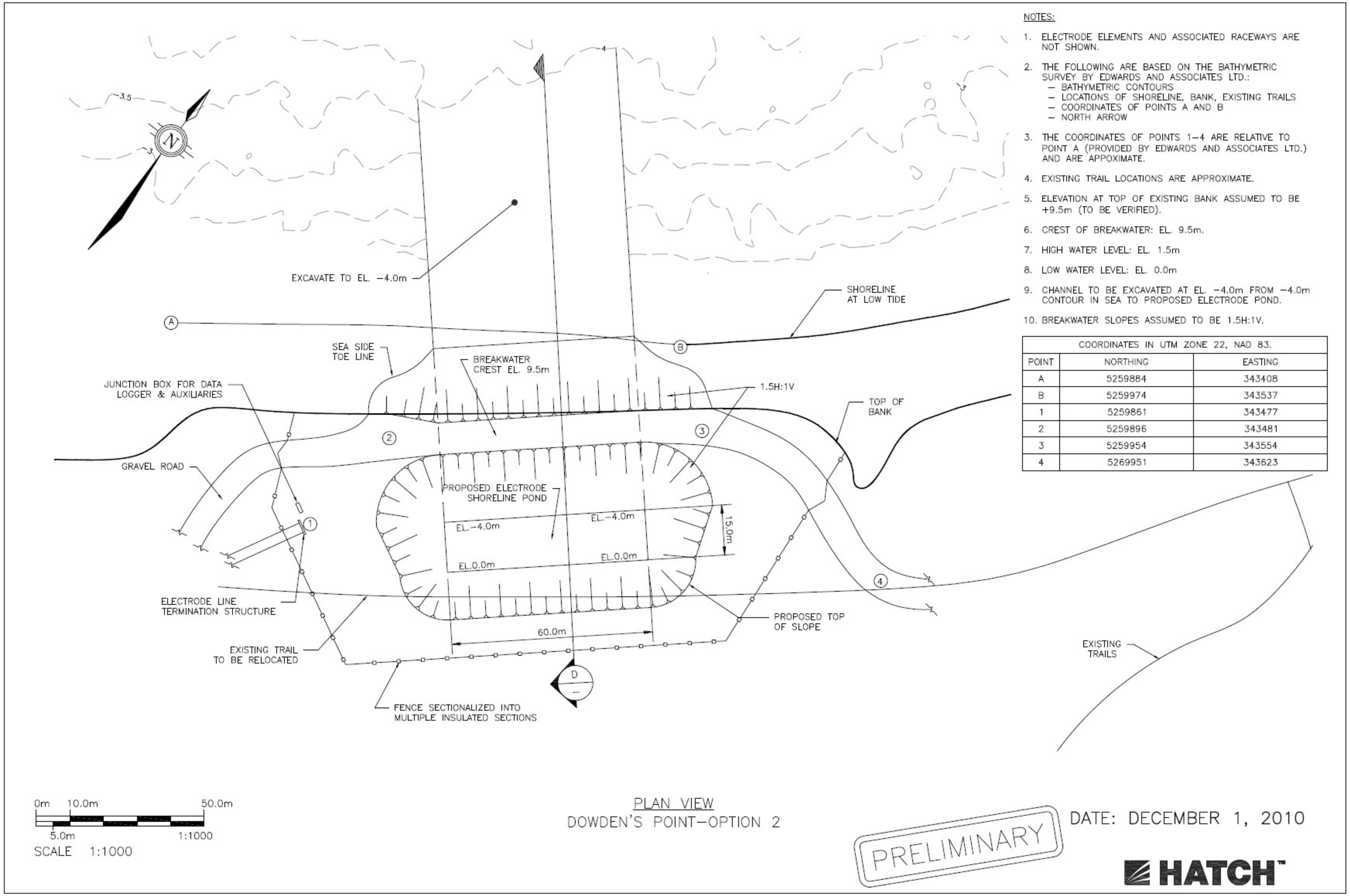

COORDINATES IN UTM ZONE 22, NAD 83.		
POINT	NORTHING	EASTING
A	5259884	343408
B	5259974	343537
1	5259861	343477
2	5259896	343481
3	5259954	343554
4	5269951	343623

Figure 6-6: Soldiers Pond Shoreline Pond and Breakwater Layout (Option 2)

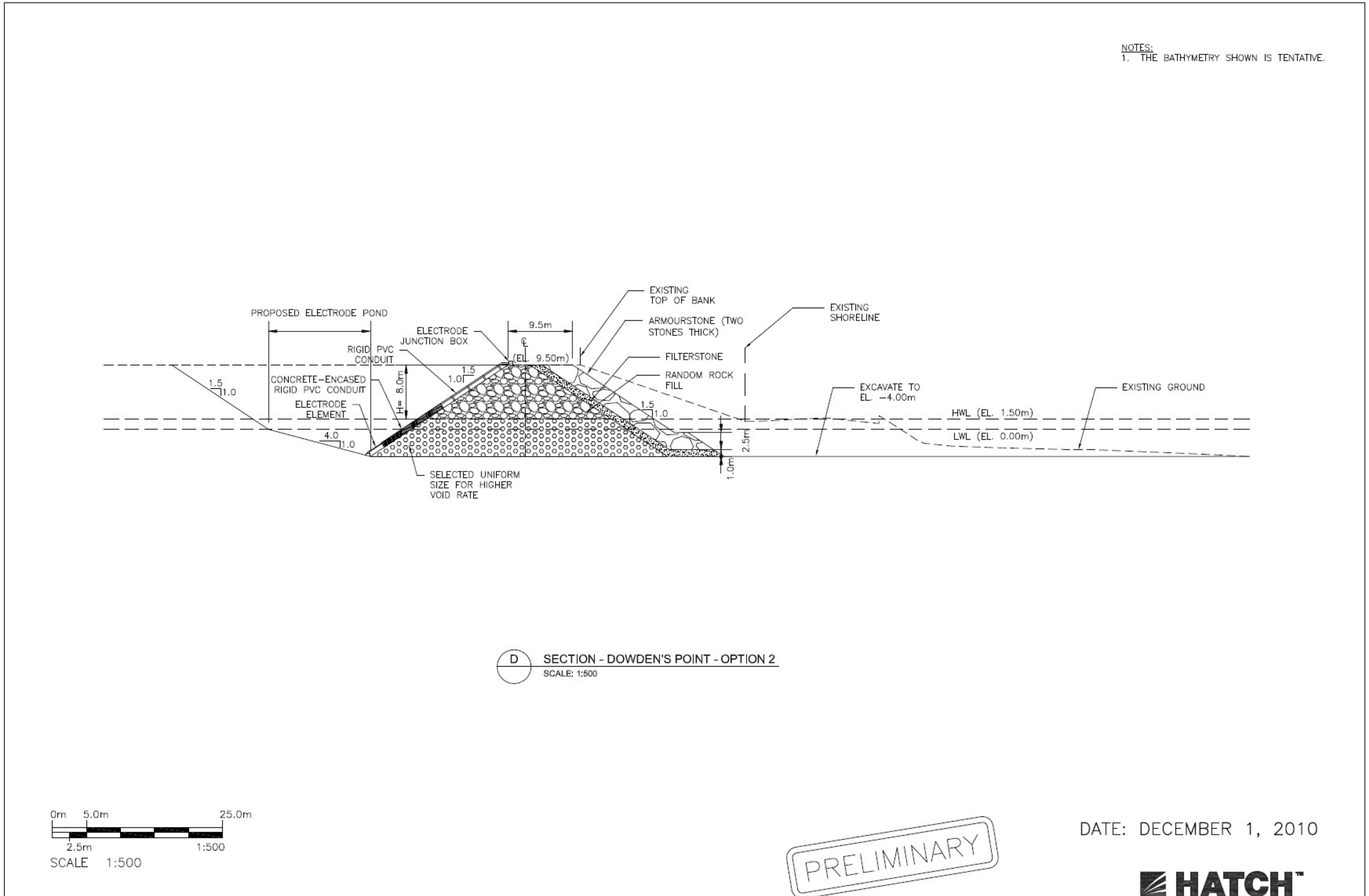

Figure 6-7: Soldiers Pond Shoreline Pond and Breakwater Section (Option 2)

6.3.1 Surge Protection, Isolating Switches, Monitoring Requirements and Auxiliary Systems

The Dowden's Point electrode site is accessible, and the electrode line is short enough that it does not require protection and communication equipment at the electrode site to detect an electrode line fault. Consequently, dedicated communication channels for electrode line fault detection and protection and a dc auxiliary system for protection and essential systems are not mandatory.

Figure 6-2 is the single line diagram of the Dowden's Point electrode. The main electrode line conductor switches and tie switch at the electrode location are manually operated and are required for isolation of the electrode installations from the electrode line and for reconfiguration of the electrode. Individual sections are provided with hookstick operated disconnect switches to facilitate inspection and maintenance of the electrode sections. Distribution class surge arresters at the electrode line termination points are required to protect the electrode site cables and instruments from transient and lightning surges. The surge arrester rating will be a function of the electrode line insulation, the voltage rating of the cables and the voltage ratings of the equipment, and the surge arrester rating needs to be determined as part of the electrode line insulation coordination study.

In normal operation, the two line switches will be closed, and the tie switch will be open. If a neutral line fault is detected on one electrode line conductor or reconfiguration of the electrode is required for maintenance, the switches at the converter station and at the electrode site will be manually operated by staff.

There will be eight dc current transducers located at site. Two will measure the electrode line currents and six will measure the current in each electrode subsection. The current data will be logged and can be interrogated from the converter station. Relative changes in the measured current values over time between the electrode subsections could detect a loss of electrode elements, indicate the development of a high resistance connection or an excessive consumption of the electrode elements.

The electrode elements are installed below the expected freezing level of the shoreline pond, supported in conduit guides (typically PVC) with pull-out provisions for inspection from the top of the breakwater. Typical installation arrangements are shown in Figure 6-5. The selection of conduit materials and installation design shall be such as to minimize the probability of freezing in conduits. A heat tracing system is not considered and an inspection program would be required during the first winter after commissioning to identify any freezing issues in the conduits.

The auxiliary power supply shall consist of a 208/120 Vac supply for site auxiliaries and data logging equipment. Figure 6-8 is the single line diagram of the proposed ac auxiliary supply.

A control house building is not required; the data logging equipment can be housed in a weatherproof enclosure. The communication infrastructure required will include a PSTN line for sending over logged data to the HVdc control room via a RS232 modem. Figure 6-9 is the block diagram of the monitoring and communication infrastructure foreseen.

A further review of auxiliaries and the monitoring system needs to be carried out with inputs from NE-LCP operation and maintenance groups to finalize the system requirements. It is possible to operate and maintain the Dowden's Point electrode without any auxiliaries or monitoring equipment because the electrode location is accessible and the electrode line length is short.

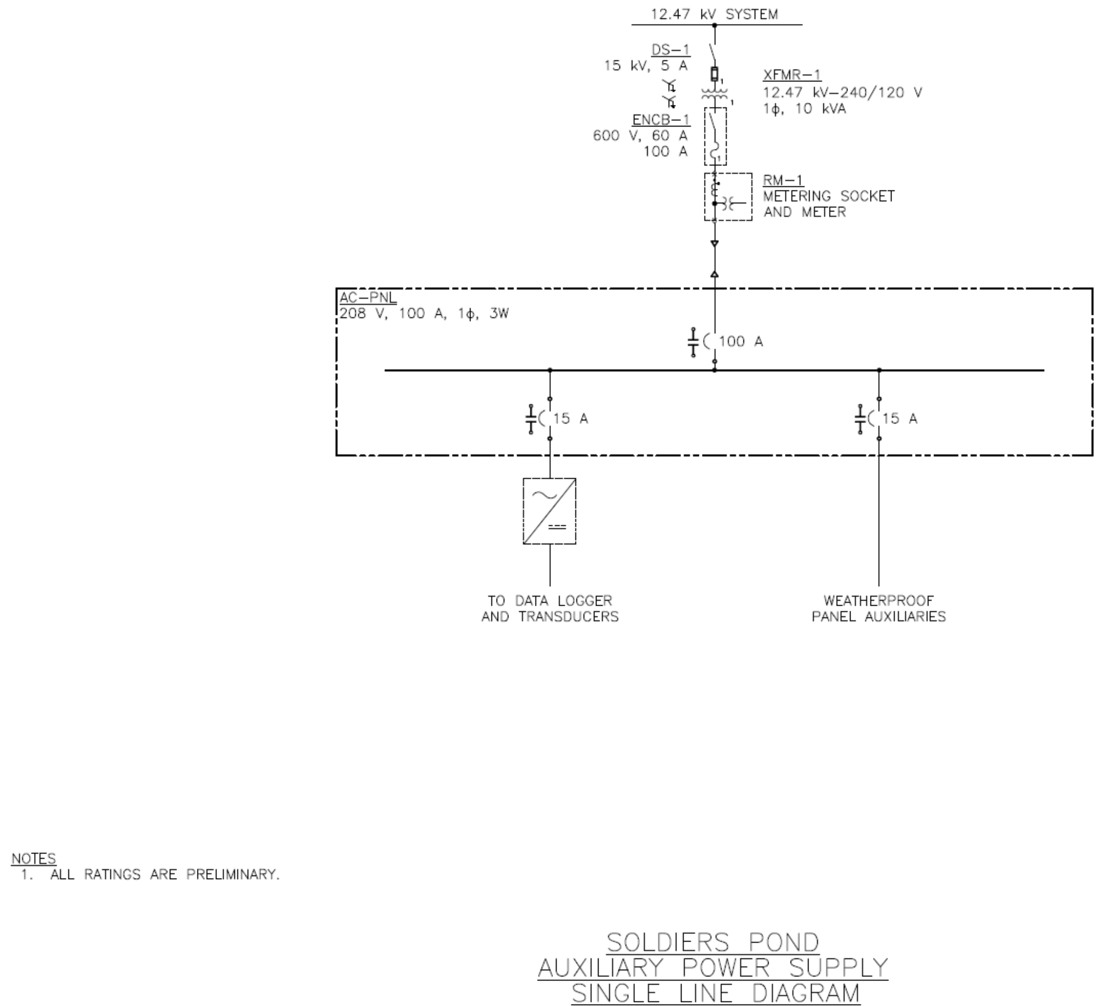

Figure 6-8: Soldiers Pond Electrode Site Auxiliary System, Single Line Diagram

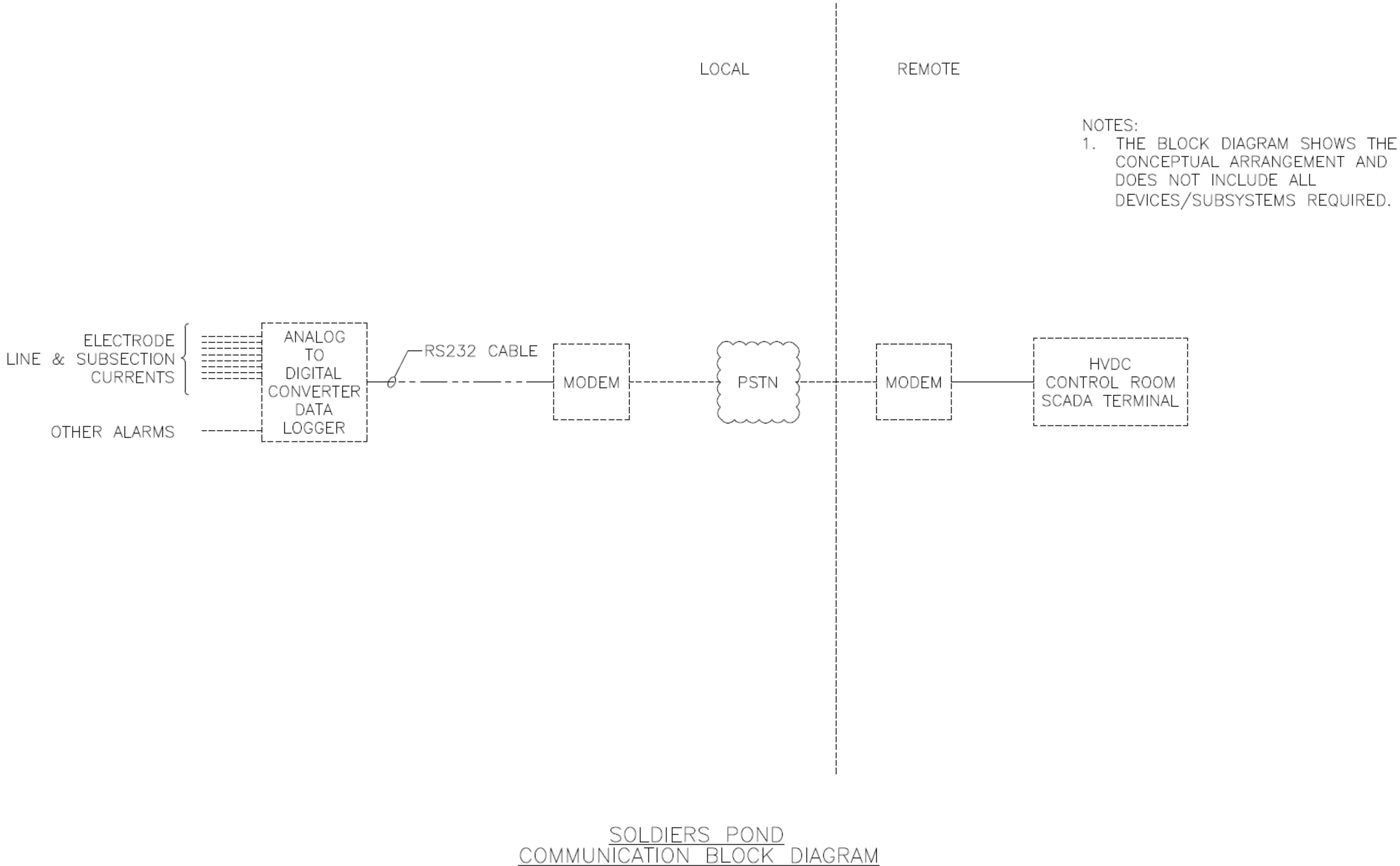

Figure 6-9: Soldiers Pond Electrode Site Auxiliary System, Communication Block Diagram

6.4 Electrode Electrical Field Simulation Model

A literature review was undertaken to better define the seawater resistivity of Conception Bay. The electrode simulation model was refined by partitioning the sea and soil model into smaller units especially near the shoreline electrode to have higher accuracy and better resolution in the ground potential rise (GPR) contours. The model was also revised by considering geological units to a depth of 50 km.

6.4.1 Soil and Sea Model

The performance of a shoreline pond electrode depends mainly on the exposure of the location to sea, seawater resistivity and the shoreline pond design. The land side mass impacts the distribution of the ground potential in the vicinity of the electrode, however its impact on the electrode's performance is negligible.

The textbook value of 0.2 Ωm for seawater was used for electrode simulation performed under DC1250. A review of the Conception Bay seawater salinity and temperature including seasonal variations was undertaken to establish the range of seawater resistivity variation and to select a representative sea model for Conception Bay.

Based on the published literature [21] and available data, it is possible to represent Conception Bay as a two-layer basin with an average depth of approximately 200 m and a top layer of approximately 50 m thick.

Table 6-4 contains the seawater resistivities for Conception Bay, based on the temperature and salinity in each layer for winter and summer conditions.

Table 6-4: Seawater Resistivity for Conception Bay

Season	Top Layer Resistivity (Ωm)	Bottom Layer Resistivity (Ωm)
Winter	0.37	0.38
Summer	0.29	0.37

The land model was originally developed based on the resistivity soundings near the proposed electrode location and a literature review of the geology in the area; the model was retained including spatial parameters for geological units and the unit resistivities.

The two new modeling scenarios as well as the model developed in DC1250 are shown in Table 6-5.

Table 6-5: Soldiers Pond Suggested Soil and Sea Modeling Scenarios

Unit Description	Parameter Description	Most Likely 2009 (DC1250)	Worst Case 2010 (DC1500)	Most Likely 2010 (DC1500)
Seawater				
Conception Bay	Resistivity (Ωm)	0.2	0.38	0.38
	Thickness (m)	per bathymetry	per bathymetry	per bathymetry
Seal Cove Pond	Resistivity (Ωm)	100	0.55	0.55
	Thickness (m)	10	10	10
Lance Cove Pond	Resistivity (Ωm)	10	10	10
	Thickness (m)	10	10	10
Indian Cove Pond	Resistivity (Ωm)	0.2	0.35	0.35
	Thickness (m)	10	10	10
Surficial				
Glacio-marine Top	Resistivity (Ωm)	5000	10000	5000
	Thickness (m)	4	4	4
Glacio-marine Middle	Resistivity (Ωm)	300	500	300
	Thickness (m)	3	3	3
Glacio-marine Lower	Resistivity (Ωm)	5000	10000	5000
	Thickness (m)	5	5	5
Till Undifferentiated	Resistivity (Ωm)	2000	2000	2000
	Thickness (m)	5	5	5
Poor Till	Resistivity (Ωm)	2000	2000	2000
	Thickness (m)	5	5	5
Sub-surficial				
Cambro-Ordovician	Resistivity (Ωm)	500	2000	500
	Thickness (m)	500	500	500
Granitoid-Volcanics	Resistivity (Ωm)	5000	10000	5000
	Thickness (m)	To max depth	To max depth	To max depth

The worst case seawater resistivity of winter bottom layer is used in the model. The average seawater resistivity is expected to be 0.33 Ωm.

The sea depths considered in the model are low tide depths as shown in bathymetric charts [14], and the depths in the near vicinity of Dowden's Point are based on the bathymetric survey (Appendix M). The low resistivity mud or sediment at the sea bed is not considered in the model as a conservative design measure. The details of the sea and soil models are included in Appendix H.

6.4.2 *Electrode, Shoreline Pond and Breakwater Model*

There are three aspects to the model which have a bearing on the simulation outcome: the resistivity properties of the geological units, their spatial extents, and electrode current. The details of assigning these parameters and the development of the specific models for use in simulation are documented in the following subsections.

This analysis was carried out using Teshmont's GRELEC program. This program calculates voltages and potential gradients within a 3-Dimensional model of non-homogeneous material when a current is injected at one point or at a number of points.

The GRELEC program divides the soil into layers, rings and sectors, and calculates the self- and mutual-resistances of each element. The spatial extents and resistivities were based on:

- Sea and soil model detailed in Appendix H,
- The bathymetric data of the Conception Bay [14], and
- The shoreline pond electrode design (a void ratio of 19.3% and resistivity of 2 Ωm for the breakwater and 0.01 Ωm resistivity for the shoreline pond water was assumed; a lower resistivity of the water body of the pond is used to offset the impact of a point source current injection).

The electrode model developed by Teshmont under DC1250 was improved by partitioning the geological mass into smaller units especially near the shoreline electrode, and including ponds near the electrode location in the model to have higher accuracy and better resolution. A cylindrical volume of 600 km in radius and 50 km in depth was modeled; volumes outside the modeled mass will not have significant impact on the simulation results.

Figure 6-10 shows the model of the shoreline pond and breakwater. Figure 6-11 shows the partial view of surficial geology and water bodies; rings with radii greater than 40 km are omitted.

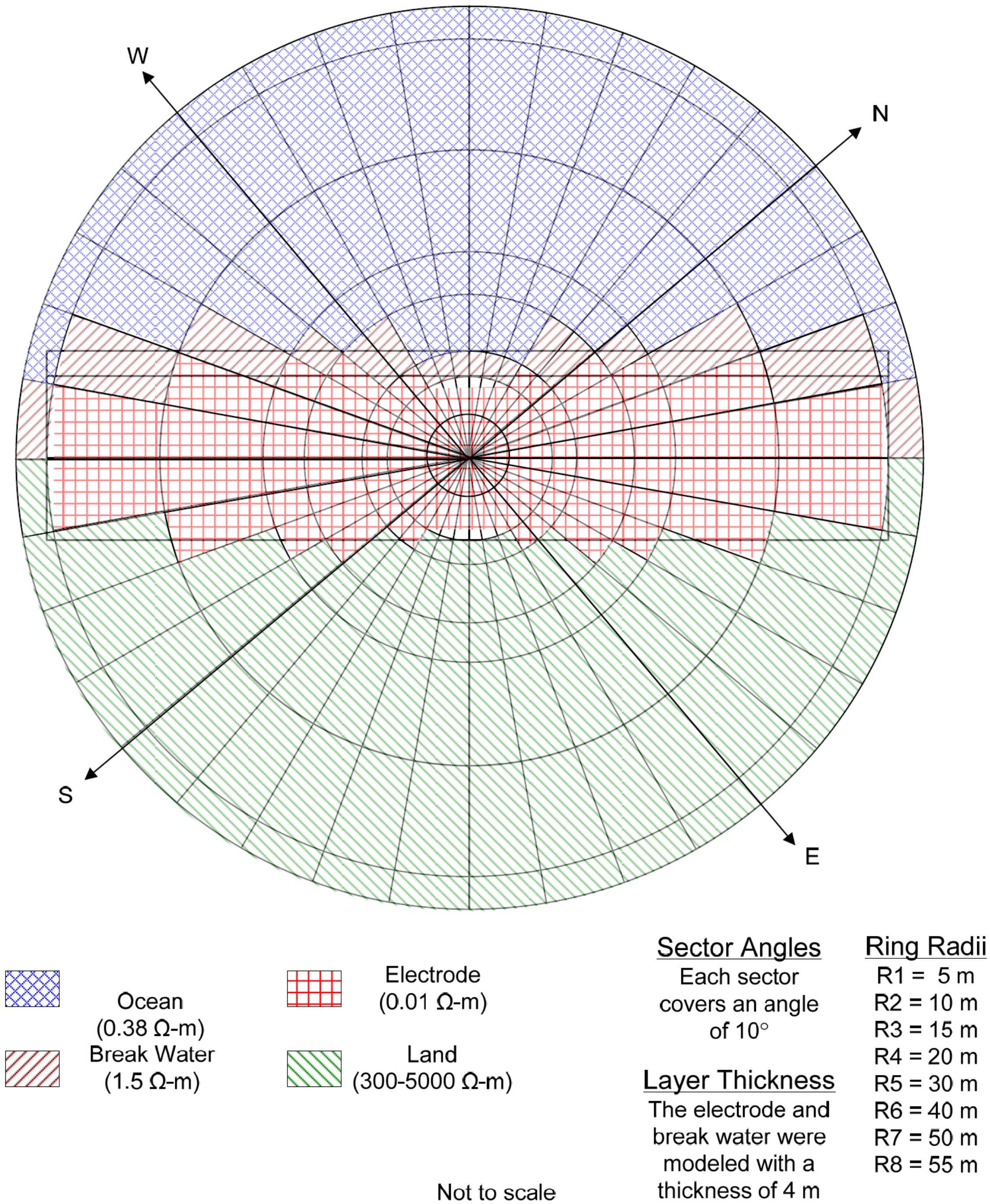

Figure 6-10: Dowden's Point Shoreline Pond and Breakwater Model

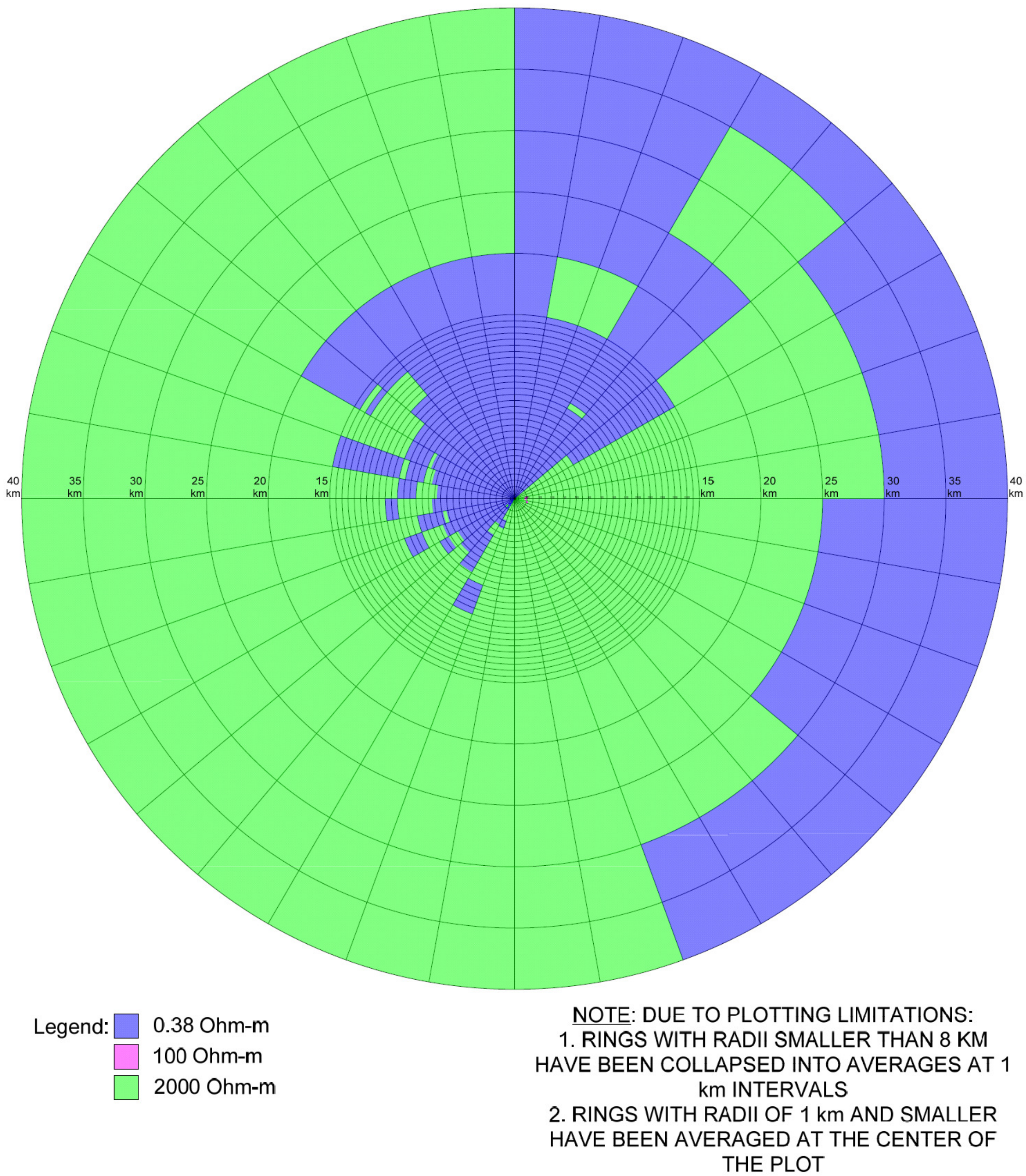

Figure 6-11: Dowden's Point Top Layer of the Soil and Sea Model

The details of the improved model are contained in Appendix J.

6.4.3 Electric Field Simulation Results

A current of 1340 A, the maximum continuous electrode current, was injected at Dowden's Point location (5259955N, 343476E in UTM 22). The current injected into the GRELEC model was distributed among the low resistivity volumes representing the electrode (the red area shown in Figure 6-10).

The body of water in the shoreline pond was assumed of low 0.01 Ωm resistivity to offset the local impact of point source current injection.

Figure 6-12 shows the GPR contours in the vicinity of the electrode based on the most likely soil modeling case (2010).

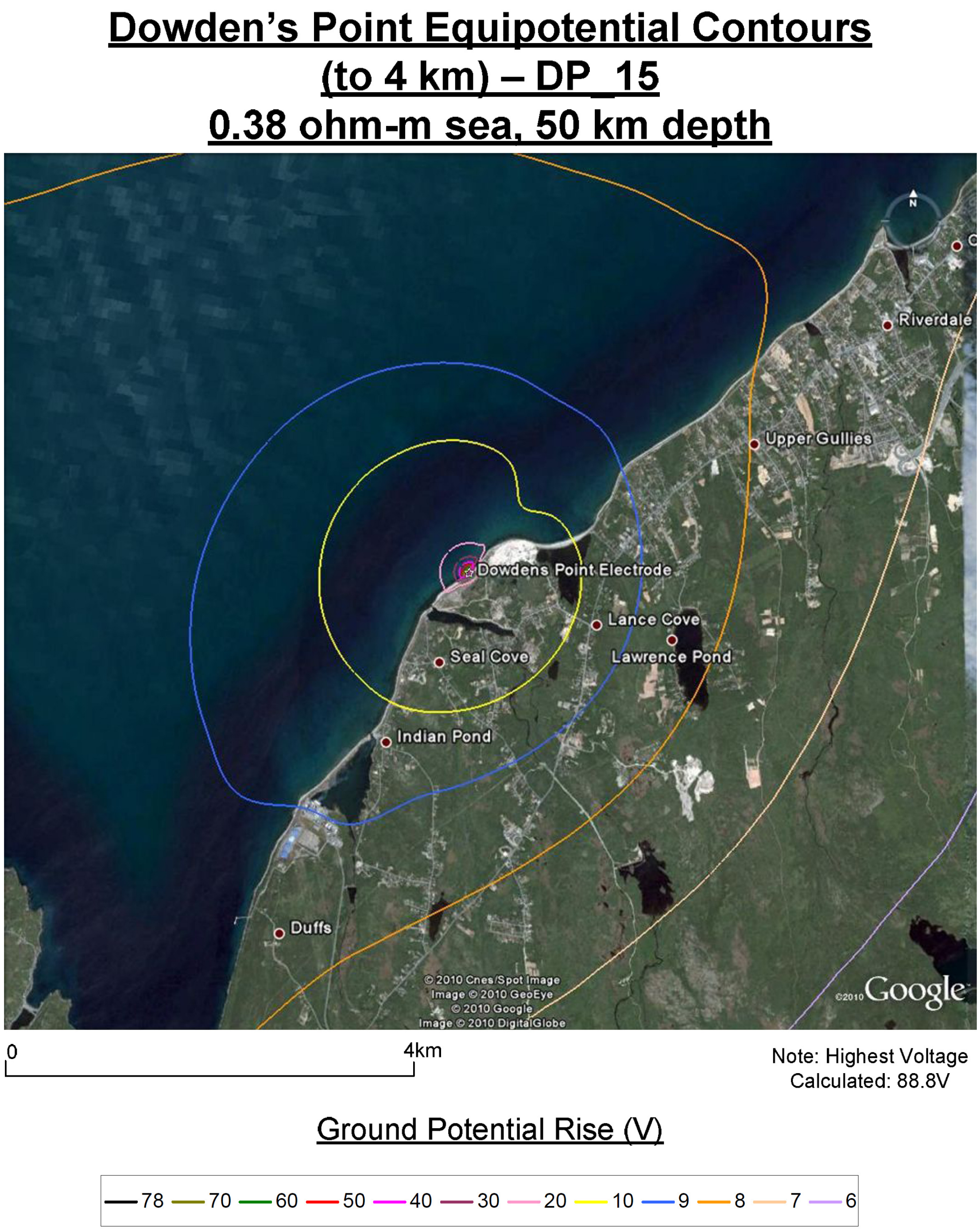

Figure 6-12: GPR Contours in the Vicinity of Dowden's Point

The details of the analysis and the results are included in Appendix J. From these simulations, GPR values were observed at various locations of interest and are summarized in Table 6-6.

Table 6-6: Revised GPR Values at Locations of Interest (Dowden's Point)

Description	Coordinates in UTM 22 (Northing, Easting)	Revised GPR Value (DC1500) (V) Note 1, 2
Holyrood Station (HRD)	5257650N, 341900E	8.9
Seal Cove Station (SCV)	5258050N, 344150E	8.8
Bay Roberts Station (BRB)	5273100N, 328350E	6.1
Kelligrews Station (KEL)	5262500N, 349400E	6.7
Western Avalon Station (WAV)	5266050N, 297900E	0.9
Oxen Pond Station (OPD)	5270350N, 367950E	2.0
Hardwoods Station (HWD)	5265050N, 360900E	3.5
1.6 km south of Holyrood	5256050N, 341900E	7.8

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. The values observed in the DC1250 study were lower than those presented here.

The GPR values above were used as inputs for electrical interference and corrosion impact assessment.

6.5 Impact Assessment

The infrastructure in the vicinity of the electrode mainly includes generation transmission and distribution systems; industrial installations; and marine infrastructure. The infrastructure models were based on infrastructure data provided by NE-LCP and the electrical simulation results. The data provided by NE-LCP included network diagrams showing system interconnections; transformer configuration and parameters; grid impedances; transmission line routes, configurations and grounding arrangements; distribution network plans, configurations and grounding arrangements; and miscellaneous infrastructure in the vicinity of the electrode. The infrastructure information received from NE-LCP is included in Appendix Q. The data provided did not cover all aspects of the above infrastructure and conservative assumptions were made if data was not available. This section presents the models and results of the impact assessment, and the details are contained in the project memo [4] prepared under WTO DC1500.

A significant improvement was the use of actual grounding grid impedances values, and transmission line foundation and guy anchor details provided by NE-LCP. Previously in the DC1250 study, all station grounding grids were assumed to have an impedance of 0.5 Ω. The actual grounding grid impedances of stations in the area are of the order of 5-15 Ω and therefore the levels of dc stray current entering the stations are much less than those found in DC1250, even with higher GPR values observed at the station locations. Table 6-7 below lists the revised grounding grid impedances. Some ground impedances were measured, others were calculated based on the area of the ground grid, and the remaining stations were assumed to have a value of 5 Ω where information was not available.

Table 6-7: Revised Grounding Grid Impedances at Stations of Interest (Dowden's Point)

Station	Ground Grid Area (m^2)	Ground Grid Impedance (Ω)	Remarks
Holyrood (HRD)	15000	6.14	See Note 1
Seal Cove (SCV)	unknown	5.00	Assumed
Bay Roberts (BRB)	16000	15.01	NE-LCP input
Kelligrews (KEL)	9800	9.40	NE-LCP input
Western Avalon (WAV)	11000	8.37	See Note 1
Oxen Pond (OPD)	unknown	5.00	Assumed
Hardwoods (HWD)	unknown	5.00	Assumed

1. Values are calculated based on the area of the grid, and per unit area grid impedance established based on grid impedances data provided by NE-LCP for other stations.

Details of the 230 kV transmission line tower foundations and guywire anchors were provided and equivalent impedances of these components were modeled in CDEGS.

The infrastructure that was analyzed qualitatively in DC1250 (e.g. above ground pipelines and industrial buildings) has not been re-evaluated in this analysis as no more details were made available.

6.5.1 Land Impacts

6.5.1.1 Transmission and Distribution System Infrastructure

230 kV Skywires

Two skywires are strung on each of the 230 kV lines (TL217, TL218 and TL242) for a distance of 1.6 km from the Holyrood transmission station; 138 kV and 69 kV transmission lines are without skywires.

The skywires are bonded to the pole foundation electrodes, comprised of grillage foundation steel and guywire anchors that are bonded by a continuous counterpoise.

Details of foundation grillages, foundation anchors, guywire anchors, anchor bearing plates, and wood pole bearing plates received from NE-LCP were used to establish the impedances of different tower footing components and subsequently the permissible dc stray currents at which integrity of these structures will not be compromised by corrosion. The foundation and guying arrangement, as well as the footing impedances, depend on the resistivity of the earth. For the transmission lines with steel lattice towers (TL217 and TL242), two installation arrangements are indicated on the detail drawings for the foundations and the anchoring of the towers: (1) anchored directly into the rock, and (2) secured in the soil. The actual installation would be combination of these two installation arrangements, depending on the type of earth (rock or soil) present at each tower location. For the transmission line supported by wood poles (TL218), the detail drawings indicate a bearing plate installation and a ground wire wrapped around the base of the pole. The impedances of each component were simulated in CDEGS based on the contact area of the sub-components with the soil and their spatial arrangement; the results are summarized in Table 6-8.

Table 6-8: Impedances of 230 kV Tower Footing Components (Dowden's Point)

Tower Footing Component	Tower Type	Earth Condition	Equivalent Impedance (Ω)	Remarks
Steel grillage (TL217 & TL241)	Steel	Soil	59.0	Based on drawing 217-T-57
Guywire anchors with bearing plates (TL217 & TL241)	Steel	Soil	69.2	Based on drawing 217-T-58
Foundation anchors (TL217 & TL241)	Steel	Rock	1365	Based on drawing 217-T-57
Guywire anchor (TL217 & TL241)	Steel	Rock	1888	Based on drawing 217-T-58
Pole grounding wire and bearing plate (TL218)	Wood	Soil	131	Based on drawing A3-2-230TL

The counterpoise was modeled as a ladder network of series impedances of the wire and lumped ground contact impedances.

Three cases were analyzed: steel towers in soil (500 Ωm), steel towers on rock (5000 Ωm) and wood poles in soil (500 Ωm), where the earth resistivity was based on the suggested values of the surficial layers from AMEC's report, included in Appendix H.

Different skywire models were analyzed to account for different tower types (i.e. steel lattice for TL217 and TL242 versus wood pole TL218). Figure 6-13 shows the generic model of the skywires considered. Although each transmission line has a different span (TL217 – 250 m; TL218 – 200 m; TL242 – 220 m), the spans for all three transmission lines are modeled as 200 m.

Information provided by NE-LCP indicates that a continuous counterpoise is installed for lines TL217 and TL218, and it is isolated from the Holyrood terminal station ground grid. The counterpoise is modeled as ladder network of series of wire impedance (#1/0 bare copper stranded conductor) and lumped ground contact impedance of the wire buried at a depth of 18″ in 500 Ωm soil. The continuous counterpoise is modeled an additional 1.6 km beyond the last transmission tower equipped with a skywire (at 1.6 km from Holyrood), for a total length of 3.2 km; a longer counterpoise in the model will reduce the wire current leakage density and effective impedance of remote counterpoise can be considered negligible.

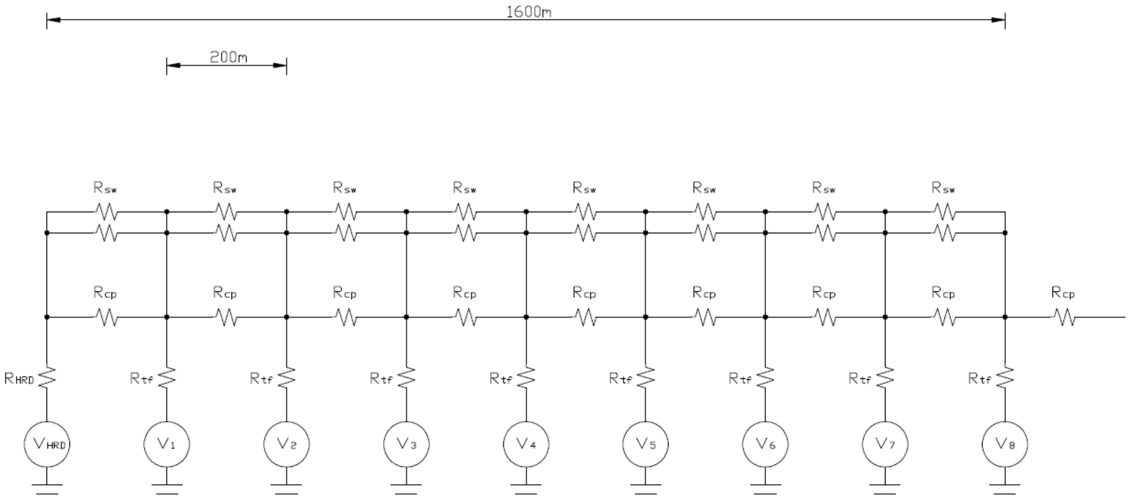

Figure 6-13: 230 kV Skywire and Counterpoise Model (Dowden's Point)

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 for the foundation steel. 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 details of the skywire network data are included in Appendix C. Table 6-9 shows the permissible loss for the grillage foundation, anchors and counterpoise.

Table 6-9: 230 kV Tower Footing Permissible Material Loss and dc Stray Current (Dowden's Point)

Description	Permissible Loss of Material (kg)	Permissible dc Stray Current (A)	Remarks
Foundation in soil (steel grillage)	3.811	0.245	1% of 381.1 kg steel foundation
Guywire anchors in soil (two rods with anchor plates)	7.964	0.512	10% of 79.6 kg steel anchors
Foundation in rock (four anchor rods)	0.133	0.009	1% of 13.3 kg steel foundation
Guywire anchors in rock (single anchor rod)	0.958	0.062	10% of 9.6 kg steel anchors
Ground wire in soil (wrapped around wood pole)	0.082	0.005	10% of 0.822 kg steel ground wire
Bearing plate in soil (angled steel)	0.094	0.006	1% of 8.2 kg steel bearing plate
Grounding System in soil (Counterpoise)	15.706 (per 67 m section)	0.887 (per 67 m section)	50% of the counterpoise

The results of the revised skywire models are outlined in Table 6-10, Table 6-11 and Table 6-12. All calculated dc stray currents are less than the permissible currents.

Table 6-10: 230 kV Steel Tower Footing Components in 500 Ωm Soil (Dowden's Point)

Tower Designation	GPR (V)	Total Calculated dc Stray Current, I_{dc} (A)	Calculated Current through Foundation Grillage (A)	Permissible Current through Foundation Grillage (A)	Calculated Current through Guywire Anchors (A)	Permissible Current through Guywire Anchors (A)
Holyrood Terminal Station	8.900	0.3759	N/A	N/A	N/A	N/A
1st Tower from Holyrood	8.763	0.0395	0.0090	0.2450	0.0076	0.5120
2nd Tower from Holyrood	8.625	0.0298	0.0068	0.2450	0.0058	0.5120
3rd Tower from Holyrood	8.488	0.0203	0.0046	0.2450	0.0039	0.5120
4th Tower from Holyrood	8.350	0.0108	0.0024	0.2450	0.0021	0.5120
5th Tower from Holyrood	8.213	0.0014	0.0003	0.2450	0.0003	0.5120
6th Tower from Holyrood	8.075	-0.0080	-0.0018	0.2450	-0.0015	0.5120
7th Tower from Holyrood	7.937	-0.0175	-0.0040	0.2450	-0.0034	0.5120
8th Tower from Holyrood	7.800	-0.0269	-0.0061	0.2450	-0.0052	0.5120

1. The current division between the components of the tower footing is according to the respective impedances of each component.
2. The polarities of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into tower; -ve from tower into ground.

Table 6-11: 230 kV Steel Tower Footing Components in 5000 Ωm Rock (Dowden's Point)

Tower Designation	GPR (V)	Total Calculated dc Stray Current, I_{dc} (A)	Calculated Current through Foundation Anchor (A)	Permissible Current through Foundation Anchor (A)	Calculated Current through Guywire Anchors (A)	Permissible Current through Guywire Anchors (A)
Holyrood Terminal Station	8.900	0.1404	N/A	N/A	N/A	N/A
1st Tower from Holyrood	8.763	0.0003	0.0001	0.0085	0.0001	0.0616
2nd Tower from Holyrood	8.625	-0.0001	0.0000	0.0085	0.0000	0.0616
3rd Tower from Holyrood	8.488	-0.0005	-0.0001	0.0085	-0.0001	0.0616
4th Tower from Holyrood	8.350	-0.0008	-0.0002	0.0085	-0.0001	0.0616
5th Tower from Holyrood	8.213	-0.0012	-0.0003	0.0085	-0.0002	0.0616
6th Tower from Holyrood	8.075	-0.0016	-0.0004	0.0085	-0.0003	0.0616
7th Tower from Holyrood	7.937	-0.0020	-0.0005	0.0085	-0.0004	0.0616
8th Tower from Holyrood	7.800	-0.0024	-0.0006	0.0085	-0.0004	0.0616

1. The current division between the components of the tower footing is according to the respective impedances of each component.
2. The polarities of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into tower; -ve from tower into ground.

Table 6-12: 230 kV Wood Pole Footing Components in 500 Ωm Soil (Dowden's Point)

Tower Designation	GPR (V)	Total Calculated dc Stray Current, I_{dc} (A)	Calculated Current through Ground Wire (A)	Permissible Current through Ground Wire (A)	Calculated Current through Bearing Plate (A)	Permissible Current through Bearing Plate (A)
Holyrood Terminal Station	8.900	0.3875	N/A	N/A	N/A	N/A
1st Tower from Holyrood	8.763	0.0042	0.0007	0.0053	0.0035	0.0060
2nd Tower from Holyrood	8.625	0.0032	0.0005	0.0053	0.0027	0.0060
3rd Tower from Holyrood	8.488	0.0022	0.0004	0.0053	0.0018	0.0060
4th Tower from Holyrood	8.350	0.0012	0.0002	0.0053	0.0010	0.0060
5th Tower from Holyrood	8.213	0.0003	0.0000	0.0053	0.0003	0.0060
6th Tower from Holyrood	8.075	-0.0007	-0.0001	0.0053	-0.0006	0.0060
7th Tower from Holyrood	7.937	-0.0017	-0.0003	0.0053	-0.0014	0.0060
8th Tower from Holyrood	7.800	-0.0026	-0.0004	0.0053	-0.0022	0.0060

1. The current division between the components of the pole grounding system is assumed proportional to the surface area of each component in contact with the soil.
2. The polarities of the calculated currents indicate direction of flow during anodic operation: +ve, from ground into tower; -ve from tower into ground.

As seen in Table 6-10, Table 6-11 and Table 6-12, the calculated stray currents are less than the acceptable dc stray currents. The calculated loss should be verified based on the actual installation arrangements (anchors or steel in the ground and counterpoise buried versus exposed) during the detailed engineering stage or during the electrode commissioning stage.

The dc stray currents observed through the continuous counterpoise were found to be below the permissible currents for most sections. Only the first counterpoise section from first tower closest to Holyrood terminal station experienced a higher current density; this is not of concern as counterpoise sections can be inspected and replaced as needed.

6.5.1.2 *Transmission and Distribution Lines*

The 230 kV, 138 kV, 69 kV and distribution phase conductors provide a connection through the facility equipment where 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 Transmission Lines

The phase conductors of the 230 kV transmission lines provide conductive connections between the Holyrood, Western Avalon, Oxen Pond and Hardwoods terminal stations through power transformers. The dc current flowing through the neutral of a power transformer due to GPR produced by an electrode can be quantified by analyzing the dc equivalent circuit of transmission line phase conductors connecting various stations, station ground grids and transformer windings. The equivalent dc network is shown in Figure 6-14.

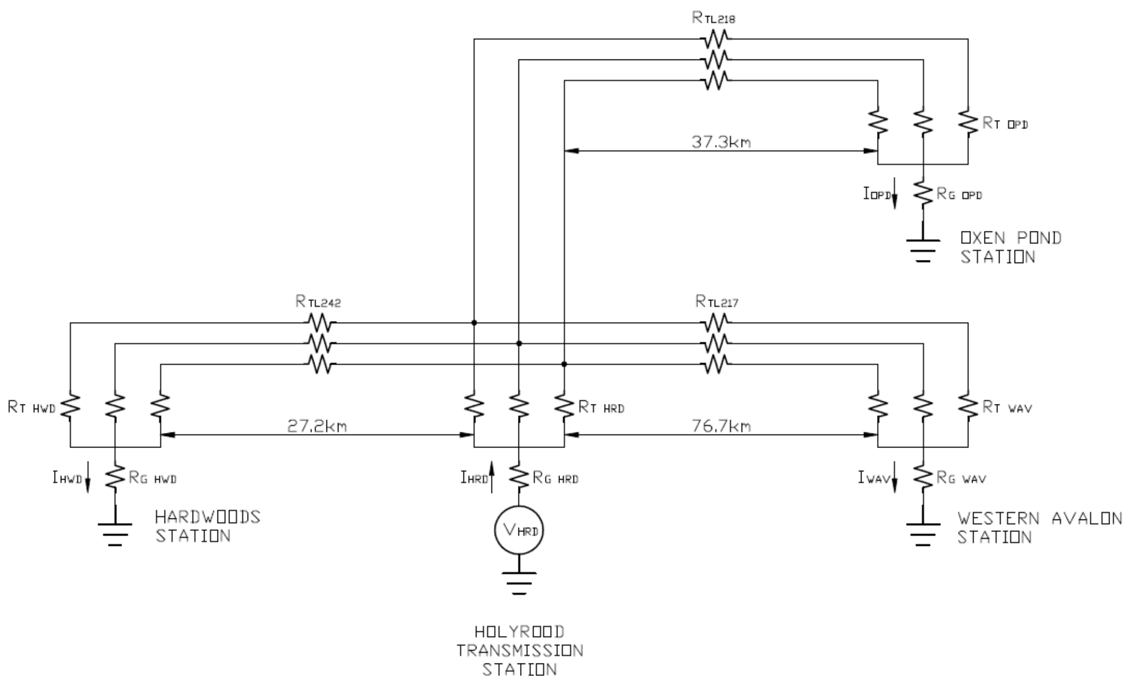

Figure 6-14: 230 kV Transmission Line Model (Dowden's Point)

A dc current level in excess of 1.5 times that of the transformer excitation current [9] can cause operational problems.

The actual excitation currents were not available and the vendor confirmations on permissible dc stray currents through the transformer winding were not obtained.

Table 6-13 summarizes the analysis results and the transformer permissible current; details of the network data are included in Appendix C.

Table 6-13: Permissible and Calculated dc Stray Currents for 230 kV Transformers (Dowden's Point)

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	0.066	Acceptable
HRD_T2/115 MVA	1.002	0.722	0.045	Acceptable
HRD_T3/100 MVA Note 3	1.207	0.64	0.038	Acceptable
HRD_T6/25 MVA	5.284	0.094	0.009	Acceptable
HRD_T7/25 MVA	5.568	0.094	0.008	Acceptable
HRD_T8/75 MVA	0.862	0.282	0.053	Acceptable
WAV_T1/15 MVA	13.90	0.094	0.003	Acceptable
WAV_T2/15 MVA	14.31	0.094	0.003	Acceptable
WAV_T3/25 MVA	5.645	0.094	0.008	Acceptable
WAV_T4/25 MVA	5.569	0.094	0.008	Acceptable
WAV_T5/75 MVA	0.870	0.282	0.054	Acceptable
OPD_T1/40 MVA	3.171	0.251	0.014	Acceptable
OPD_T2/75 MVA	0.856	0.471	0.051	Acceptable
OPD_T3/75 MVA	1.530	0.471	0.028	Acceptable
HWD_T1/40 MVA	3.861	0.251	0.009	Acceptable
HWD_T2/40 MVA	3.547	0.251	0.009	Acceptable
HWD_T3/40 MVA	4.025	0.251	0.008	Acceptable
HWD_T4/75 MVA	1.516	0.471	0.022	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 6-13, the calculated dc stray current levels at Holyrood generating station through the transformer windings are less than the tolerable limits.

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 or dc stray currents should be measured and transformer performance evaluated during the electrode commissioning stage.

Typically a higher level of dc stray current is tolerable for a three-limb core-type three-phase transformer than for a shell-type, three-phase transformer or a single-phase transformer design [12]. 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 6-13 may 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 Transmission

The 138 kV windings of 230/138 kV auto transformers at Holyrood transmission station provide limited connectivity to remote stations as there is only one wye-grounded transformer at Bay Roberts station. The 138 kV transmission model was revised based on the new ground grid impedances and GPR values.

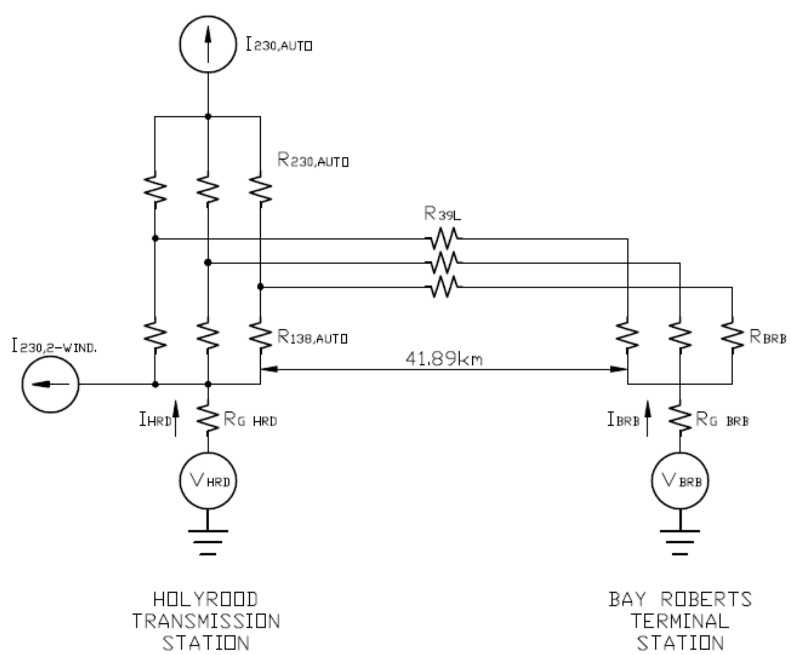

Figure 6-15: 138 kV Transmission Line Model (Dowden's Point)

Although the GPR at Holyrood (6.8 V) is greater than the GPR at Bay Roberts (3.9 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. The current injected at Bay Roberts station is 0.086 A (0.029 A per phase). This 0.029 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.

The results are listed in Table 6-14 and the details of the network are included in Appendix C.

Table 6-14: Permissible and Calculated dc Stray Currents for 138 kV Transformers (Dowden's Point)

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_T6/180 MVA	2.114	0.094	0.024	Acceptable
HRD_T7/115 MVA	2.228	0.094	0.023	Acceptable
HRD_T8/100 MVA	0.345	0.282	0.148	Acceptable
BRB_T1/25 MVA	3.861	0.251	0.030	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; for a 230/138 kV transformer split is 60% (mid tap and above) and 40% (from neutral to mid tap), 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.

69 kV Transmission

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 69 kV transmission model was revised based on the new ground grid impedances and is shown in Figure 6-16.

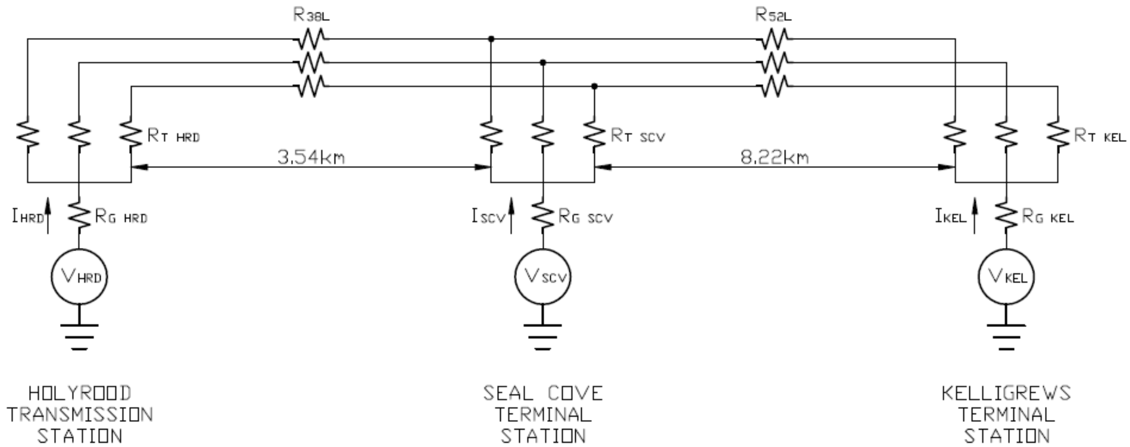

Figure 6-16: 69 kV Transmission Line Model (Dowden's Point)

The results are listed in Table 6-15 and the details of the network are included in Appendix C.

Table 6-15: Permissible and Calculated dc Stray Currents for 69 kV Transformers (Dowden's Point)

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	0.020	Acceptable
HRD_T10/15 MVA	1.065	0.188	0.020	Acceptable
SCV-T1/2.5 MVA	15.217	0.031	0.004	Acceptable
SCV-T2/11.20 MVA	1.654	0.141	0.037	Acceptable
KEL-T1/11.25 MVA	1.639	0.141	0.081	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.

12.47 kV Distribution

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.

The 12.47 kV distribution model from DC1250 was developed based on a large-scale map (included in Appendix Q) provided by NE-LCP, showing the location of the distribution lines; the map did not provide details such as location and population of distribution transformers. NE-LCP also provided information of the distribution grounding parameters: the pole grounding impedance is 25 Ω and the distributed neutral is grounded in accordance with CSA standards (4 grounds every 1000 m). A schematic of the Newfoundland Power distribution system was provided by NE-LCP, but the sizes and locations of distribution transformers were not available. The network model is shown in Figure 6-17 and the assumed locations of the distribution transformers are shown in Figure 6-18, uniformly spaced at 200 m.

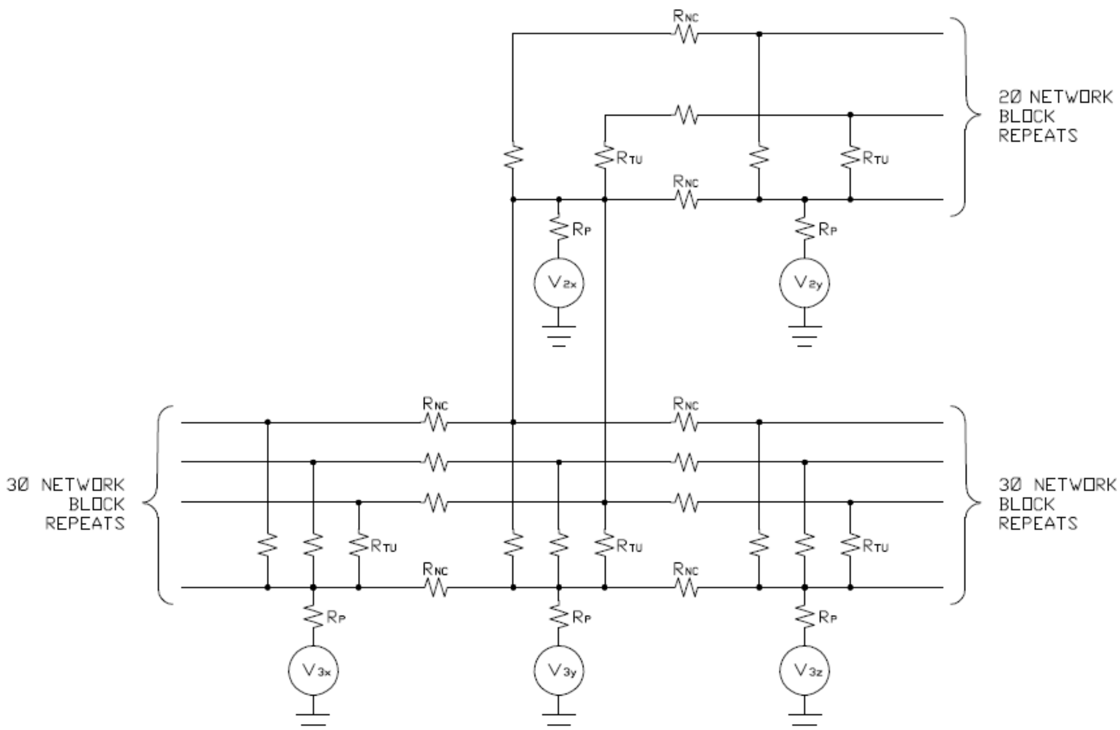

Figure 6-17: 12.47 kV Distribution Line Model (Dowden's Point)

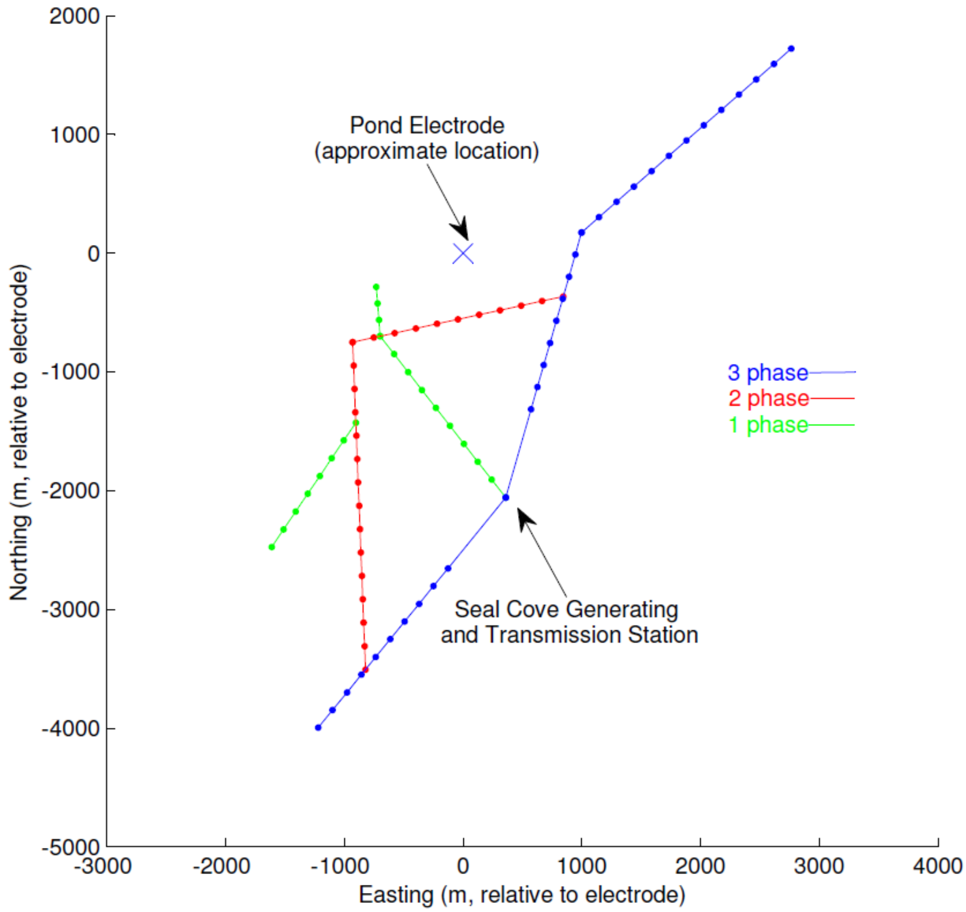

Figure 6-18: 12.47 kV Distribution Line Layout (Dowden's Point)

Results of the analysis show that the highest dc stray current through a transformer winding is 4.23 mA, which is less than the permissible limit of 23 mA. The highest dc stray current through a distribution neutral ground is 219 mA near the electrode location which is less than the permissible current of 427 mA for a 50% material loss of a 19 mm diameter and 3 m long copper bonded grounding rod. The details of the network data used is included in Appendix C.

There may be situations where the dc stray current through a pole grounding 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 grounding rods is not an issue since these can be inspected and replaced as required, and a material loss of 50% for a grounding rod is acceptable. Alternatively, the grounding rods could be replaced with high silicon chromium steel electrodes.

The segregation of HV ground from LV neutral through a spark gap could eliminate some of the operational issues with the distribution circuit [10]. This spark gap isolates the distribution neutrals connected to homes and industrial units 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.

6.5.1.3 *Other 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 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.

6.5.2 *Marine Impacts*

The marine life, infrastructure and operations can be impacted by the induced magnetic field from electrode operation and the GPR gradients. The operational impacts include compass deviation, and corrosion impacts of ships, submarine cable armours and other metallic marine infrastructures.

6.5.2.1 *Compass Deviation*

The analysis of the Soldiers Pond electrode's impact on marine navigation is analyzed in detail in Appendix D; the findings of the analysis are summarized in this section.

The worst case for compass error occurs along the line from the electrode parallel with the magnetic north, where the earth's magnetic field and the induced magnetic field from the electrode are orthogonal. A typical value for the horizontal component of the magnetic field intensity due to the earth's magnetic field is assumed to be 16 A/m [9].

The resultant horizontal magnetic field at the surface of the water along the line parallel with the magnetic north is calculated for the Soldiers Pond electrode in Table 6-16.

Table 6-16: Resultant Magnetic Field Intensity (Dowden's Point)

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)	Magnetic field intensity (earth), H_{earth} (A/m)	Magnetic field intensity (resultant), $H_{res} = [(H_{elec})^2 + (H_{earth})^2]^{0.5}$ (A/m)	Compass error, α (°)
200	1.07	16	16.035	3.811
300	0.71	16	16.016	2.543
400	0.53	16	16.009	1.908
500	0.43	16	16.006	1.526
1000	0.21	16	16.001	0.763
2000	0.11	16	16.000	0.382
3000	0.07	16	16.000	0.254
4000	0.05	16	16.000	0.191
5000	0.04	16	16.000	0.153

An angle of deviation of 0.5° or less is considered acceptable [18]. The annual deviation at Dowden's Point is 11.8′/yr (approximately 0.20°/yr) [19].

The actual compass errors at the water surface will be less than the values in Table 6-16 considering the steel hull of a ship acting as a magnetic shield and a compass located above the water level. Nowadays, large ships and vessels use gyro compasses or GPS navigation, and magnetic compasses as back-up. A gyro compass or a GPS navigation system will not be impacted by magnetic fields.

6.5.2.2 *Ship and Infrastructure Corrosion*

The corrosion impacts summarized in Section 5.5.2.2 for the Gull Island electrode also apply for the Soldier Pond electrode. A complete description of the corrosion analysis for ships and marine infrastructure is included in Appendix D.

6.5.3 *Electrolysis Emissions at Anode and Cathode*

The methodology presented above in Section 5.5.3 for the electrolysis emissions at the Gull Island electrode is identical for the Soldiers Pond electrode. The amount of chlorine gas (Cl_2) and hydrogen gas (H_2) produced in the primary chemical reactions are listed in Table 6-17. The complete review carried out by AMEC is included in Appendix K.

Table 6-17: Calculations of Cl_2 and H_2 Yield based on Faraday's Law (Soldiers Pond)

Variable	Unit	Soldiers Pond (Anode)	Soldiers Pond (Cathode)
T	seconds	1	1
I	Amps	1340	1340
z	#	2	0.50
F	C/mol	96485	96485
n	mol/s	6.94×10^{-03}	2.78×10^{-02}
n	mol/year	2.19×10^{05}	8.76×10^{05}
Cl_2 (30%)	kg/s	1.48×10^{-04}	-
Cl_2 (30%)	kg/year	4.66×10^{03}	-
H_2 (100%)	kg/s	-	5.56×10^{-05}
H_2 (100%)	kg/year	-	1.75×10^{03}
Pond Length	m	60	60
Pond Width	m	15	15
Pond Depth	m	4	4
Pond Volume	L	3.60×10^{06}	3.60×10^{06}
[Cl_2] one day	g/L	3.55×10^{-04}	-
[H_2] one day	g/L	-	1.33×10^{-03}

6.6 Cost Estimate

The engineering, procurement and the construction cost estimate based on the electrode installations foreseen for Option 1 above is of the order of $8.20 million CAD; the cost estimate corresponds to a Level 3 estimate (-20% to +30%) in accordance with AACE .

Details of the cost estimate are included in Appendix E.

The following battery limits are considered to develop the estimate:

- The electrode line dead-end termination gantry structure at Dowden's Point. The electrode line and associated instrumentation, controls, and integration of controls into the overall HVdc system are not part of this estimate.
- Serial port of the data logger in the weather proof enclosure. The communication link including cables, telephone modem and provision of PSTN line is not included in the estimate.
- The service entrance pole outside the electrode installations, the pole mounted transformer and auxiliaries associated with the transformer are considered part of the estimate. The distribution line from the nearby distribution network to the electrode installation location is not considered in the estimate.

The following assumptions are made to develop the estimate:

- Any mitigations required to address the electrode electrical interference, electrode corrosion impacts or environmental impacts are not considered. It is expected that electrical interference and corrosion impacts will be insignificant. The information on environmental impacts needs to be investigated independently by NE-LCP.
- The construction of the electrode will be a single contract.
- The seabed soil can adequately support the breakwater structure and special measures are not required to improve the soil conditions.

6.7 Summary of Findings and Next Steps

The key findings based on the above literature review to develop sea and soil model, electrical field analysis, and infrastructure impact assessment are as follows:

- The literature review suggests a worst case seawater resistivity of 0.38 Ωm, which is higher than the 0.2 Ωm value used in the DC1250 analysis and consequently higher GPR value at the locations of interests.
- The calculated dc stray current values injected into the transmission and distribution system are lower than the values observed in DC1250. The current injection is mainly limited by higher grounding impedances of the generating and transmission stations, approximately 10 to 30 times higher than the values assumed in DC1250. The calculated dc stray currents through the transformer windings, and transmission line pole foundations, guywire anchors and pole groundings are less than the calculated acceptable limits.
- The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode do not exceed the permissible dc stray current values that will consume 50% of the ground electrode material, a typical acceptable consumption of ground electrode material. There may be situations where the dc stray current through a pole grounding 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.

Corrosion of pole grounding rods can be addressed through regular inspection and replacement as required.

- The impact of the electrode operation on the marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 1.5 km into Conception Bay, and it is not of concern. The voltage gradients in the sea are not large enough to cause corrosion of a ship's hull.
- The construction of the shoreline pond and breakwater without requiring excavation of the seabed will result in extending the structure approximately 130 m into the sea. In case the development in the sea is not feasible, a pond can be developed at the shoreline and this will require excavating the seabed to achieve a depth of 4 m at the shoreline and subsequently implement a maintenance plan to monitor and maintain the depth. This aspect needs to be reviewed considering the regulatory process and the environmental assessment, and a design option should be selected accordingly.
- The engineering, procurement and construction (EPC) cost of the shoreline pond development (Option 1) at Dowden's Point electrode is expected to be $8.20 million CAD.

The actual electrical interference and corrosion impact values may be different from those calculated in this study since dc stray currents from natural sources like inhomogeneous soil chemistry, telluric currents and other industrial operations are not considered. Also, the civil/structural designs are based on assumed geotechnical information and area topography. Moreover, the auxiliary systems proposed for the electrode installations do not take into account NE-LCP's operation and maintenance practices or integration into overall HVdc system.

To increase the confidence level associated with the assumptions made for the proposed design and the resulting impact assessment, the following steps are recommended:

- Undertake an environmental assessment of the proposed installations including the electrode lines to qualify the location and design. Adjust the location or design if required, a minor adjustment in location maintaining the same electrode design parameters will not require reassessment. It is critical to pick one of the options before going ahead with detail engineering.
- Identify the shoreline and inland topographic survey requirement and undertake field program to collect the information required to better define the civil structural design. The requirements for further investigation shall be finalized following the selection of the electrode installation option (i.e. extended into the sea versus on the shoreline).
- Identify the geotechnical investigation and topographic survey requirements and undertake a field program to collect the data to further the civil structural design.

The following steps are recommended during the detail engineering and commissioning stages:

- Review the electrode duty to qualify the impact assessment based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation. The electrode duty is based on a very pessimistic operation of the HVdc link.

- Review the auxiliary systems proposed taking into operation and maintenance practices of NE-LCP and integration into overall HVdc system, and adjust the auxiliary systems as required. It is anticipated that Dowden's Point electrode installations will require lesser monitoring and ac/dc auxiliary systems of lower rating.
- Assess the corrosion potentials for pipeline (e.g. Holyrood generating station fuel line), large storage tanks (e.g. Holyrood generating facility fuel storage facility) and other major metallic structures in the area during the electrode commissioning tests.
- Measure current during the electrode commissioning tests in large transformer grounded neutral leads, transmission line and distribution line ground leads, and rotating machine grounded neutral leads.
- Review the shoreline pond electrode installation costs during the detailed engineering stage.

7. Conclusions

7.1 Gull Island

The site selection and impact analysis findings of the Gull Island study are:

- The cove at L'Anse-au-Diable (LAD) North is viable for a shoreline pond electrode. The site meets the electrode performance requirements; is strategically located for easy access and to interface with electrode line requiring the shortest independent ROW for the electrode line compared with other sites; and is relatively remote from the major infrastructure.
- The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode exceed the permissible dc stray current values that will consume 50% of the ground electrode material (a typical acceptable consumption of ground electrode material) over the life of the project. Corrosion of grounding poles is not a significant concern and the issue can be addressed through regular inspection and replacement as required.
- Based on the theoretical analysis, corrosion impact on the HVdc submarine cable is minimal and is not of concern. However, corrosion of the submarine cable is a complex phenomenon that is a function of geomagnetic induced current, chemistry of the sea environment and land fall installation, dc stray current associated with an electrode operation and should be studied during the detail engineering stage.
- The impact of the electrode operation on marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 2.6 km into the SOBI, and it is not of concern. The voltage gradients in the sea are not large enough to cause corrosion of a ship's hull. The GPR gradients on the sea side of the breakwater are maintained below the published safe level [9,10].
- Reliable fault detection on a long electrode line like the one from the Gull Island converter station to the LAD North electrode location is a difficult technical problem. It may not be possible to achieve reliable fault detection; therefore the line insulation should be designed to ensure that any arcing will be self-extinguishing and diverted away from the insulators. Undetected faults such as trees falling against the line and dropped conductors are the main safety concerns. If sensitive detection is not possible then the risks shall be mitigated by other means such as greater emphasis on tree cutting in the right of way, safe and rugged electrode line design, and more frequent line patrols.
- The engineering, procurement and construction (EPC) cost of the shoreline pond electrode installations (Option 1) at LAD North is expected to be $8.27 million CAD.

The analysis demonstrates the suitability of the LAD North location for a shoreline pond electrode for the Gull Island converter station.

7.2 Soldiers Pond

The findings of the Soldiers Pond study are:

- The literature review suggests a worst case seawater resistivity of 0.38 Ωm, which is higher than the 0.2 Ωm value used in the DC1250 analysis and consequently higher GPR value at the locations of interests.
- The calculated dc stray current values injected into the transmission and distribution system are lower than the values observed in DC1250. The current injection is mainly limited by higher grounding impedances of the generating and transmission stations, approximately 10 to 30 times higher than the values assumed in DC1250. The calculated dc stray currents through the transformer windings, and transmission line pole foundations, guywire anchors and pole groundings are less than the calculated acceptable limits.
- The calculated dc stray current values through the distribution pole grounding rods in close proximity to the electrode do not exceed the permissible dc stray current values that will consume 50% of the ground electrode material, a typical acceptable consumption of ground electrode material. There may be situations where the dc stray current through a pole grounding 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. Corrosion of pole grounding rods can be addressed through regular inspection and replacement as required.
- The impact of the electrode operation on the marine activities and operations is not significant. The zone in which a ship may be subject to compass deviation is limited to an oval shaped zone extending roughly 1.5 km into Conception Bay, and it is not of concern. The voltage gradients in the sea are not large enough to cause corrosion of a ship’s hull.
- The construction of the shoreline pond and breakwater without requiring excavation of the seabed will result in extending the structure approximately 130 m into the sea. In case the development in the sea is not feasible, a pond can be developed at the shoreline and this will require excavating the seabed to achieve a depth of 4 m at the shoreline and subsequently implement a maintenance plan to monitor and maintain the depth. This aspect needs to be reviewed considering the regulatory process and the environmental assessment, and a design option should be selected accordingly.
- The engineering, procurement and construction cost of electrode installations (Option 1) will be of the order of $8.20 million CAD.

The above findings clearly reaffirm the earlier analysis and confirms that the Dowden’s Point shoreline pond electrode site is viable for the Soldiers Pond converter station. The location of the electrode site relative to infrastructure should not be a concern. The analysis does not indicate any negative impact of electrode operation and similar shoreline pond electrode installations located near population and infrastructure (e.g. Vancouver Island link shoreline electrode) have proven to be safe with no adverse impacts on infrastructure.

8. Next Steps

The actual electrical interference and corrosion impact values may be different from those calculated in this study since dc stray currents from natural sources like inhomogeneous soil chemistry, telluric currents and other industrial operations are not considered. Also, the civil/structural designs are based on assumed geotechnical information and area topography. Moreover, the auxiliary systems proposed for the electrode installations do not take into account NE-LCP's operation and maintenance practices or integration into overall HVdc system.

8.1 Gull Island

To increase the confidence level associated with the assumptions made for the proposed design and the resulting impact assessment, the following steps are recommended:

- Undertake an environmental assessment of the proposed installations including the electrode lines to qualify the location and design. Adjust the location or design if required (a minor adjustment in location maintaining the same electrode design parameters will not require reassessment).
- Identify the shoreline and inland topographic survey requirements and undertake a field program to collect the information required to better define the civil/structural design.
- Identify the geotechnical investigation, wind and wave study requirements, and undertake a field program to collect the data to further the civil/structural design.

The following steps are recommended during the detail engineering and commissioning stages:

- Review the electrode duty to qualify the impact assessment based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation. The electrode duty is based on a very pessimistic operation of the HVdc link.
- Review the auxiliary systems proposed taking into account operation and maintenance practices of NE-LCP and integration into the overall HVdc system. Adjust the auxiliary systems as required.
- Assess the corrosion potentials for any major metallic structures in the area during the electrode commissioning tests.
- Measure current during the electrode commissioning tests in large transformer grounded neutral leads, transmission line and distribution line ground leads, and rotating machine grounded neutral leads.
- Review the shoreline pond electrode installation costs during the detailed engineering stage.

8.2 Soldiers Pond

To increase the confidence level associated with the assumptions made for the proposed design and the resulting impact assessment, the following steps are recommended:

- Undertake an environmental assessment of the proposed installations including the electrode lines to qualify the location and design. Adjust the location or design if required, a minor adjustment in location maintaining the same electrode design parameters will not require reassessment. It is critical to pick one of the options before going ahead with detail engineering.
- Identify the shoreline and inland topographic survey requirement and undertake field program to collect the information required to better define the civil structural design. The requirements for further investigation shall be finalized following the selection of the electrode installation option, extended into the sea versus on the shoreline.
- Identify the geotechnical investigation, topographic survey, and wind and wave study requirements, and undertake a field program to collect the data to further the civil structural design.

The following steps are recommended during the detail engineering and commissioning stages:

- Review the electrode duty to qualify the impact assessment based on vendor data for equipment failure rates and bipolar imbalances; future system reliability and availability studies; maintenance practices; and planned modes of operation. The electrode duty is based on a very pessimistic operation of the HVdc link.
- Review the auxiliary systems proposed taking into operation and maintenance practices of NE-LCP and integration into overall HVdc system, and adjust the auxiliary systems as required. It is anticipated that Dowden’s Point electrode installations will require lesser monitoring and ac/dc auxiliary systems of lower rating.
- Assess the corrosion potentials for pipeline (e.g. Holyrood generating station fuel line), large storage tanks (e.g. Holyrood generating facility fuel storage facility) and other major metallic structures in the area during the electrode commissioning tests.
- Measure current during the electrode commissioning tests in large transformer grounded neutral leads, transmission line and distribution line ground leads, and rotating machine grounded neutral leads.
- Review the shoreline pond electrode installation costs during the detailed engineering stage.

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Appendix A

Number of Electrode Elements and Breakwater Sizing Calculations

Table A-1: Number of Electrode Elements and Breakwater Sizing Calculations, Gull Island

GULL ISLAND - Shoreline Pond Electrode

Anode Element Resistance and Current Density

References:

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

Kimbark, E.W., "Direct Current Transmission, Vol. 1", Chapter 9, Wiley Interscience, 1971.

					Remarks
Inputs					
Resistivity of the surrounding volume	ρ	=	0.39	Ωm	Salt water
Length of the anode	L	=	2.13	m	From Anotec
Diameter of the anode	d	=	0.122	m	From Anotec
Current Density					
Electrode current	I_{tot}	=	2320	A	Maximum continuous current, Gull Island
Current per anode	I_{anode}	=	45	A	Based on Anotec input, typical value for shoreline pond electrode design
Number of anode elements	$N_{anode} = I_{tot}/I_{anode}$	=	51.556		
		=	55		
		=	66		One redundant section of 11 elements
Maintenance Operation (54 elements)					
Anode element surface area	A_{anode}	=	0.820	m^2	From Anotec
Surface area of anodes	A_{tot}	=	45.100	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	51.441	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	20.062	V/m	
Voltage gradient required at breakwater	E_{bw}	=	1.250	V/m	Safe limit
Current density required at breakwater	$J_{bw} = J_{tot}*E_{bw}/E_{tot}$	=	3.205	A/m^2	
Area of breakerwater	$A_{bw} = I_{tot}/J_{bw}$	=	723.840	m^2	
Normal Operation (66 elements)					
Anode element surface area	A_{anode}	=	0.820	m^2	From Anotec
Surface area of anodes	A_{tot}	=	54.120	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	42.868	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	16.718	V/m	
Voltage gradient required at breakwater	E_{bw}	=	1.250	V/m	Assumed
Current density required at breakwater	$J_{bw} = J_{tot}*E_{bw}/E_{tot}$	=	3.205	A/m^2	
Area of breakwater	$A_{bw} = I_{tot}/J_{bw}$	=	723.840	m^2	
Pond Size					
Slope of breakwater	m_{bw}	=	1 : 1.5		Conservative value assumed
Height of breakwater	h_{bw}	=	4	m	
Length of pond	$L_{pond} = A_{bw}/(h_{bw}^2+1.5h_{bw}^2)^{1/2}$	=	100.379	m	
		=	100	m	

A 100 m (L) x 15 m (W) x 4 m (D) pond will provide a safe and conservative design.

Table A-2: Number of Electrode Elements and Breakwater Sizing Calculations, Soldiers Pond

SOLDIERS POND - Shoreline Pond Electrode

Anode Element Resistance and Current Density

References:

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

Kimbark, E.W., "Direct Current Transmission, Vol. 1", Chapter 9, Wiley Interscience, 1971.

Inputs					***Remarks***
Resistivity of the surrounding volume	ρ	=	0.38	Ωm	Salt water
Length of the anode	L	=	2.13	m	From Anotec
Diameter of the anode	d	=	0.122	m	From Anotec
Current Density					
Electrode current	I_{tot}	=	1340	A	Maximum continuous current, Gull Island
Current per anode	I_{anode}	=	45	A	Based on Anotec input, typical value for shoreline pond electrode design
Number of anode elements	$N_{anode} = I_{tot}/I_{anode}$	=	29.778		
		=	30		
		=	36		One redundant section of 6 elements
Maintenance Operation (30 elements)					
Anode element surface area	A_{anode}	=	0.820	m^2	From Anotec
Surface area of anodes	A_{tot}	=	24.600	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	54.472	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	20.699	V/m	
Voltage gradient required at breakwater	E_{bw}	=	1.250	V/m	Safe limit
Current density required at breakwater	$J_{bw} = J_{tot}*E_{bw}/E_{tot}$	=	3.289	A/m^2	
Area of breakerwater	$A_{bw} = I_{tot}/J_{bw}$	=	407.360	m^2	
Normal Operation (36 elements)					
Anode element surface area	A_{anode}	=	0.820	m^2	From Anotec
Surface area of anodes	A_{tot}	=	29.520	m^2	
Current density	$J_{tot} = I_{tot}/A_{tot}$	=	45.393	A/m^2	
Voltage gradient	$E_{tot} = J_{tot}\rho$	=	17.249	V/m	
Voltage gradient required at breakwater	E_{bw}	=	1.250	V/m	Assumed
Current density required at breakwater	$J_{bw} = J_{tot}*E_{bw}/E_{tot}$	=	3.289	A/m^2	
Area of breakwater	$A_{bw} = I_{tot}/J_{bw}$	=	407.360	m^2	
Pond Size					
Slope of breakwater	m_{bw}	=	1 : 1.5		Conservative value assumed
Height of breakwater	h_{bw}	=	4	m	
Length of pond	$L_{pond} = A_{bw}/(h_{bw}^2 + 1.5h_{bw}^2)^{1/2}$	=	56.491	m	
		=	60	m	

A 60 m (L) x 15 m (W) x 4 m (D) pond will provide a safe and conservative design.

Appendix B

Electrode Element Arrangement Analysis

Electrode Element Arrangement Analysis

A sensitivity analysis was performed for various electrode element arrangements to examine the current sharing among electrode elements. Equal current distribution among the electrode elements is desirable to achieve similar life expectancies for all elements. For a linear array of uniformly spaced electrodes, the current flowing through the few electrodes at both ends of the electrodes will be higher than the currents in the middle of the array.

The electrode element arrangements studied are described in the following table:

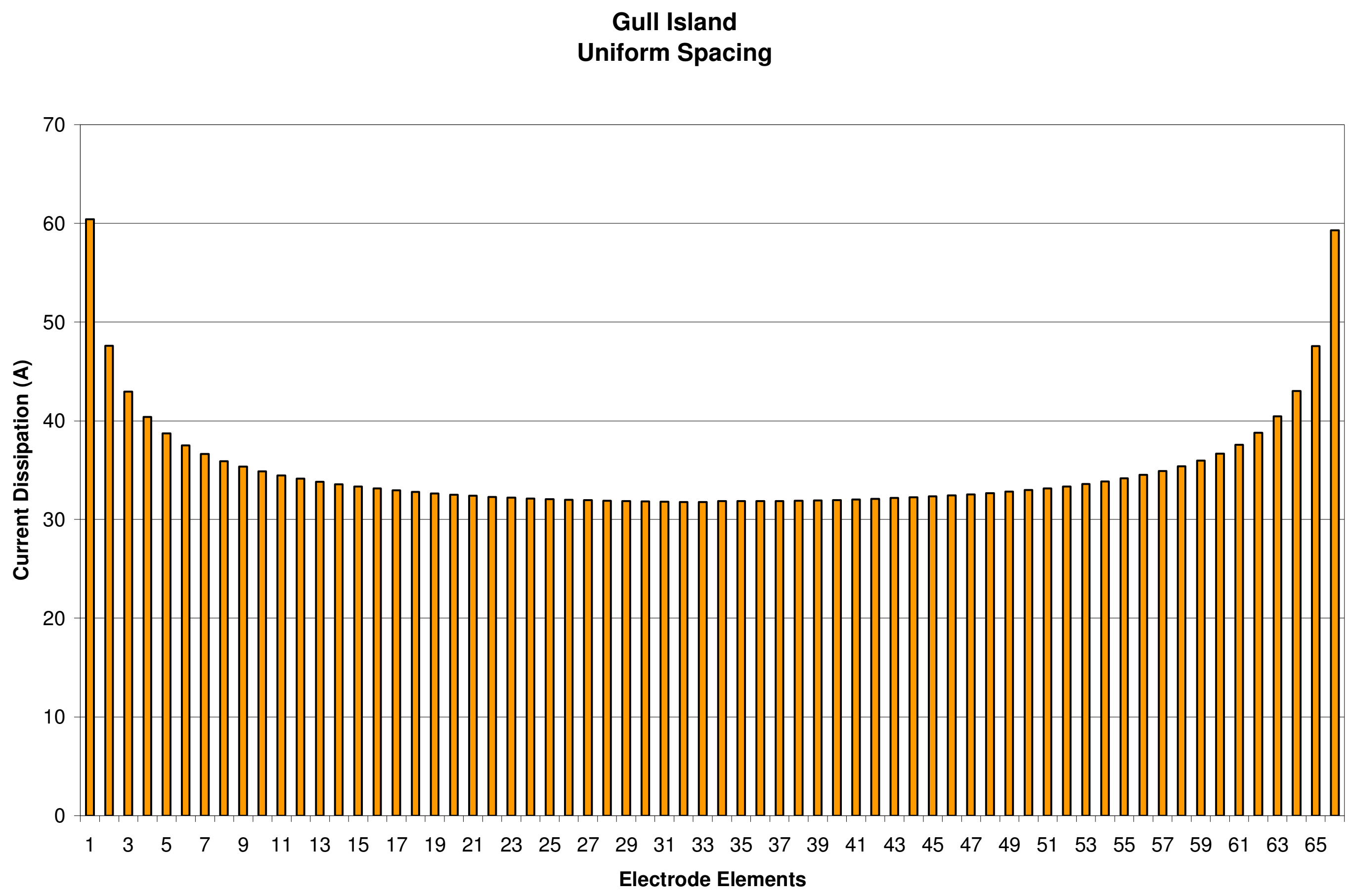
Electrode Arrangement	Description
Uniform Spacing	The elements are arranged in a linear array with a uniform spacing of 1.5 m.
Quasi-Uniform Spacing	The elements are uniformly spaced except the last few elements at each end of the array which are more closely spaced.
Uniform Spacing by Subsection	Uniform spacing is used for each subsection (2.0 m spacing for the two outer subsections, 1.0 m spacing for the two middle sections, and 1.5 m spacing for the two other subsections).
Non-Uniform Spacing	The elements are arranged in a linear array with continuously decreasing spacing moving from the middle elements towards the outer elements.
Uniform, Non-Linear Spacing	Four subsections are arranged along the breakwater and one subsection on either side of the pond, all subsections with uniform spacing.

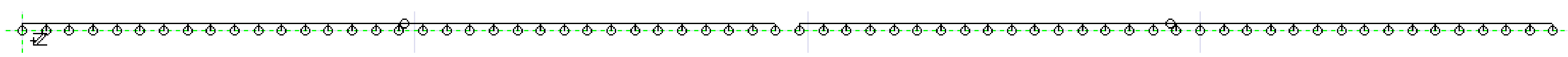
A current dissipation of the order of 45 A per electrode element is considered. The number of electrodes elements is estimated based on the electrode current (corresponding to the 10 minute continuous maximum current), and a contingency of one subsection (for maintenance). The Gull Island electrode requires 66 elements (i.e. 6 subsections of 11 elements) and the Soldier Pond electrode requires 36 elements (i.e. 6 subsections of 6 elements). A uniform soil model is considered in the analysis.

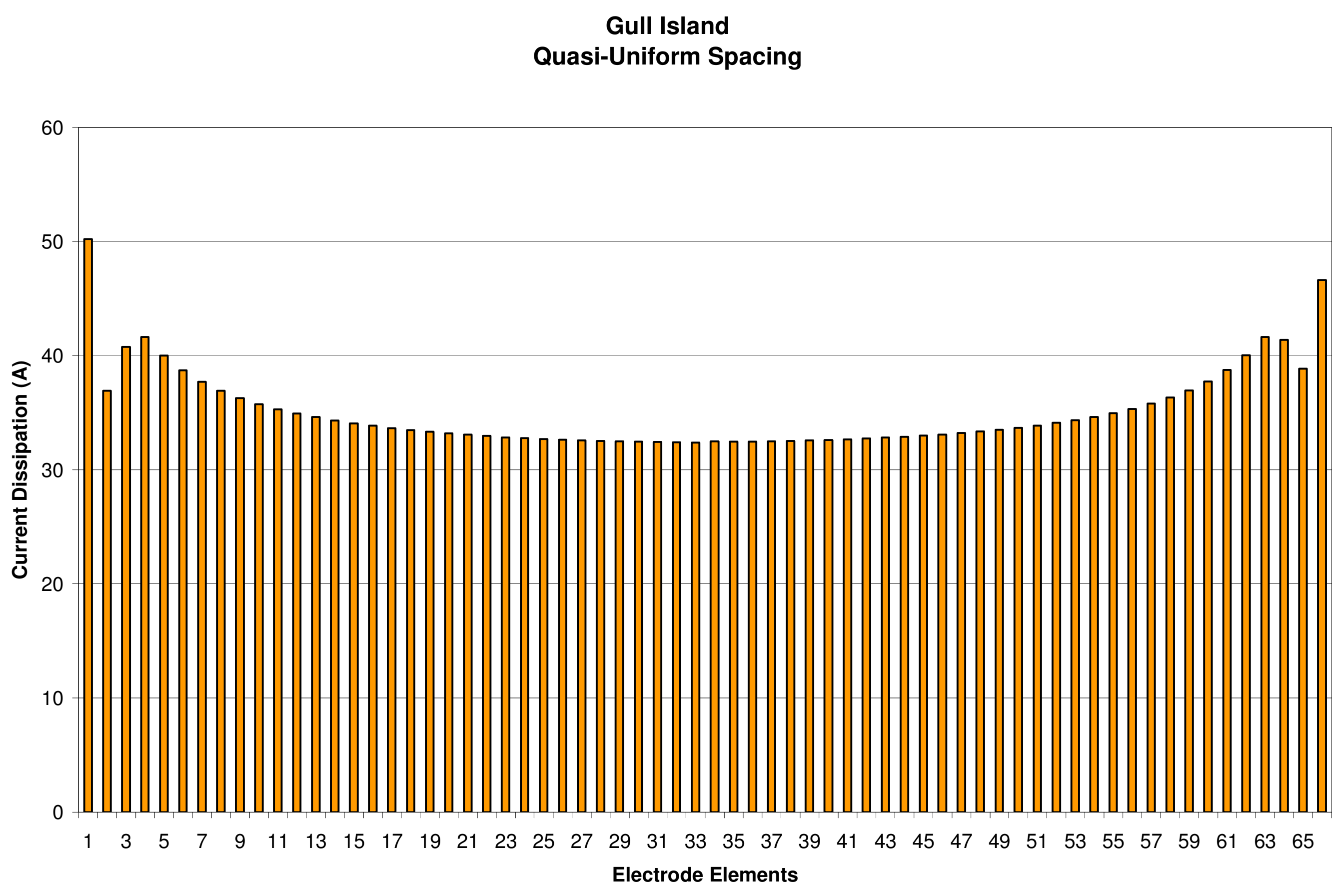
The electrode arrangements described above are studied for both the Gull Island and Soldiers Pond electrodes. The results of the analysis are presented in the following sections.

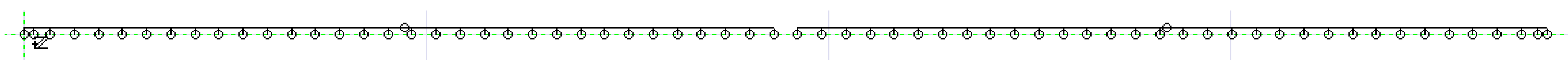
Gull Island

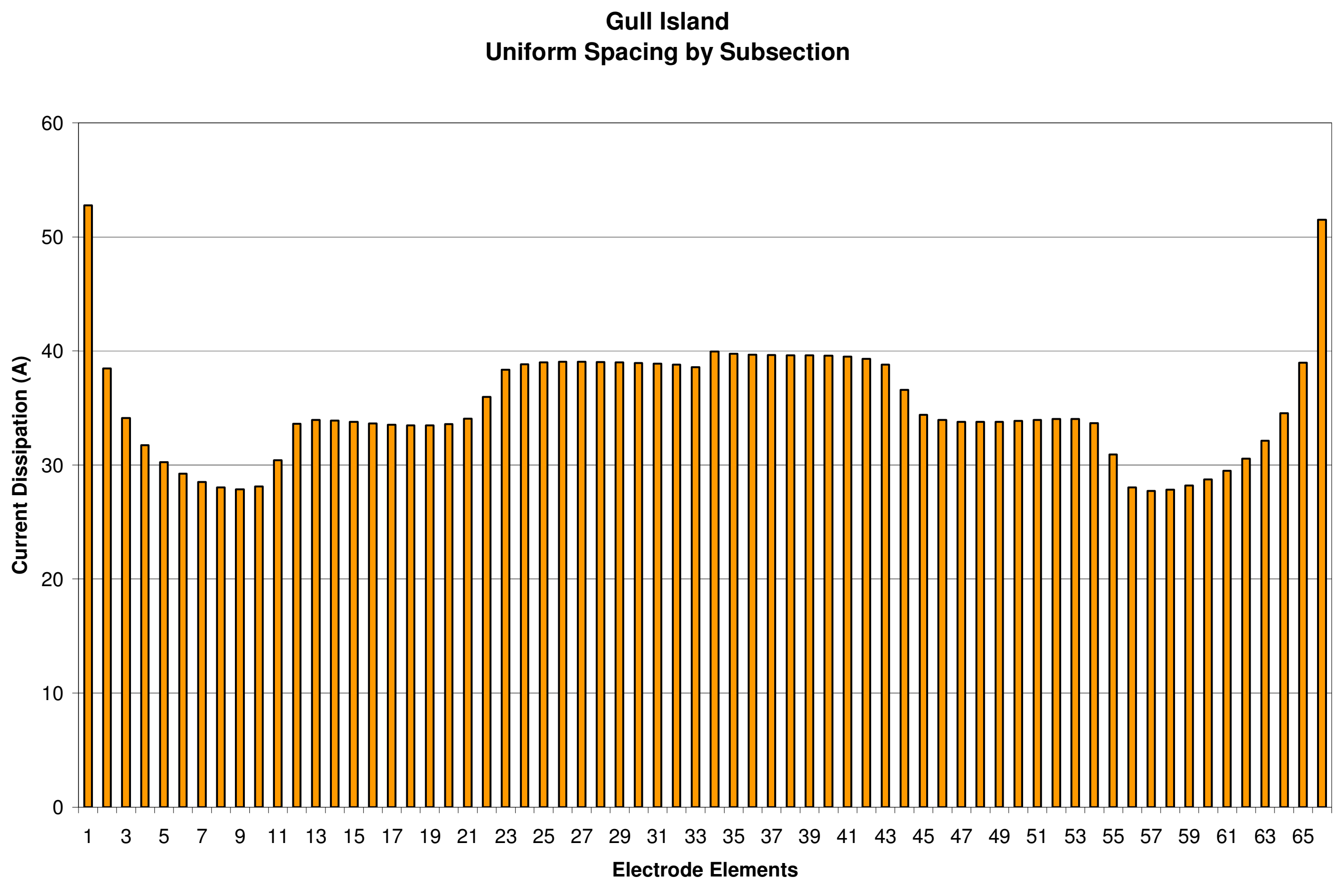
Electrode Element Arrangement Analysis

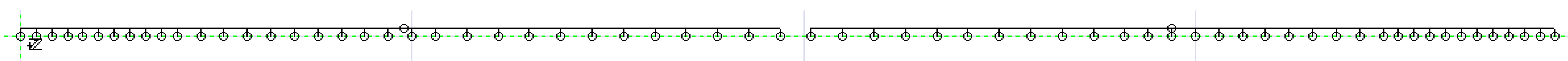

Gull Island
Uniform Spacing
Current Dissipation (A)
0
10
20
30
40
50
60
70
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Electrode Elements

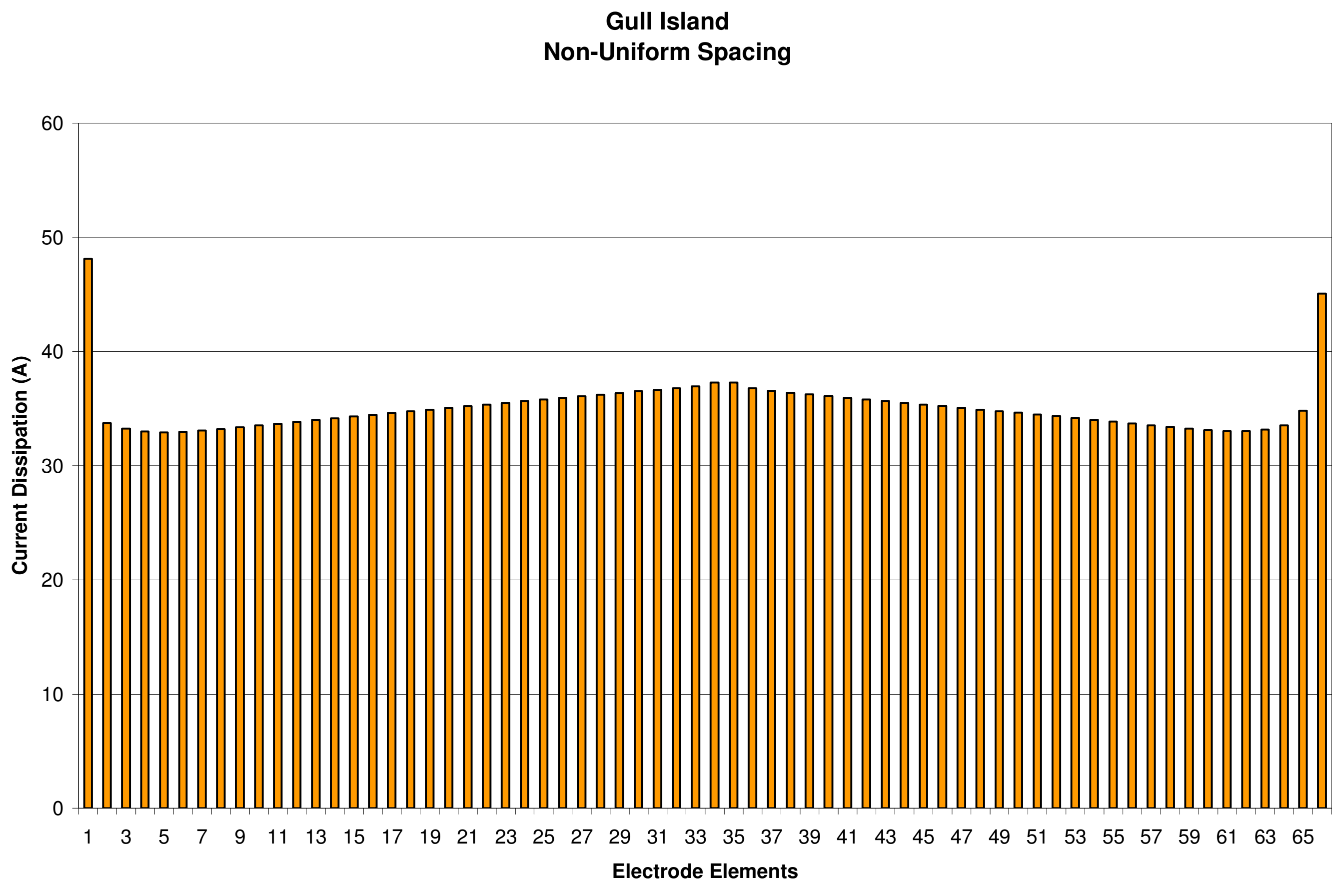


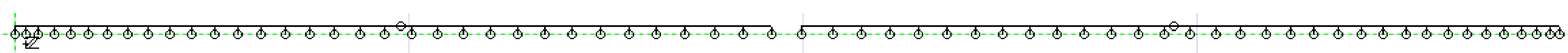

Gull Island
Quasi-Uniform Spacing
Current Dissipation (A)
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Electrode Elements

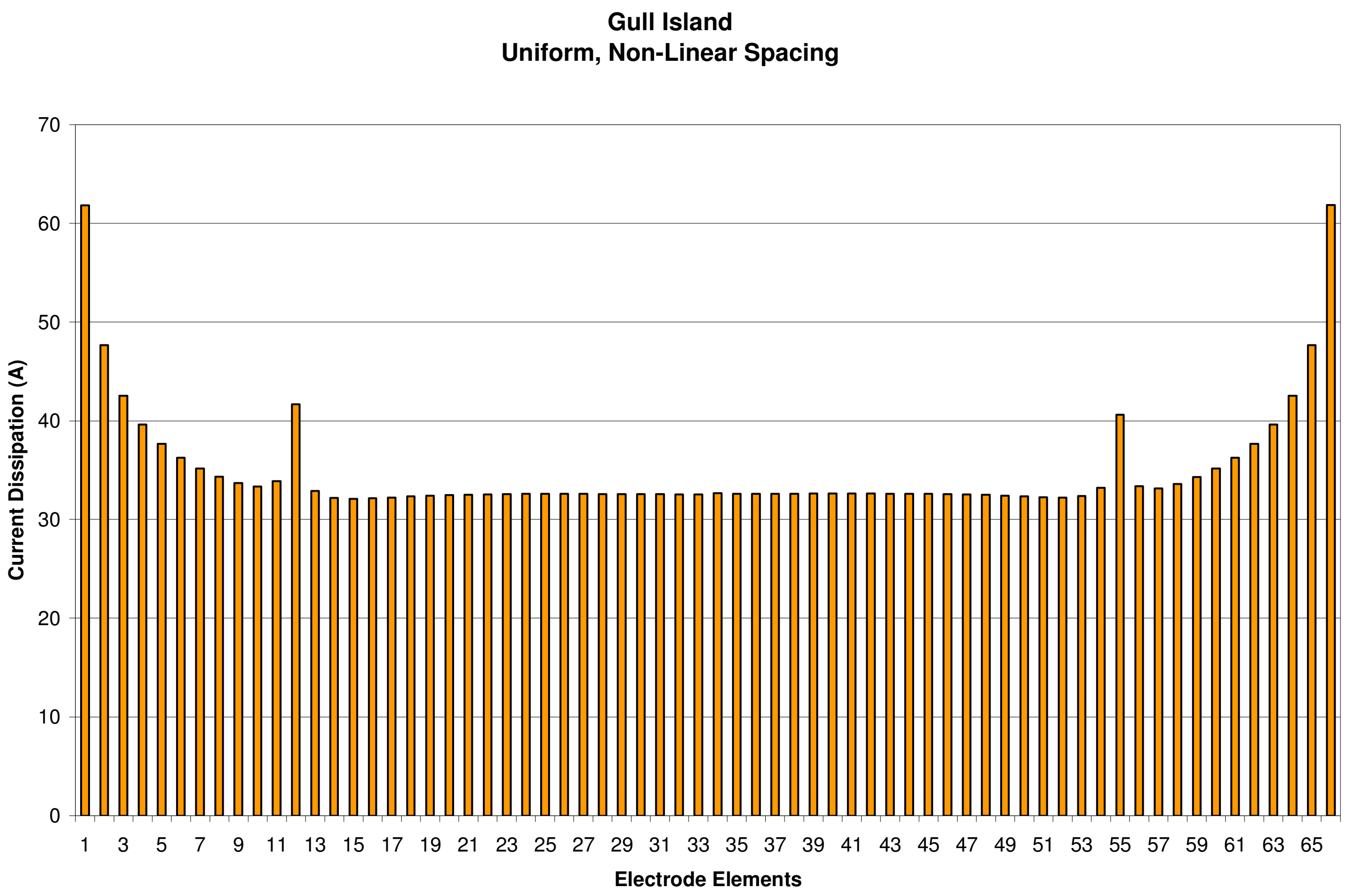



Gull Island
Uniform Spacing by Subsection
Current Dissipation (A)
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Electrode Elements




Gull Island
Non-Uniform Spacing
Current Dissipation (A)
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65
Electrode Elements

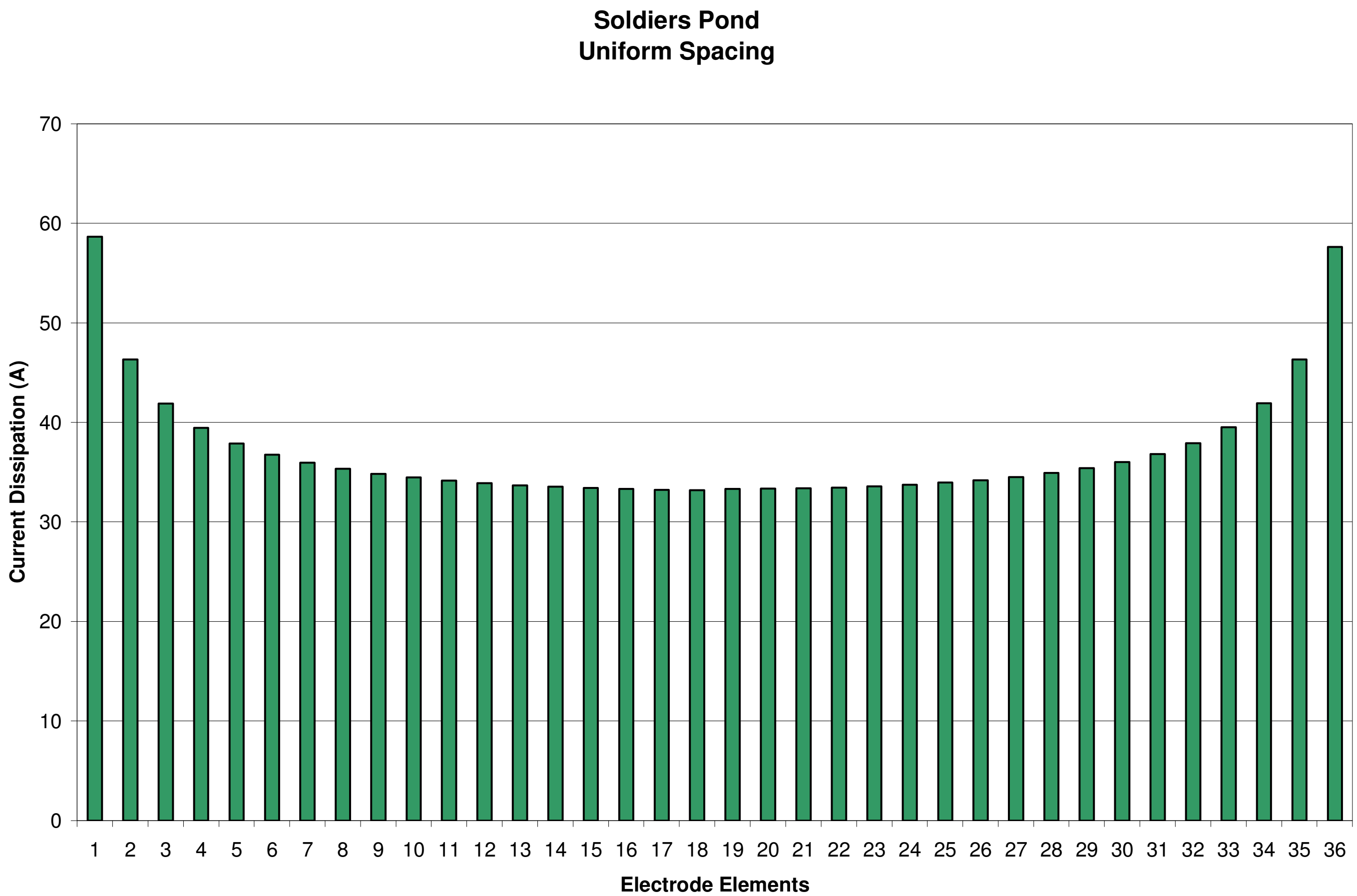


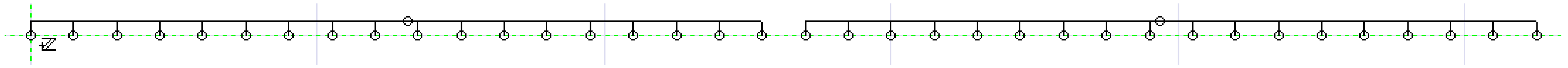

Gull Island
Uniform, Non-Linear Spacing
70
60
50
40
30
20
10
0
Current Dissipation (A)
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
65
Electrode Elements

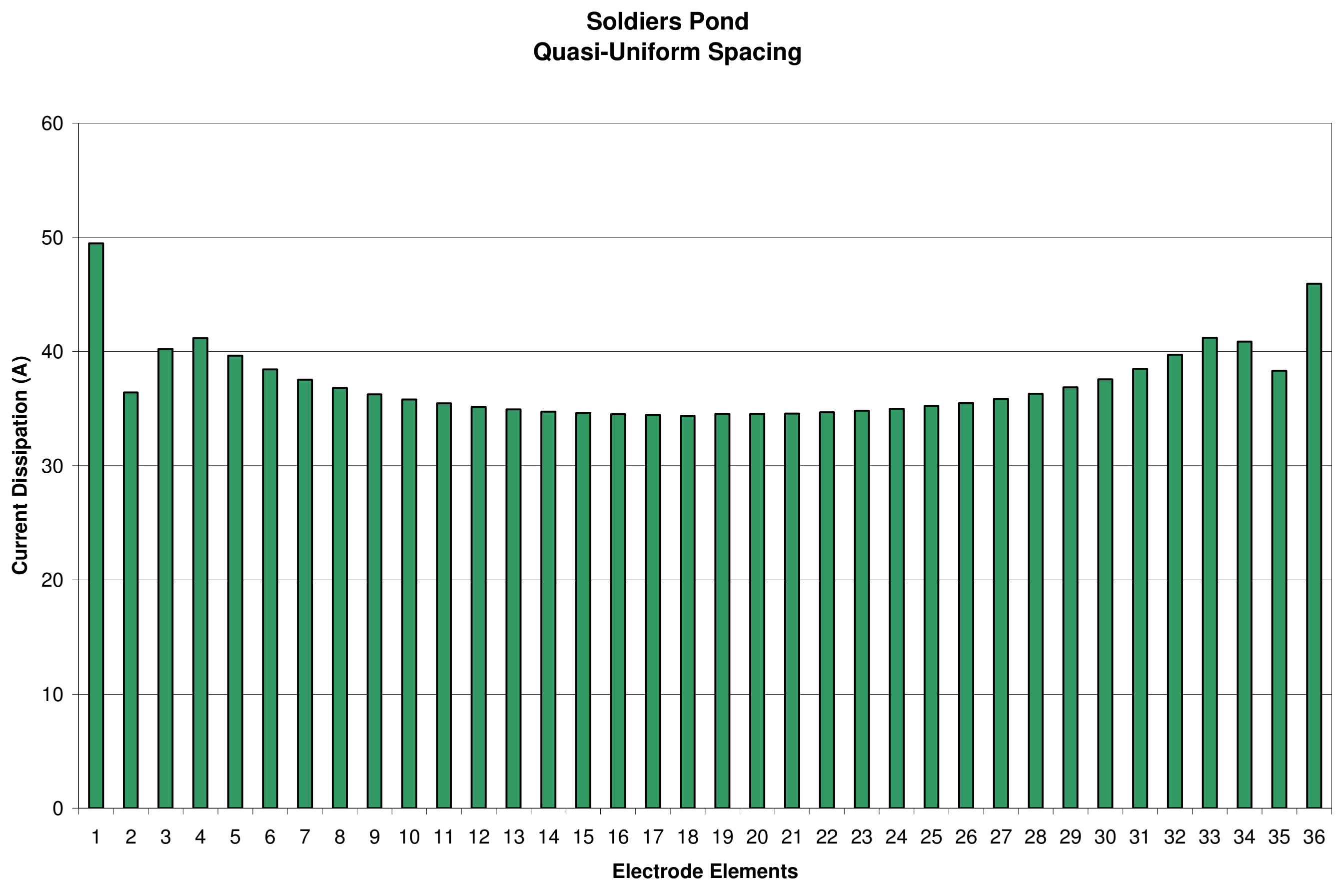
Electrode Arrangement	Maximum Current (A)	Standard Deviation
Uniform Spacing	60.41	5.656
Quasi-Uniform Spacing	50.22	3.556
Uniform Spacing by Subsection	52.76	4.977
Non-Uniform Spacing	48.12	2.414
Uniform, Non-Linear Spacing	61.88	5.929

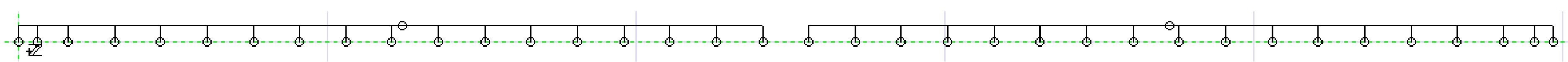
Soldiers Pond

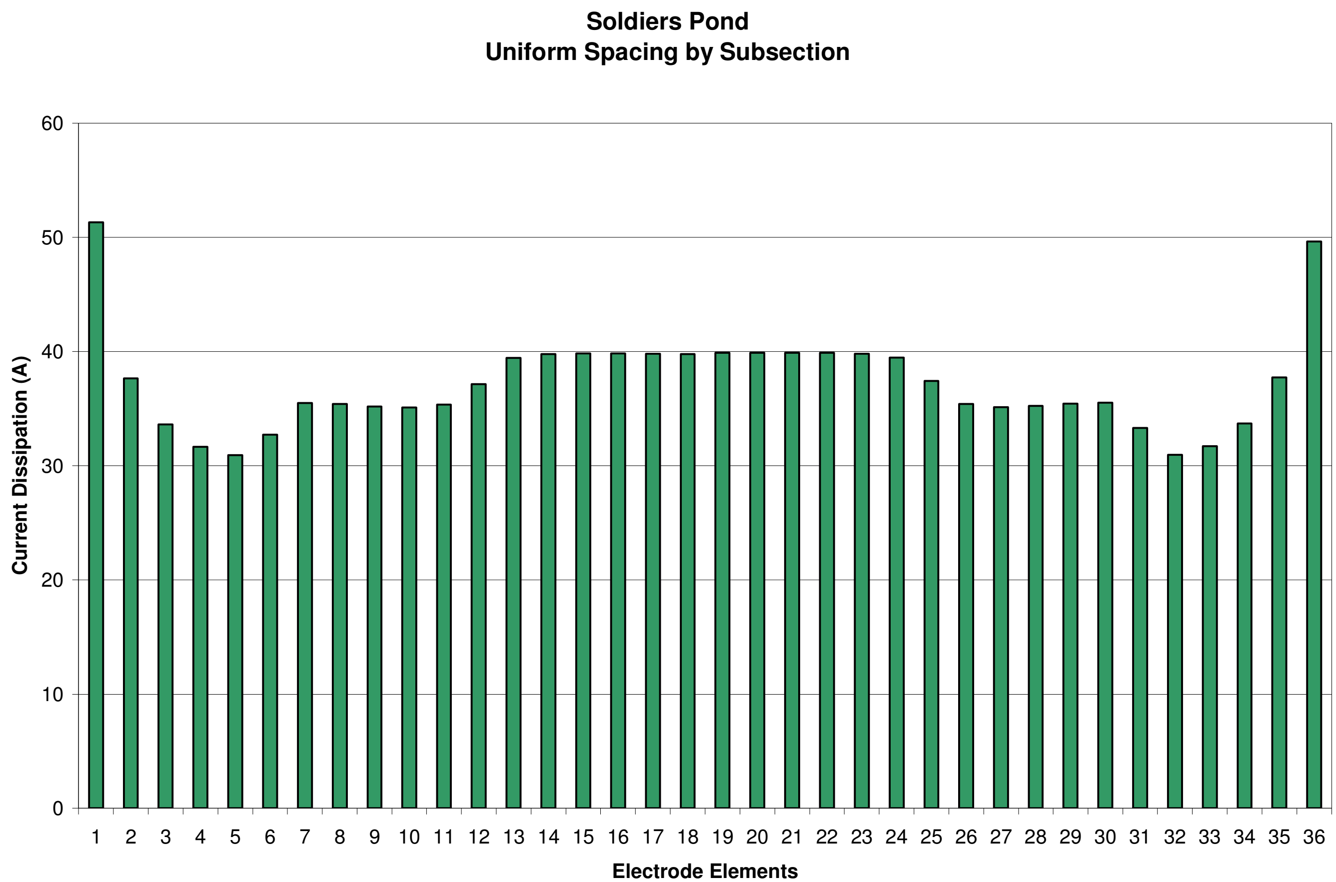
Electrode Element Arrangement Analysis

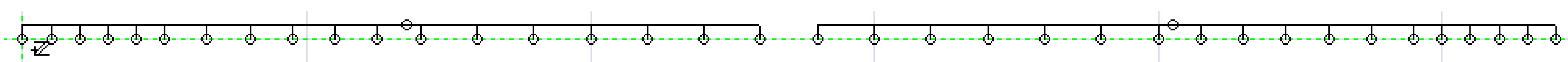

Soldiers Pond
Uniform Spacing
Current Dissipation (A)
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Electrode Elements

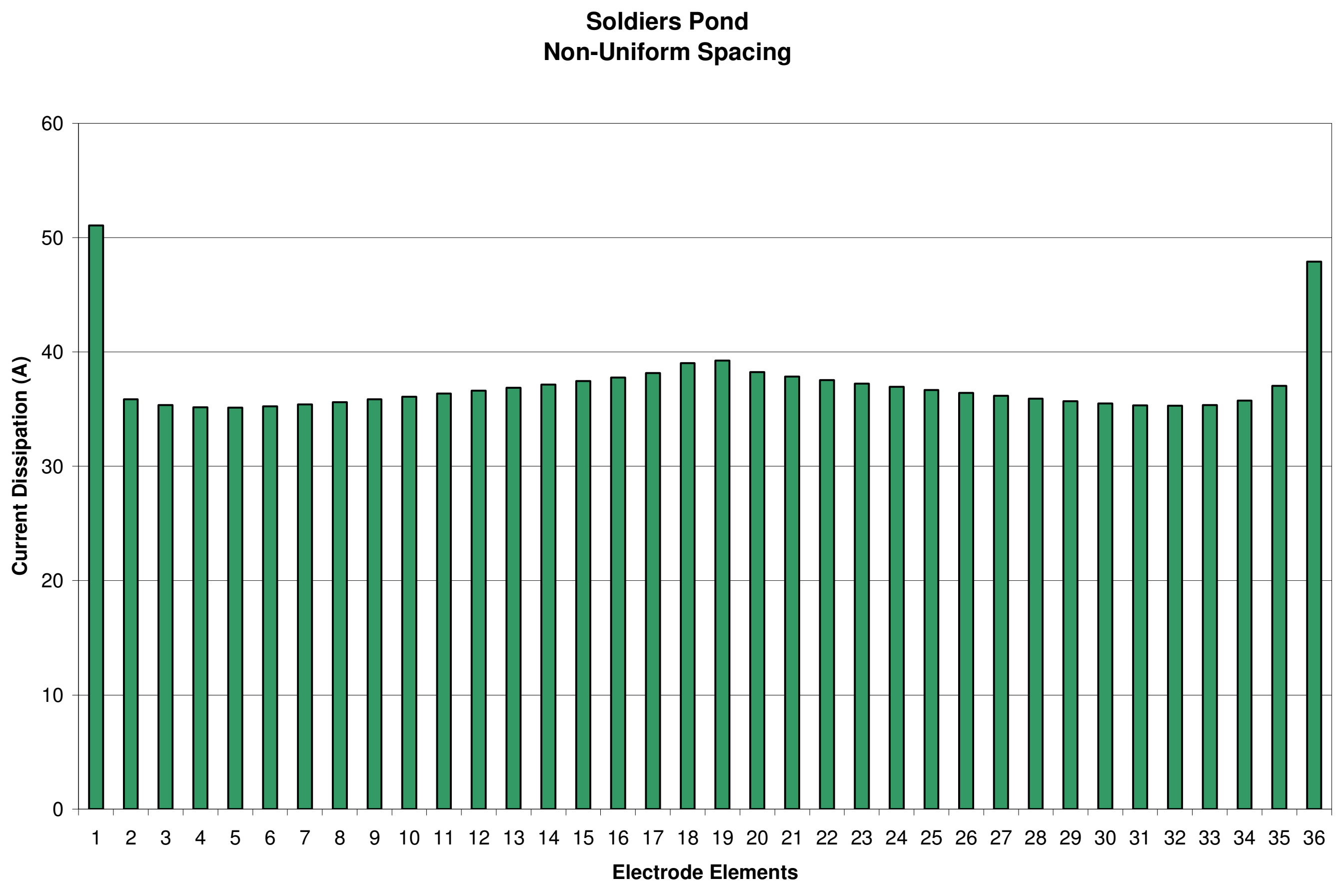


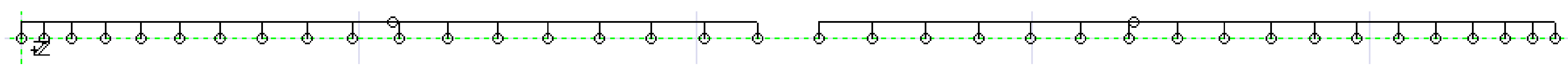

Soldiers Pond
Quasi-Uniform Spacing
Current Dissipation (A)
0
10
20
30
40
50
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Electrode Elements



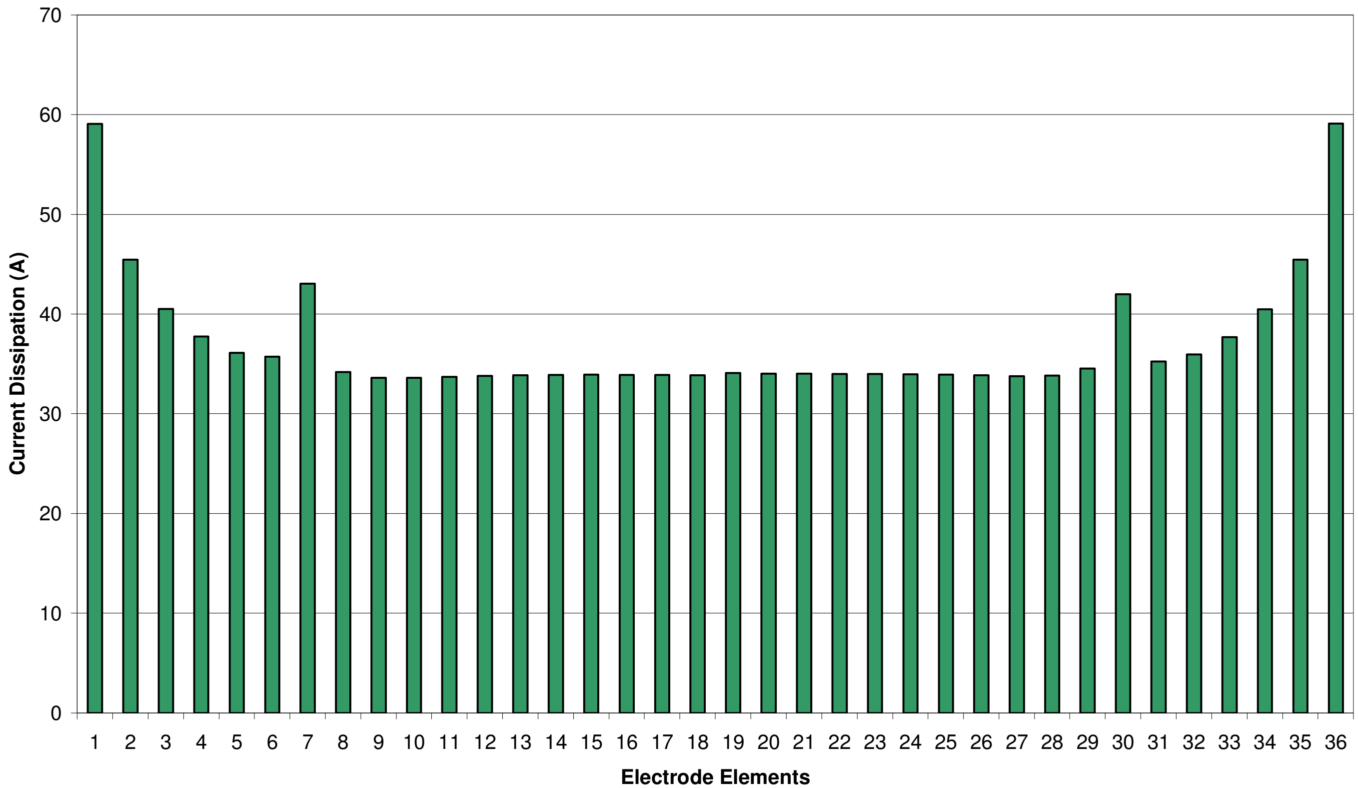

Soldiers Pond
Uniform Spacing by Subsection
Current Dissipation (A)
0
10
20
30
40
50
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Electrode Elements




Soldiers Pond
Non-Uniform Spacing
Current Dissipation (A)
0
10
20
30
40
50
60
Electrode Elements
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36



Soldiers Pond
Uniform, Non-Linear Spacing



Electrode Arrangement	Maximum Current (A)	Standard Deviation
Uniform Spacing	58.67	6.201
Quasi-Uniform Spacing	49.47	3.371
Uniform Spacing by Subsection	51.33	4.375
Non-Uniform Spacing	51.07	3.236
Uniform, Non-Linear Spacing	59.12	6.372

Conclusion

The trends observed in current distribution among elements for the different arrangements are similar for both electrode sites. As expected, the current imbalance is high at the ends of the electrode arrays. In all cases, the last electrode elements on each end dissipate more than the design value of 45A. Exceeding the design value is not of concern since 45 A is still less than the manufacturer's recommended value.

The current dissipation of the end elements for the "Uniform" and "Uniform, Non-Linear" arrangements are on the order of 60 A, while the "Quasi-Uniform", "Uniform by Subsection" and "Non-Uniform" arrangements are on the order of 50 A. The "Uniform" and "Uniform, Non-Linear" spacing arrangements are not considered because of the higher currents at the ends of the array. The "Uniform by Subsection" spacing results in high variance of currents in the middle of the element array and is not desirable. The lowest variance in terms of current imbalance occurs in the "Non-Uniform" arrangement; however, the irregular spacing of the elements would make construction and difficult and therefore this arrangement is not ideal. The most favourable electrode element arrangement is the "Quasi-Uniform" arrangement. The standard deviations of the current dissipated in the Gull Island and Soldiers Pond "Quasi-Uniform" arrangements are 3.556 and 3.371, respectively. The regular spacing of the electrode elements lends itself to easy construction. Therefore, the "Quasi-Uniform" element spacing arrangement is considered for the installation of both the Gull Island and Soldiers Pond shoreline pond electrodes.

Appendix C

Transmission Network, Distribution Network and Corrosion Data

Table C-1: 25 kV Distribution Network Data, Gull Island

Pole Grounding Resistance				
Pole Grounding Resistance	R_P	Ω	5	Assumed, based on NE-LCP input (< 6 Ω)
Distribution Transformers				
Utility Distribution Transformer	kVA_{TU}	kVA	25	Input from NE-LCP
Utility Distribution Transformer Resistance	R_{TU}	Ω	749.96	HV Windings resistance based on 1% distribution transformer loss.
Line Resistances				
Span of Spacing of Distribution Transformers	l	m	425	
DC Resistance of Phase Conductor (1/0 ACSR)	R_{cond}	Ω/km	0.5364	
Resistance of Distribution Line	$R_{sw}=l*R_{cond}$	Ω	0.22797	per 425 m
DC Resistance of Neutral Conductor (1/0 ACSR)	R_{cond}	Ω/km	0.5364	
Resistance of Distribution Line Neutral	$R_{sw}=l*R_{cond}$	Ω	0.22797	per 425 m

Notes:
1. All utility transformers are assumed to be 1Ø.
2. All utility transformers are assumed to be located on the same pole (3 transformers of total 25 kVA every 425 m).
3. A 3Ø distribution line is assumed to follow the Trans-Labrador Highway (HWY 510).

Table C-2: 25 kV Distribution Network Pole Grounds Corrosion Data, Gull Island

Steel Grounding Rods (two assumed)				
Electrode Continuous Current Duty	I_r	2320	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}	36763968	A.h	Based on DC1250 analysis
	=	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	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.402	A	

Table C-3: HVdc Submarine Cable Corrosion Data, Gull Island

Mass Impregnated Cable, Steel Armour				
Electrode Continuous Current Duty	I_r	2320	A	
Permissible Loss of Material	$m_{\%}$	1.667	%	0.1 mm loss of armour assumed
Cable Diameter	d	0.135	m	Assumed
Cable Length	l	1	m	per 1 m unit length
Armour Thickenss	t	0.006	m	
Steel Density	w	7800000	g/m^3	Typical values assumed.
Total Weight	$m_{tot}=d\pi*l*t*w$	19848.582	g	
Electrode Duty (as Anode)	Ah_{duty}	36763968	A.h	Based on DC1250 analysis
	=	4196.800	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	$m_{loss}=m_{tot}*m_{\%}$	330.876	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	317.568	A.h	
Permissible Leakge Current per m of Armour	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.020	A	

Table C-4: 230 kV T/L Skywire Network Data, Soldiers Pond

Station Grounding Grids						**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	6.14			Proportional
Steel Tower Footing Resistance - Rock						
Tower Footing Resistance	R_{tf}	Ω	350.72			Calculated
Steel Tower Footing Resistance - Soil						
Tower Footing Resistance	R_{tf}	Ω	13.38			Calculated
Wood Tower Footing Resistance - Soil						
Tower Footing Resistance	R_{tf}	Ω	24.2			Calculated
Counterpoise Leakage/Contact Resistance - Soil (per 66.7 m)		Ω	15.4			Calculated
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℃)	R_{cond}	Ω/km	1.405	1.405	1.405	See Note 1
Resistance of Skywire per span	$R_{sw}=l*R_{cond}$	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)
3. Two skywires per transmission line

Table C-5: 230 kV Transmission Network Data, Soldiers Pond

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	$R_{HRD}=R_{T1}\Vert R_{T2}\Vert R_{T3}\Vert R_{T6}\Vert R_{T7}\Vert R_{T8}$	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	$R_{WAV}=R_{T1}\Vert R_{T2}\Vert R_{T3}\Vert R_{T4}\Vert R_{T5}$	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)	$I_{e3p}=I_{e3p\%} * I_{rated}/100$	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)	$I_{e3p}=I_{e3p\%} * I_{rated}/100$	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

Terminal Station Ground Grid Impedances

			Resistance						Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	6.14						Calculated
Western Avalon Grounding Grid Resistance	$R_{G\ WAV}$	Ω	15.01						Measured
Oxen Pond Grounding Grid Resistance	$R_{G\ OPD}$	Ω	9.4						Measured
Hardwoods Grounding Grid Resistance	$R_{G\ HWD}$	Ω	8.37						Calculated

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				

<u>Notes</u>

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

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Table C-6: 230 kV Transmission Network Simulation Results, Soldiers Pond

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	0.066	0.045	0.038	0.009	0.008	0.053

Stray DC Current at Holyrood	I_{HRD}	A	0.654
Stray DC Current at Holyrood (per phase)	$I_{HRD}/3$	A	0.218
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	0.003	0.003	0.008	0.008	0.054	

Stray DC Current at Western Avalon	I_{WAV}	A	0.230
Stray DC Current at Western Avalon (per phase)	$I_{WAV}/3$	A	0.077
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	0.014	0.051	0.028			

Stray DC Current at Oxen Pond	I_{OPD}	A	0.279
Stray DC Current at Oxen Pond (per phase)	$I_{OPD}/3$	A	0.093
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	0.009	0.009	0.008	0.022		

Stray DC Current at Hardwoods	I_{HWD}	A	0.145
Stray DC Current at Hardwoods (per phase)	$I_{HWD}/3$	A	0.048
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.

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Table C-7: 138 kV Transmission Network Data, Soldiers Pond

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

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Station Grounding Grids

Description			Resistance			Remarks
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	6.14			Calculated
Bay Roberts Grounding Grid Resistance	$R_{G\ BRB}$	Ω	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 total resistance calculated based on copper losses is split between the windings proportionally to 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 stabilizing windings are ignored for auto transformers.
5. The 138 kV transfomer windings connected in Delta are not included in the tables.

Table C-8: 138 kV Transmission Network Simulation Results, Soldiers Pond

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	0.024	0.023	0.148

Stray DC Current through T6, T7 and T8 Windings	I_{HRD}	A	0.584
Stray DC Current through T6, T7 and T8 (per phase)	$I_{HRD}/3$	A	0.195
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	0.030

Stray DC Current at Bay Roberts	I_{BRB}	A	0.090
Stray DC Current at Bay Roberts (per phase)	$I_{BRB}/3$	A	0.030
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.

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Table C-9: 69 kV Transmission Network Data, Soldiers Pond

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

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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	6.14		Calculated
Seal Cove Grounding Grid Resistance	$R_{G\ SCV}$	Ω	5		Assumed
Kelligrews Grounding Grid Resistance	$R_{G\ KEL}$	Ω	5		Assumed

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 total resistance calculated based on copper losses is split between the windings proportionally to the square of the voltage ratio.
4. Resistances of Delta stabilizing windings are ignored for auto transformers.
5. The 69 kV transfomer windings connected in Delta are not included in the tables.

Table C-10: 69 kV Transmission Network Simulation Results, Soldiers Pond

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	0.020	0.020

Stray DC Current at Holyrood	I_{HRD}	A	0.119
Stray DC Current at Holyrood (per phase)	I_{HRD} /3	A	0.040
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	0.004	0.037

Stray DC Current at Seal Cove	I_{SCV}	A	0.122
Stray DC Current at Seal Cove (per phase)	I_{SCV} /3	A	0.041
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	0.081

Stray DC Current at Kelligrews	I_{KEL}	A	0.242
Stray DC Current at Kelligrews (per phase)	I_{KEL} /3	A	0.081
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.

Table C-11: 12.47 kV Distribution Network Results, Soldiers Pond

Station Grounding Grids				**Remarks**
Holyrood Grounding Grid Resistance	$R_{G\ HRD}$	Ω	6.14	Calculated
Pole Grounding Resistance				
Pole Grounding Resistance	R_P	Ω	25	(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	11.25	NE-LCP
Seal Cove Station Distribution Transformer Resistance	R_{SCVdis}	Ω	1.639	
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	0.1073	

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.

Table C-12: 12.47 kV Distribution Network Results, Soldiers Pond

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	8.800	-1.3648	N/A	0.0714	0.0500	0.0728	0.7802
Closest Pole in 1Ø Line	15.500	0.2193	0.4266	N/A	0.0042	N/A	0.0232
Closest Pole in 2Ø Line	13.500	0.1478	0.4266	0.0030	N/A	0.0030	0.0232
Closest Pole in 3Ø Line	9.800	0.0098	0.4266	0.0017	0.0018	0.0017	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.

Table C-13: 230 kV Steel Tower (TL217 & TL242) in 500 Ωm Soil Corrosion Data, Soldiers Pond

Foundation in soil (steel grillage)				***Remarks***
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	1	%	Assumed
Volume	v	0.048855704	m^3	
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=v*w$	381074.491	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	3810.745	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	3657.477	A.h	
Permissible Current through Steel Grillage	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.245	A	
Guywire Anchors in soil (two rods with anchor plates)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	10	%	Assumed
Volume	v	0.0102099	m^3	
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=v*w$	79637.220	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	7963.722	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	7643.422	A.h	
Permissible Current through Anchors	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.512	A	

Table C-14: 230 kV Steel Tower (TL217 & TL242) in 5000 Ωm Rock Corrosion Data, Soldiers Pond

Foundation in rock (four anchor rods)				***Remarks***
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	1	%	Assumed
Volume	v	0.001701172	m^3	
Steel Density	w	7800000	g/m^3	
Total Weight	m_{tot}=v*w	13269.142	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	132.691	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	127.355	A.h	
Permissible Current through Steel Grillage	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.009	A	
Guywire Anchors in rock (single anchor rod)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	10	%	Assumed
Volume	v	0.001228259	m^3	
Steel Density	w	7800000	g/m^3	
Total Weight	m_{tot}=v*w	9580.420	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	958.042	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	919.510	A.h	
Permissible Current through Anchors	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.062	A	

Table C-15: 230 kV Wood Pole (TL218) in 500 Ωm Soil Corrosion Data, Soldiers Pond

Wrapped Ground Wire in soil				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	10	%	Assumed
Grounding Rod Diameter	d	0.0046213	m	#5 AWG steel
Grounding Rod Length	l	6.2832	m	5 wraps, 200 mm radius pole
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	822.039	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	82.204	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Cu,mol}$	78.898	A.h	
Permissible Current through Ground Wire	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.005	A	
Bearing Plate in soil				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	1	%	Assumed
Volume	v	0.001203356	m^3	
Steel Density	w	7800000	g/m^3	
Total Weight	$m_{tot}=v*w$	9386.177	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	93.862	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Fe,mol}$	90.087	A.h	
Permissible Current through Bearing Plate	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.006	A	

Table C-16: 230 kV Transmission Line (TL214, TL218 & TL24) Counterpoise Corrosion Data, Soldiers Pond

Copper Counterpoise (per 67 m section)				
Electrode Continuous Current Duty	I_r	1340	A	
Permissible Loss of Material	$m_{\%}$	50	%	Assumed
Grounding Rod Diameter	d	0.0082515	m	1/0 copper
Grounding Rod Length	l	66	m	per 67 m section
Copper Density	w	8900000	g/m^3	
Total Weight	$m_{tot}=\pi/4*d^2*l*w$	31411.569	g	
Electrode Duty (as Anode)	Ah_{duty}	20004336	A.h	
	=	2283.600	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	$m_{loss}=m_{tot}*m_{\%}$	15705.785	g	
Permissible Ampere-Hour	$Ah_{perm}=Ah_f*m_{loss}/m_{Cu,mol}$	13241.405	A.h	
Permissible Current through Rods	$I_{dc}=I_r*Ah_{perm}/A_{duty}$	0.887	A	

Table C-17: 12.47 kV Distribution Network Pole Grounds, Soldiers Pond

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	
	=	2283.105	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 D

Compass Error Analysis

and

Ship Corrosion Analysis

Compass Error Analysis

The induced magnetic field resulting from current flowing in the sea during electrode operation will be circular about the electrode, as shown in Figure D-1; the magnetic field on the land side is not shown. The magnetic field shown in Figure D-1 assumes the electrode is operating as an anode, and its direction can be established using the right hand rule.

The worst case for compass error occurs along the line from the electrode to the magnetic north, where the earth's magnetic field and the induced magnetic field from the electrode are orthogonal.

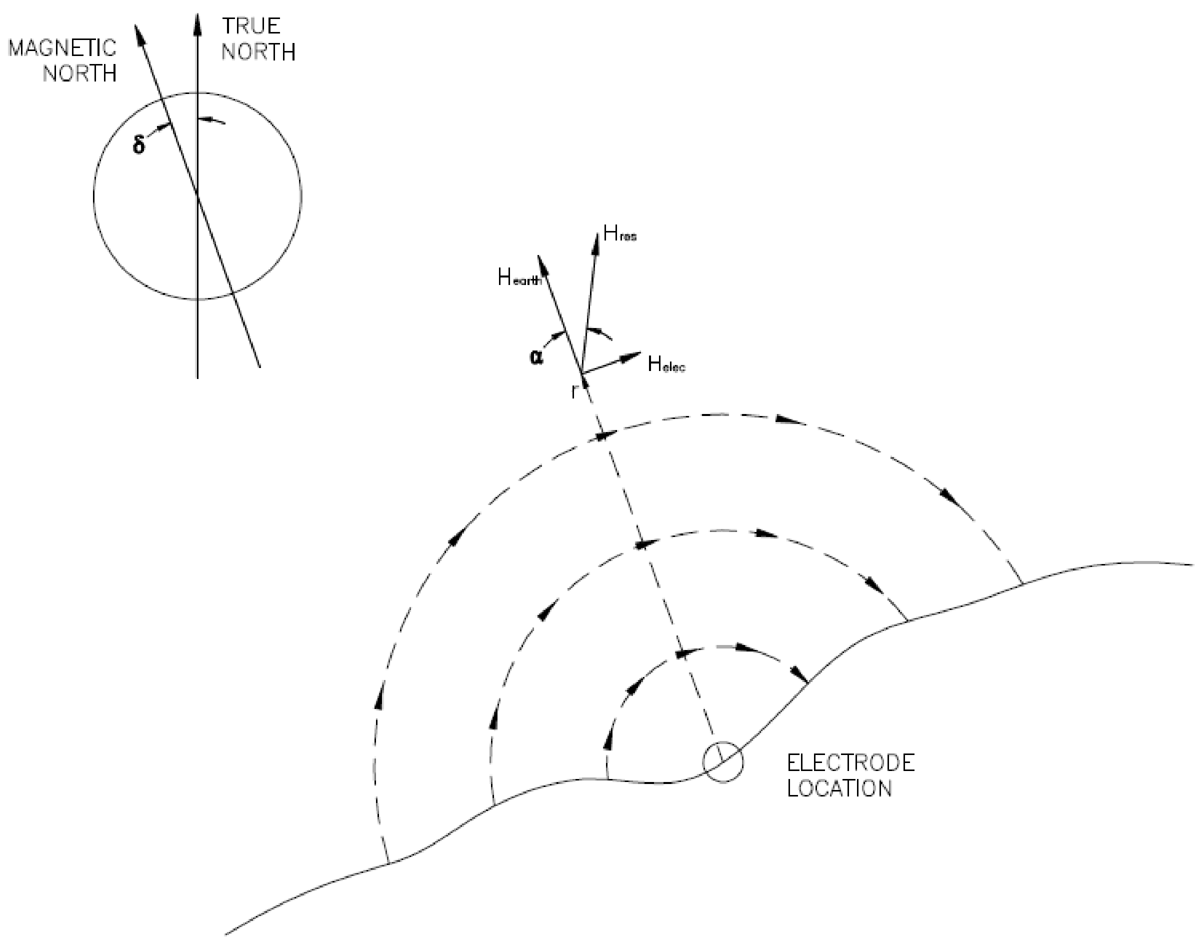


Figure D-1: Vector Diagram and Magnetic Fields

The current flowing outward in the sea is encompassed in a half-cylindrical shell, as shown in Figure D-2.

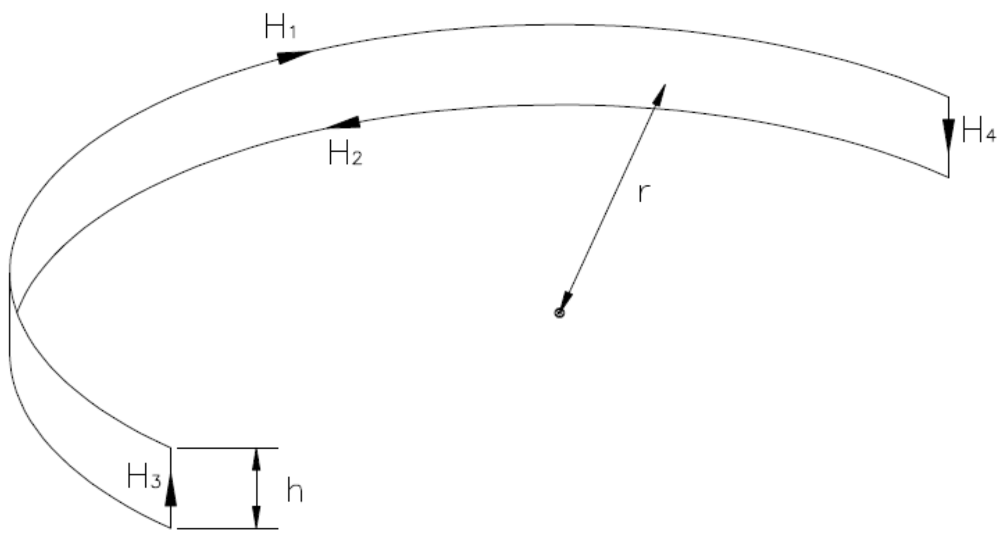


Figure D-2: Half-cylindrical Shell in the Sea

The magnitude of the magnetic field intensity can be established using Ampere's circuital law.

$$\oint H \cdot dl = I$$

In this special case,

$$I = H_1 \pi r + H_2 \pi r + H_3 h + H_4 h$$

A uniform current density is assumed along the complete half-cylindrical shell; in reality, smaller currents will be present along the shoreline compared to the middle of the of the sea due to the difference in water depth. The end magnetic field distortion at the sea shoreline is ignored and soil at the bottom is assumed to have relative permeability of 1; the actual soil relative permeability is typically in the range of 1 to 5.

For $h << r$

$$I = 2H\pi r$$

$$\Rightarrow H = \frac{I}{2\pi r}$$

The magnetic field intensity moving radially away from the Gull Island electrode along the line parallel with the magnetic north is:

Table D-1: Magnetic Field Intensity, Gull Island

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)
200	1.85
300	1.23
400	0.92
500	0.74
1000	0.37
2000	0.18
3000	0.12
4000	0.09
5000	0.07

The magnetic field intensity moving radially away from the Soldiers Pond electrode along the line parallel with the magnetic north is:

Table D-2: Magnetic Field Intensity, Soldiers Pond

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)
200	1.07
300	0.71
400	0.53
500	0.43
1000	0.21
2000	0.11
3000	0.07
4000	0.05
5000	0.04

A typical value for horizontal component of the magnetic field intensity due to the earth's magnetic field is assumed to be 16 A/m [9].

The resultant horizontal component of the magnetic field at the surface of the water is calculated for the Gull Island electrode in Table D-3.

Table D-3: Resultant Magnetic Field Intensity, Gull Island

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)	Magnetic field intensity (earth), H_{earth} (A/m)	Magnetic field intensity (resultant), $H_{res} = [(H_{elec})^2 + (H_{earth})^2]^{0.5}$ (A/m)	Compass error, α (°)
200	1.85	16	16.106	6.579
300	1.23	16	16.047	4.397
400	0.92	16	16.027	3.301
500	0.74	16	16.017	2.642
1000	0.37	16	16.004	1.321
2000	0.18	16	16.001	0.661
2600	0.14	16	16.001	0.508
3000	0.12	16	16.000	0.441
4000	0.09	16	16.000	0.330
5000	0.07	16	16.000	0.264

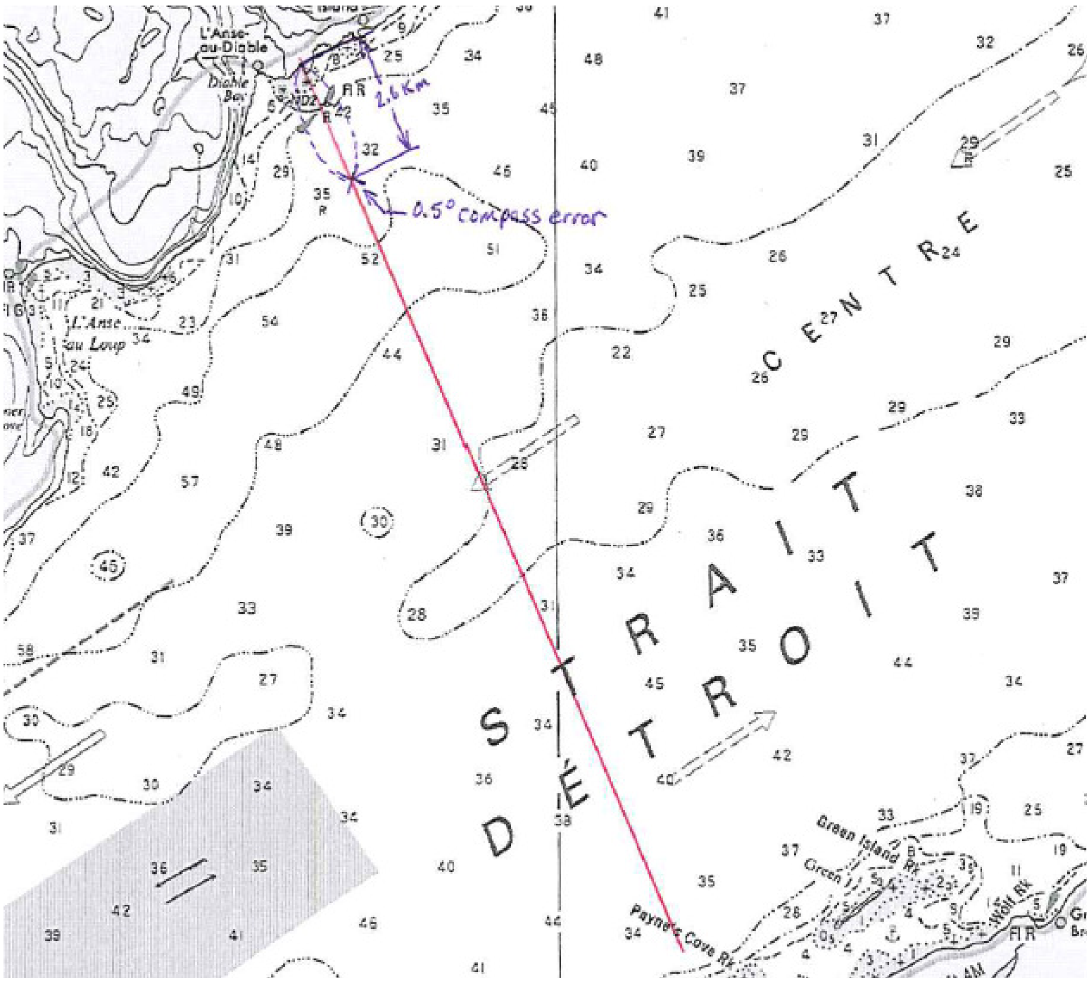
The resultant horizontal component of magnetic field at the surface of the water is calculated for the Soldiers Pond electrode in Table D-4.

Table D-4: Resultant Magnetic Field Intensity, Soldiers Pond

Distance from electrode, r (m)	Magnetic field intensity (electrode), H_{elec} (A/m)	Magnetic field intensity (earth), H_{earth} (A/m)	Magnetic field intensity (resultant), $H_{res} = [(H_{elec})^2 + (H_{earth})^2]^{0.5}$ (A/m)	Compass error, α (°)
200	1.07	16	16.035	3.811
300	0.71	16	16.016	2.543
400	0.53	16	16.009	1.908
500	0.43	16	16.006	1.526
1000	0.21	16	16.001	0.763
1500	0.14	16	16.001	0.509
2000	0.11	16	16.000	0.382
3000	0.07	16	16.000	0.254
4000	0.05	16	16.000	0.191
5000	0.04	16	16.000	0.153

An angle of deviation of 0.5° or less is considered acceptable [18]. The annual deviation at L'Anse-au-Diable North is 13.6′/yr (approximately 0.23°/yr), and the annual deviation at Dowden's Point is 11.8′/yr (approximately 0.20°/yr) [19].

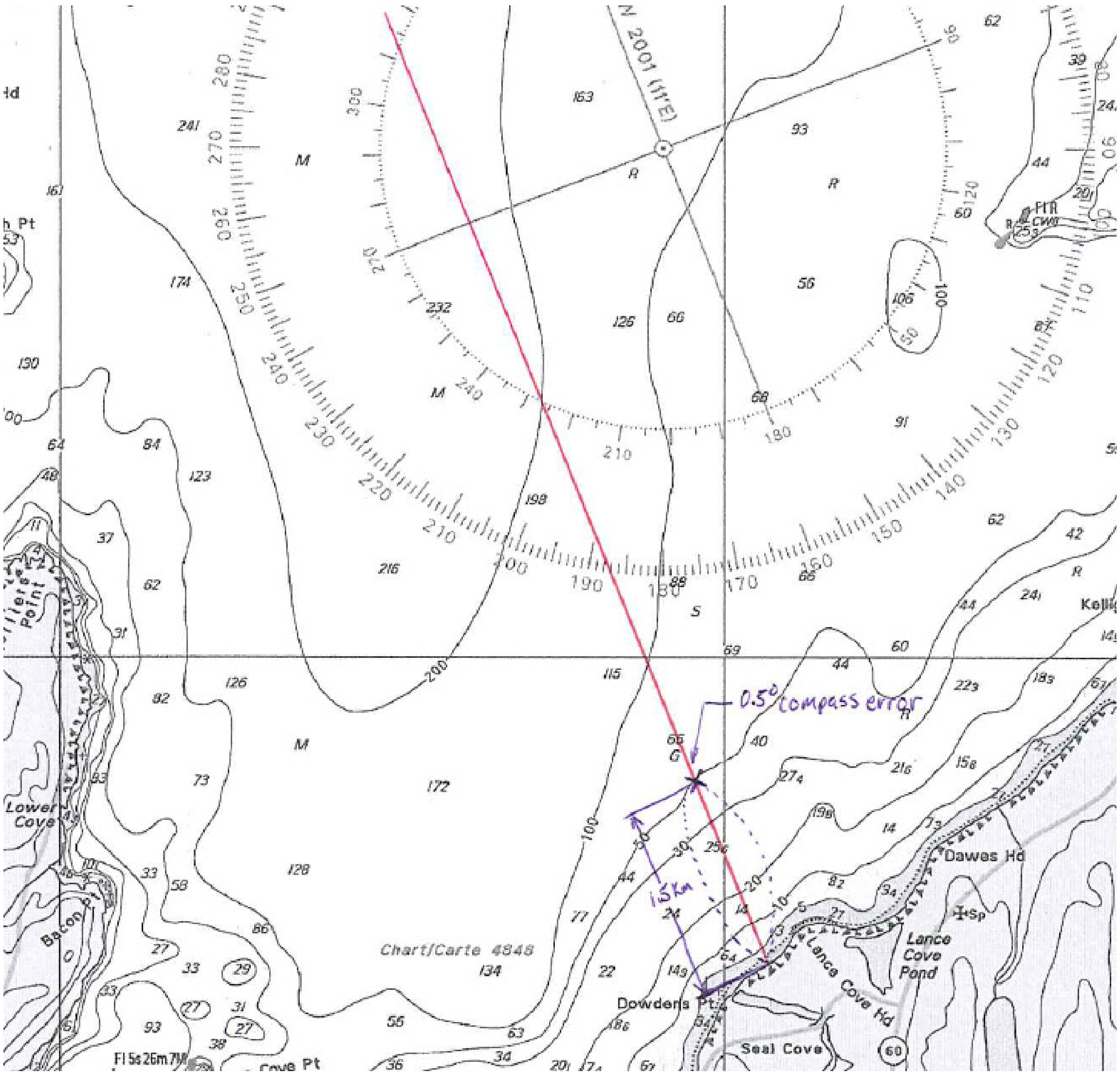
Sketch D-1 shows the worst case distance from the Gull Island electrode at L'Anse-au-Diable where a compass deviation of 0.3° occurs; any point beyond that distance will experience a lesser error. The zone of influence from that point towards the shore will resemble the shape of a cone.



Sketch D-1: Compass error of 0.3° at L'Anse-au-Diable North

HATCH™

Sketch D-2 shows the worst case distance from the Soldiers Pond electrode at Dowden's Point where a compass deviation of 0.3° occurs; any point beyond that distance will experience a lesser error. The zone of influence from that point towards the shore will resemble the shape of a cone.



Sketch D-2: Compass error of 0.3° at Dowden's Point

The actual compass errors at the surface of water will be less than the values in Tables D-3 and D-4 considering the steel hull of a ship acting as a magnetic shield and a compass located above the water level. Nowadays, large ships and vessels use gyro compasses or GPS navigation, and magnetic compasses as back-up.

Working Together SAFELY

Ship Corrosion Analysis

Most large ships use an impressed current cathodic protection (ICCP) system to suppress natural electro-chemical activity on the hull and prevent corrosion. An ICCP system monitors and controls the electric potential at the interface between the ship's hull and the seawater, making it more effective than a sacrificial anode system.

A typical ICCP system is shown below in Figure D-3.

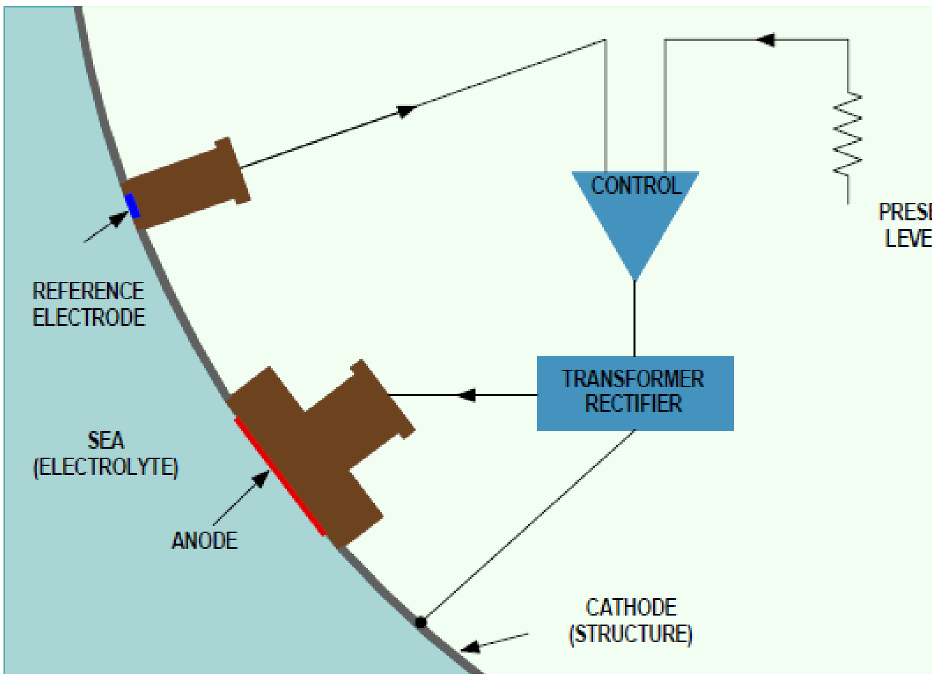


Figure D-3: Schematic of a Typical Ship ICCP System

An ICCP impresses a low voltage dc output onto the ship hull through an anode attached to but insulated from the hull; a ship will have multiple anodes. The impressed voltage is typically 0.85 V. The reference cells are used to measure the potential on the ship's hull and to feedback the voltages to the controller.

The voltage gradient at a distance of 1500 m or larger from an electrode will be very small and the voltage difference between the two ends of a 200 m long ship will be less than 0.85 V; this will not impact the ICCP system operation. For a smaller yacht or boat, even without cathodic protection, the impact will be insignificant.

An anchored ship connected to the conductive infrastructure (e.g. power system grounding system or pipeline) on land can be impacted negatively. This aspect can be reviewed in detail on a case-by-case basis.

Any ferry terminals or marine structures are assumed to be equipped with cathodic protection and will not be impacted negatively by the electrode operation.

Appendix E

Cost Estimate

Cost Estimate not filed in public version

Appendix F

Electrode Line Fault Detection and Protection

(RBJ Engineering)

NALCOR ENERGY – LOWER CHURCHILL PROJECT
HVDC GROUND ELECTRODE REVIEW AND SITE SELECTION
ELECTRODE LINE FAULT DETECTION AND PROTECTION

Memo *140-10000-1*

Electrode Line Fault Detection and Protection

Revision History

Rev	Date	Prepared By	Reviewed By	Comments
0	13-August-2010	Joanne Hu	Bruno Bisewski	Initial issue
1	20-August-2010	Joanne Hu	Bruno Bisewski	Incorporated comments
2	2-September-2010	Joanne Hu	Bruno Bisewski	Revised Summary and Recommendations
3	21-September-2010	Joanne Hu	Bruno Bisewski	Incorporated Nalcor's comments

ELECTRODE LINE FAULT DETECTION AND PROTECTION

Table of Contents

ELECTRODE LINE FAULT DETECTION AND PROTECTION

1. INTRODUCTION

As part of the Lower Churchill Project dc transmission system, NE-LCP is planning to develop shoreline pond electrodes at L'Anse-au-Diable (LAD) North on the northern coastline of the Strait of Belle Isle (SOBI) for the Gull Island converter station and at Dowden's Point for the Soldiers Pond converter station. The shoreline pond electrode at LAD North requires an electrode line of roughly 407 km for connection to the Gull Island converter station neutral bus while a short length roughly 11 km is required for connection between the Soldiers Pond converter station and the proposed Dowden's Point electrode.

Figure 1-1 shows a simplified overview of the dc transmission system. The Salisbury terminal is optional.

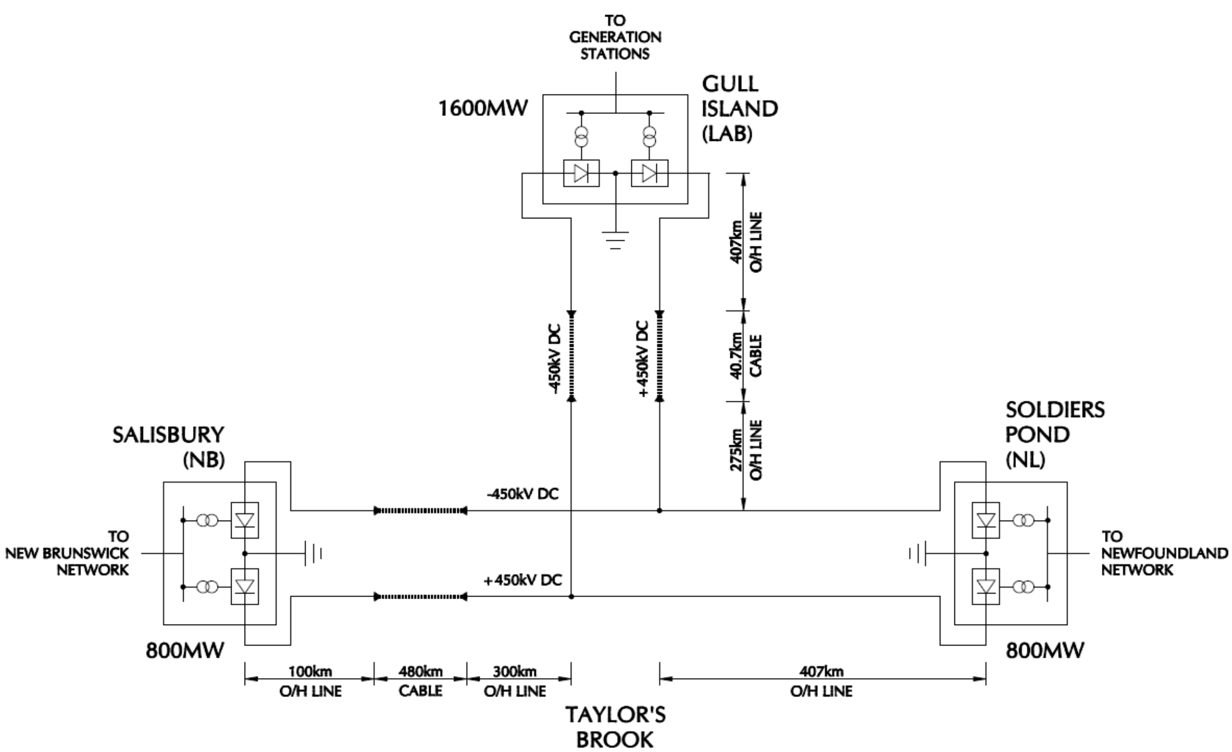


Figure 1-1 Proposed Lower Churchill Multi-Terminal HVdc System

Figure B-1 in Appendix B provides an indication of the geographic location of the proposed Gull Island and Soldiers Pond stations and the associated shoreline pond electrodes. Table 1-1 provides the summary of nominal and maximum electrode line current ratings.

Table 1-1 Terminal Station Monopolar Current Duties

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

This memo summarizes the technology and methodology that could be used for electrode line fault detection and protection based on preliminary electrode line conductor information provided, the information is included in Appendix A.

2. SCOPE

The scope of this review included:

- Identification of the issues that may be associated with electrode line fault detection and protection and in particular the long electrode line in Labrador
- Provision of a summary of the available technology/methodology for the electrode line fault detection and protection for the following scenarios under both monopolar and bipolar operation conditions.
    - Fault conditions
        - Conductor drop/touching ground
        - Insulator flashover
        - Conductor drop but not touching ground
        - Conductor–conductor contact without touching ground
        - Open conductor conditions with or without touching ground
- Preparation of recommendations for a fault detection and protection scheme

Overvoltage protection and insulation coordination of the electrode line should be considered in the overall line and system insulation protection scheme and is not covered in this memo.

3. ELECTRODE LINE FAULT DETECTION AND PROTECTION

It is difficult to provide adequate protection for electrode lines regardless of their length for a number of reasons:

a) Electrode lines are connected to ground at the electrode end and thus are in a sense already "faulted". This means that there is very little voltage available to provide any fault current should a fault occur at any location along the line. The available voltage, even in monopolar mode, is limited to the voltage drop in the electrode line conductor with the electrode voltage assumed to be almost zero. Thus the available ground fault current would vary with distance from the electrode and near the electrode almost no fault current would be present.

b) The converter acts a current source thus there is no increase in total electrode line current even if an electrode line-to-ground fault occurs.

c) There is very little electrode line current in the bipolar mode of operation, (typically only 0.5% to 1% of the rated HVdc current). Bipolar mode is the most prevalent mode of operation as the converter stations would typically be operated in this mode for about 98% of the time.

d) For the electrode line being considered in this report the situation is even more difficult as it traverses an area with high earth resistivity and tower footing resistances will generally be high resulting in very low fault currents for line-to-ground faults.

The generally low insulation level of the electrode lines generally means that flashover will occur for most direct and nearby lightning strikes and possibly also for dc line flashovers if the electrode line and HVdc line are on the same tower or in close proximity. Flashovers can occur at multiple locations along the electrode line.

These factors make it difficult to apply normal fault detection techniques as commonly applied on ac systems.

Even when line-to-ground faults have been detected they cannot be cleared in a conventional way by tripping of the electrode line since the electrode line must remain in service to sustain the transfer of power on the dc system in monopolar mode.

Special issues associated with long electrode lines include:

a) Larger voltage drop on the conductors – While this provides additional voltage for generating fault currents in the case of line-to-ground faults, it makes it more likely that a sustained arcing fault may be established and would make it harder for arcing horns to clear the fault.

b) Larger signal levels would be needed for fault detection techniques, such as high frequency impedance measuring, that do not rely on the HVdc electrode line voltage and current to detect faults.

c) Increased noise pickup and signal attenuation may decrease sensitivity of fault detection techniques based on time domain reflectometry.

d) It is more difficult to provide end to end communications from the converter station to the electrode site and, in the case of very long lines exceeding maximum length that is possible on a single leg of a fiber optic communications system, communications repeater stations could be required.

4. FAULT DETECTION AND PROTECTION METHODS

A summary fault detection and protection methods that have been applied in existing HVdc systems or which have been described in the literature is given in this section.

4.1 Conductor Unbalance Current Fault Detection (CUC)

Principle of Operation:

The Conductor Unbalance Current method is based on the measurement/monitoring of the current unbalance between the two electrode line conductors as shown in Figure 4-1. Currents I_1 and I_2 would have same magnitudes under no fault conditions, while a difference in current would occur if either of the electrode conductors has a ground fault or open circuit condition.

The basic requirement for this method to work is the current in the line has to be large enough for the current transducer to reliably establish that there is a difference in current taking into account the transducer's tolerances and accuracy and the natural unbalance in the conductor currents due to differences in conductor resistance. Typical tolerances in dc current transducers would be about 0.7 % of full load current and the unbalance in conductor resistance would be less than 0.1 %. The lowest practical setting would also require margin to avoid nuisance tripping. Thus the lowest practical setting may be in the order of 2% of the maximum current in each conductor at short time overload or about 28 A.

During bipolar operation, the current in the lines would generally be less than 1-2% rated dc current (35 A) and it would be impossible to detect any line to ground faults particularly if the tower footing resistance is high

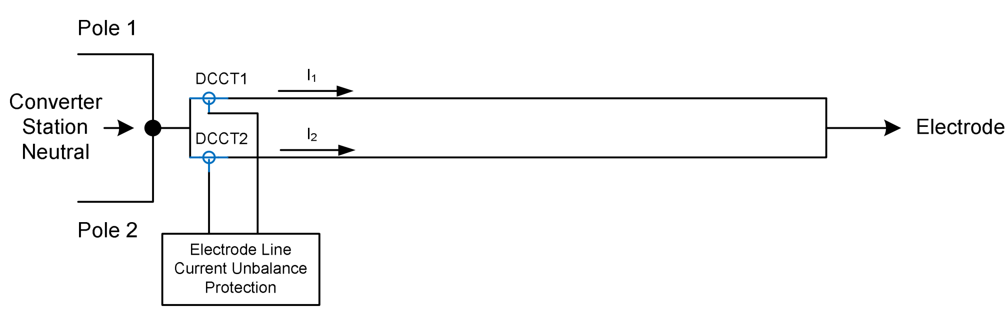


Figure 4-1 Conceptual Diagram of Current Unbalance Scheme

Pros:

a) This method is simple and cheap.
b) It does not require any equipment at electrode site
c) It does not require any communications equipment between converter station and electrode station.

Cons:

a) It is doubtful that this type of protection could reliably detect line-to-ground faults over most of the line either in bipolar or monopolar mode.
b) It would not be able to detect line-to-ground faults at the same location or open circuits occurring simultaneously on both conductors.
c) It would be useful only as an indication that one of the two conductors has become open circuited. Even this indication would only be possible in monopolar operation.

4.2 End-to-End Differential Protection (ETED)

Principle of Operation:

This type of differential protection is based on the measurement of the current at the both ends of the electrode line as shown in Figure 4-2. A fault would be indicated if the current difference exceeds a specified current level. As with the conductor unbalance, the sensitivity of this protection is limited by current transducer tolerances and the need to provide margins against nuisance tripping. High tower footing resistances make it difficult to obtain sufficient difference in current for fault detection.

Pros:

This protection method has few positive features. It could reliably detect open circuited conductors in monopolar mode,

Cons:

a) This method is more expensive than conductor unbalance current fault detection.
b) It requires installation of equipment at the electrode site and the installation of communications between the electrode sites and the converter station
c) It does not provide reliable detection of conductor ground faults during bipolar operation and may not detect line-to-ground faults on large portions of the line even in monopolar operation.

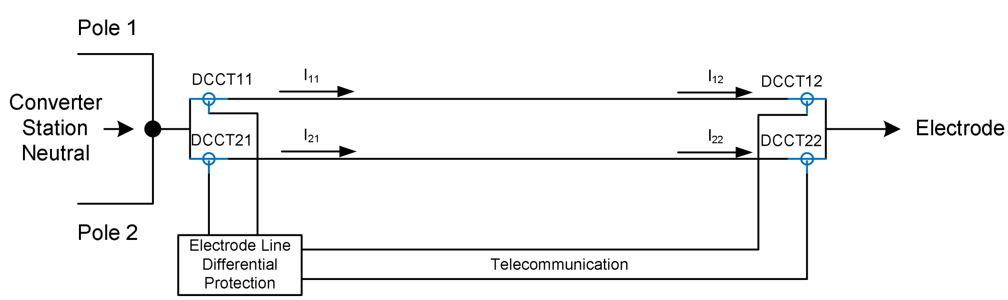
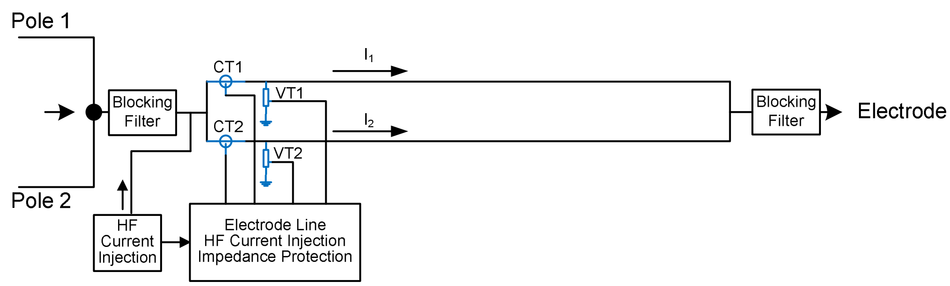


Figure 4-2 - Conceptual Diagram of Differential Protection Scheme

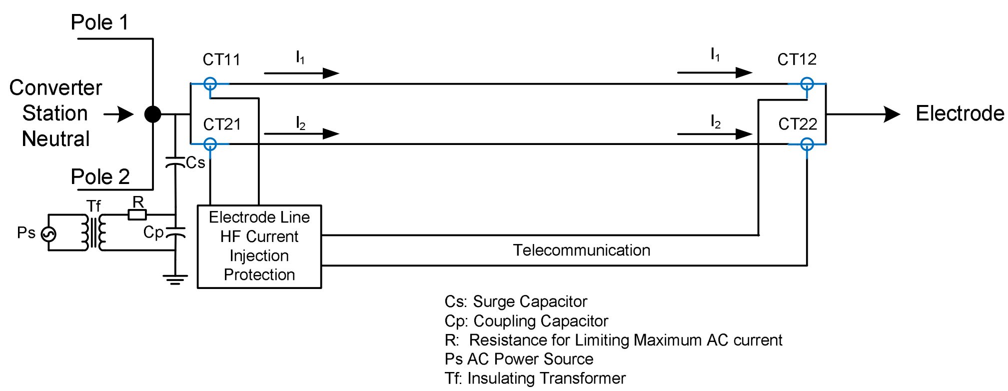
4.3 High Frequency Current Injection Method

Principle of Operation:

Two types of high frequency current injection schemes, impedance scheme and current differential scheme, are available. In impedance scheme, a high frequency signal (about 1 kHz) is injected into the electrode line and the voltage and current are monitored at the sending end to determine the impedance as shown in Figure 4-3 (a). In current differential scheme, a high frequency signal is injected at one end and the currents are monitored at both ends as shown in Figure 4-3 (b).



(a) Impedance Measuring Scheme



(b) High Frequency Current Differential Scheme

Figure 4-3 - Conceptual Diagram of High Frequency Current Injection Method

4.3.1 High Frequency Line Impedance Measuring Method (HFLI)

For protection based on the impedance measuring principle, the calculated impedance would be used to discriminate if there is a fault on the line. As there is a blocking filter at each end of the line the impedance measuring system could discriminate faults ground faults for the full length of the line. Open circuited conductors would also be detected as the impedance of each conductor would be measured separately. The detection of faults would not be affected by HVdc operating mode as it uses an independent source for the measuring signal rather than relying on the HVdc electrode line current.

Pros:

a) Operation and sensitivity do not depend on HVdc operation mode
b) The protection covers the full line
c) End to end communication between the converter station and electrode is not required

Cons:

a) The impedance measuring system requires a blocking filter at each end of the electrode line. As the blocking equipment must be rated to carry the maximum HVdc monopolar current, it is relatively expensive and would also increase overall HVdc transmission losses in monopolar operation.
b) There are very few suppliers of the impedance measuring equipment at the high frequency (about 1 kHz) and it tends to be of laboratory quality rather than relay system quality and reliability.
c) The signal levels injected on the line are generally low and thus system may not reliably detect high impedance ground faults.

4.3.2 High Frequency Current Differential System (HFCD)

Protections using the current differential principle use the difference in current in the two line conductors measured at receiving end (electrode end) to detect the fault along the electrode line except close to receiving end which will be picked up by the injecting end (converter end) current change [1].

Pros:

a) The current injection method should be able detect a fault on the electrode line during both monopolar and bipolar operation.
b) It should be possible to detect faults on the whole line if the signal level is large enough.

Cons:

a) Requires end-to-end communications between the converter station and electrode station
b) Requires more power to inject the high frequency current signal than the impedance measuring system.
c) It may not be possible to inject sufficient current into a long electrode line for reliable operation. A significant signal level would be required for long electrode lines taking into account the tolerances of the measuring transducers, normal conductor unbalance and margins against nuisance tripping
d) It would generally require a blocking filter at the converter station end.

4.4 Neutral Bus Voltage Measurement (NBV)

Principle of Operation:

The neutral bus voltage is measured on each pole as shown in Figure 4-4. If electrode line conductor is open circuited, a high neutral bus voltage would be measured. The setting needs to be higher than the maximum voltage drop in the electrode line at maximum monopolar current.

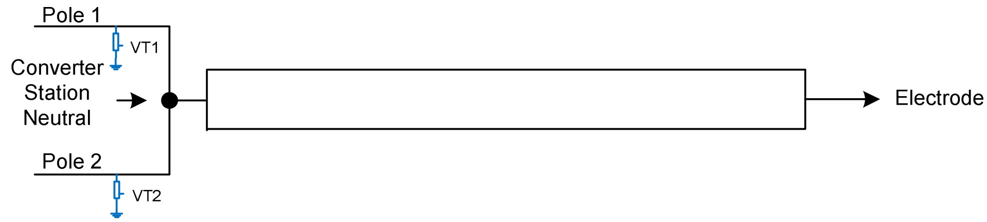


Figure 4-4 - Conceptual Diagram of Neutral Bus Voltage Fault Detection

Pros:

a) This protection is very simple and can reliably detect if both electrode line conductors are open circuited.
b) The equipment needed for voltage measuring would already be installed and thus no new equipment needs to be installed.
c) It does not require communications or equipment at the electrode sites.

Cons:

a) It cannot detect line-to-ground faults.
b) It cannot detect a single open conductor; both conductors would need to be open circuited.

4.5 Pulse-Echo Method (PE)

Two types of pulse echo system have been described in the literature. The pulse-echo method based on time domain reflectometry (TDR) [2] principles has been applied for fault identification and location of faults on at least one electrode line. A more sensitive methodology based on pseudorandom binary sequences (PRBS) [3] rather than a single pulse, has been developed and proposed as an alternative to TDR scheme.

4.5.1 Single Pulse Time-domain Reflectometry (TDR):

Principle of operation:

TDR echo method discriminates faults by detecting changes in the high frequency (HF) characteristics of the electrode line.

As shown in Figure 4-5, a single HF pulse is injected from one end of the line and it travels down the line at the velocity with attenuation as determined by the transmission line propagation characteristics. Part of the pulse energy will be reflected at the electrode or any other impedance discontinuity along the line and will travel back towards the injection point where it can be detected and analyzed.

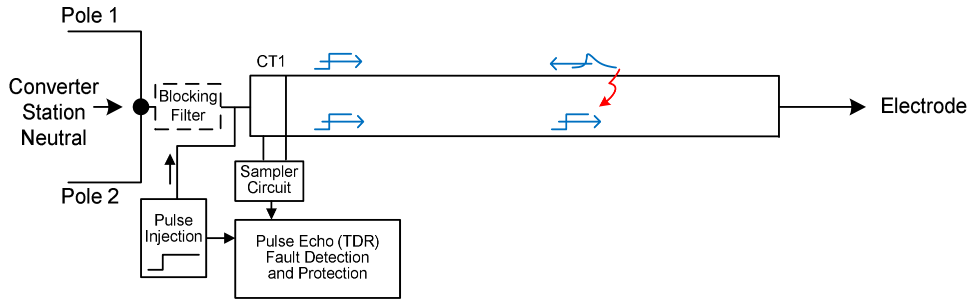


Figure 4-5 - Conceptual Diagram of Pulse Echo Method Using TDR

Both injected and reflected pulses would be recorded and compared. The location of the impedance discontinuity (ground fault, open circuit or dropped conductor) can be estimated based on the time interval between two pulses, while the magnitude, polarity and shape of the reflected pulse will be used to diagnose the nature of the discontinuity, such as an open circuit, short circuit with/without short circuit resistance.

<u>Pros:</u>

a) This method is relatively insensitive to line characteristics.
b) It is cost effective as it only requires the pulse echo equipment and blocking filter equipment to be installed at converter station. No equipment is needed at the electrode site.
c) It can detect both ground faults and open circuit conditions on each conductor of the line.

<u>Cons:</u>

a) As TDR relies on a single pulse echo strategy, the measurement accuracy can be affected by attenuation with fault distance and phase change distortion with frequency as well as resolution error due to noise pickup [3]. This will be more problematic for long lines.

4.5.2 Pseudorandom Binary Sequences (PRBS)

<u>Principle of Operation:</u>

The PRBS pulse echo scheme injects a bipolar coded pulse train (PRBS) as shown in Figure 4-6 rather than a single pulse. Figure 4-6 also shows the spike like attributes of PRBS autocorrelation (ACR) function which would be used as reference to determine the location and characteristics (type) of the fault.

The PRBS will be reflected if there is a line impedance discontinuity/mismatch and a conditioned waveform containing both the input and reflected waveshape components as shown in Figure 4-7 would be captured for analysis.

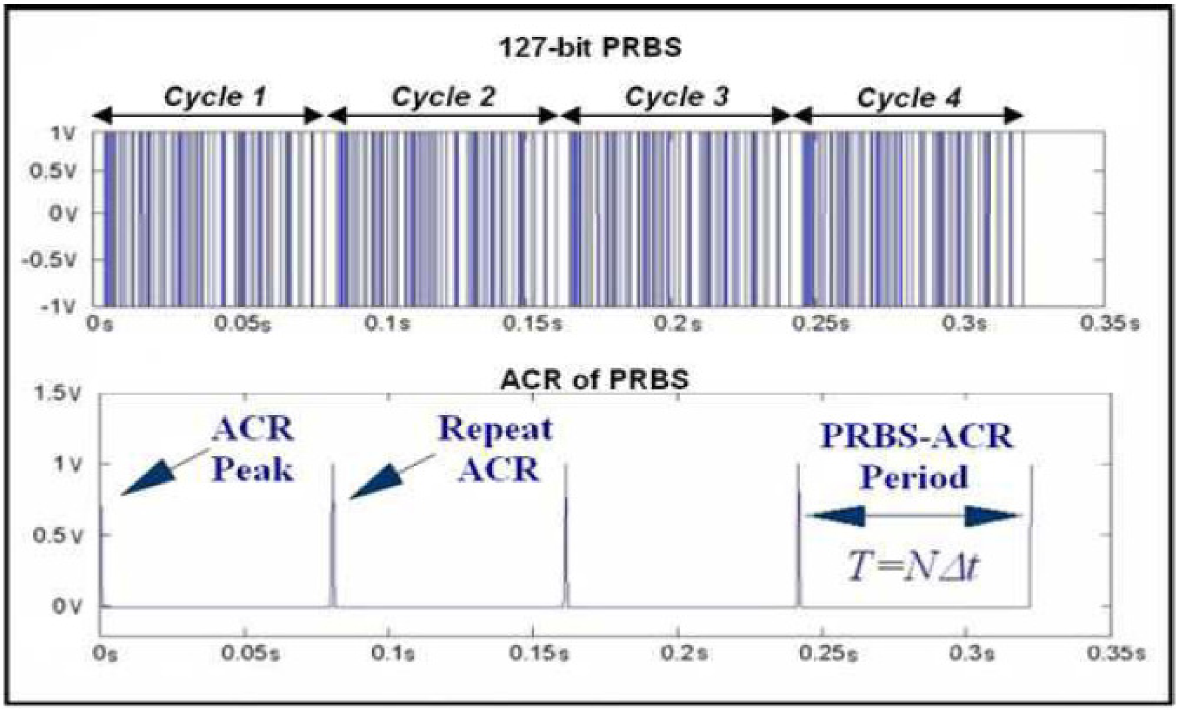


Figure 4-6 - Example of PRBS [3]

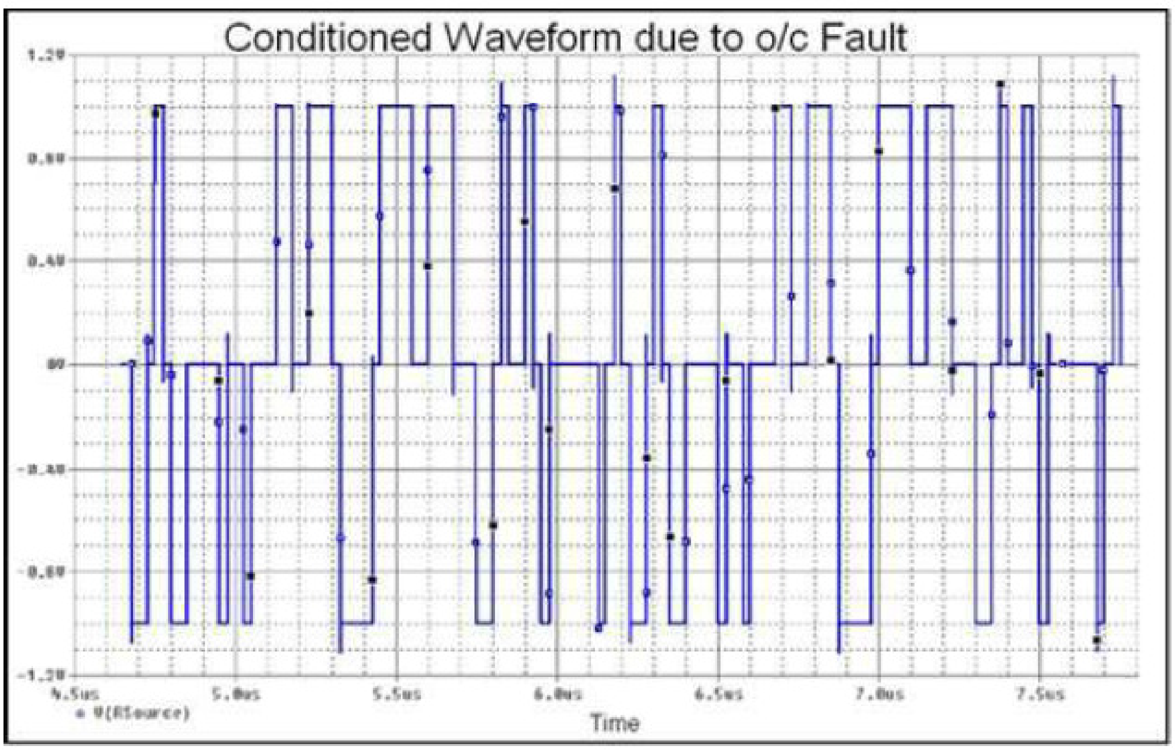


Figure 4-7 - Example of Sampled Conditioned Waveform due to Open Circuit Fault [3]

A sustained pulse echo response, as shown in Figure 4-8, will be obtained when the input PRBS and reflected fault responses are cross-correlated (CCR) as

$$Fccr_{xy}(x) = \frac{1}{L}\sum_{i=1}^{L} x(i)y(i+k)$$

Where:
$L=2^n-1$
x(t)={x(1), x(2), …., x(L)} is PRBS inputs
y(t)= {y(1), y(2), …., y(L) is conditioned echo response due to a fault

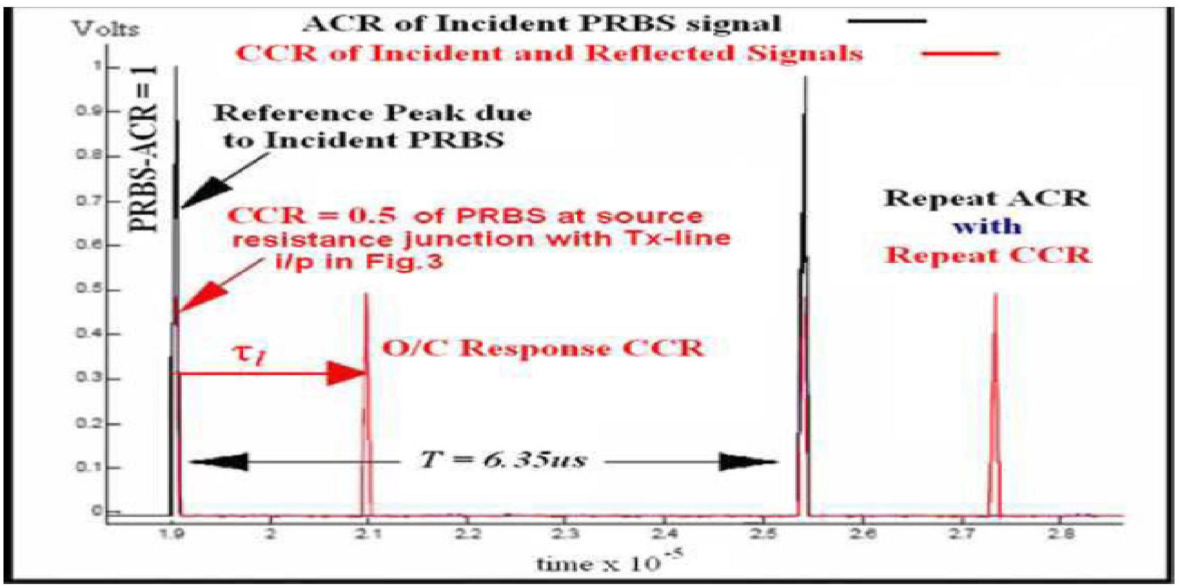


Figure 4-8 Example of Sustained Pulse Echo Response Due to Open Circuit Fault [3]

This sustained pulse echo response contains the characteristic signature of the fault and can be used together with the spike like attribute of PRBS autocorrelation (ACR) function to accurately identify the location and type of fault.

Pros:

a) This method is relatively insensitive to line characteristics and provides sensitive detection of all fault types.
b) It can detect both ground fault and open circuit conditions on each conductor of the line.
c) It is expected to be cost effective as it only requires the pulse echo equipment to be installed at converter station.
d) PRBS method has been validated experimentally to provide more accurate and reliable identification of fault location and type than TDR method as it averages out the noise pickup.

Cons:

a) There is little field experience for this type of protection as there are few if any projects where this method has been applied.
b) As there are few suppliers of this type equipment, and it would be a special design by the supplier.

5. ELECTRODE LINE ARC SUPRESSION

Due to the relatively low insulation level the electrode line has a high probability of flashover from lightning strikes either on or close to the electrode line. In bipolar operation it is unlikely that sufficient dc current would be present to establish and maintain a sustained arc. However in monopolar mode a sustained arc may be established, especially near the converter station where the electrode line voltage would be highest.

Irrespective of the types of electrode line detection and protection schemes that are applied, it is desirable to ensure that dc arcing would self-extinguish once established. It is also essential that arcing be diverted away from the insulators to avoid insulator damage. Therefore, the electrode line insulators of both conductors should be fitted with arcing horns having horizontal gaps which have demonstrated capability to extinguish the maximum expected dc arcing current at the highest dc voltage that would be present on the electrode line.

The self-clearing gaps will generally require some time to clear arcing faults (1-2 seconds) and thus any protective action taken as a result of electrode line fault detection would need to be delayed until it is certain that the fault cannot be cleared by the arcing horns.

In the event the fault cannot be cleared passively by the arcing horns, a number of active fault suppression actions could be taken to try and clear a fault on the assumption that it is an arcing fault:

a) Temporarily close a ground switch at the converter station. This reduces the line voltage to a much lower value and should be sufficient to allow the arcing horns of the line insulators to clear. The ground switch would be reopened within one second and must be specified to have sufficient capability to commutate the current from the station ground back into the electrode line.
b) The converter current could be reduced in magnitude (to zero if necessary) for a brief duration to extinguish the electrode line arc. Following this the converter could be restarted.

If the fault re-establishes after either of the above fault suppression actions it should be taken as an indication that the electrode line is permanently faulted and the converter would be tripped.

Provision could be made in the design of the electrode line to individually isolate each of the electrode line conductors to allow repairs to be made on one conductor while the other conductor remains in service. Live line maintenance procedures would need to be applied during such work.

6. SUMMARY AND RECOMMENDATIONS

Reliable fault detection on electrode lines is a difficult technical problem especially for long electrode lines. A range of fault detection and protection methodologies for electrode line protection and schemes have been briefly discussed in Section 4 and Section 5. A summary of the pros and cons of each method/scheme has been tabulated in Table 8-1.

Based on the advantages/disadvantages and availability of each fault detection and protection method, the following techniques should be applied:

- A protection system based on high frequency impedance measurement (HFLI) or high frequency current differential (HFCD) is recommended to use as ***primary*** fault detection scheme.
- Neutral bus overvoltage protection (NBV) should always be installed as a ***primary protection*** of the neutral bus equipment in the event that both conductors of the electrode become open circuited. It is protective action should be to close a high speed ground switch at the converter station. It would also be necessary to reduce the HVdc converter current or possibly trip the converter.
- Conductor unbalance current (CUC) protection and end-to-end differential (ETED) protections using the HVdc electrode line current should be installed as ***secondary protections***.
- Regardless of the type of protection that is installed an electrode line, the line insulation should be designed to ensure that:
  - any arcing due to flashovers will be diverted away from the insulators, and
  - any arcing will be self-extinguishing even at the maximum monopolar HVdc converter current and the largest electrode line voltage that is likely to occur at 10 minute overload current rating.
- Active fault suppression action consisting of either a high speed ground switch at the converter station or a converter temporary block sequence should be specified for clearing of persistent arcing faults on the electrode line that do not self-extinguish.
- The provision for individually isolating each electrode line conductor should be considered to ensure minimum unavailability of the dc system in the event that only one conductor of the electrode line needs to be maintained.
- Fault detection using pulse echo techniques (either TDR or PRBS) may not be practical on electrode lines of the length being considered on this project due to the expected high attenuation. Further work is needed to establish the practicality of these protection principles for this project.
- It is recommended to use pulse echo method based on TDR as the primary protection scheme for Soldiers Pond electrode line since the scheme has better accuracy and coverage for shorter electrode line.

7. FUTURE WORK

Conceptual methods/schemes for electrode line protection have been identified. This has shown that it may be very difficult to provide a fault detection system that would provide reliable indication of line to ground faults or conductor drop over much of the line depending on the soil resistivity, and practically achievable tower footing resistances.

The primary concern with undetected electrode line faults is the safety of the public and others having access to the transmission line right of way. Undetected faults such as trees falling against the line or dropped conductors where the conductor is not broken are the main concerns. Such faults could pose an electrical hazard or fire risk. If suitably sensitive protections are not available then the risks must be mitigated by other means such as greater emphasis on tree cutting in the right of way and more frequent line patrols to discover dropped conductors.

Further work is needed before the final recommendation of the electrode line fault detection/protection as follows:

a) Calculations should be carried out to establish the extent of the line where line-to-ground faults cannot be reliably detected using conventional detection methods based on measurement of the HVdc electrode line current in monopolar mode. The calculations should include consideration of dc current level, transducer accuracy and tolerances, margins to avoid nuisance operation, conductor resistance variation with temperature, and range of tower footing and fault resistances. This would require determination of practical values of tower footing resistances over the line route. Soil surface resistivity measurements along the line route would be needed.

b) The practicality of high frequency impedance measurement, high frequency current injection, or pulse echo method based on TDR or PRBS should be established for the 400 km line being considered. This will require consultation with suppliers as to the characteristics of available equipment which has already been supplied as well as equipment that they may be developing. Simulation of the electrode line in an electromagnetic transients program to establish the high frequency impedance and attenuation characteristics would be useful to help establish minimum signal levels and detector sensitivity needed for fault detection using these techniques. This information would be useful when discussing the possibility of implementing such systems with HVdc suppliers.

c) Depending on the findings of a) and b) and the degree of concern over undetected faults it may be useful to establish a working relationship with one or more HVdc suppliers for the purpose of developing a more reliable fault detection system for long electrode lines.

8. REFERENCES

[1]. Neutral Line Protection System for HVdc Transmission, IEEE Transaction on Power Delivery, Vol. PWRD-1. No. 3, July 1986.

[2]. Time Domain Reflectometry Theory, Application Note 1304-2

[3]. A Novel Pulse Echo Correlation Tester for Transmission Line Fault Location and Identification using Pseudorandom Binary Sequences

Table 8-1 Summary of Electrode Line Fault Detection and Protection Method/Schemes

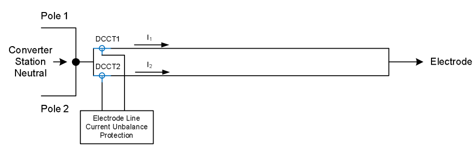
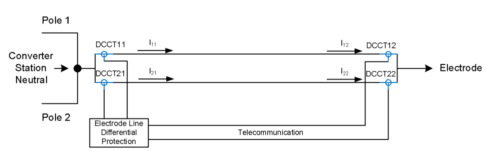
Method/Scheme	Principle	Pros & Cons	Application	Recommendation
Conductor Unbalance Current Fault Detection **(CUC)**	Measure/monitor the current unbalance between the two electrode line conductors. Currents in both conductors would have same magnitudes under no fault conditions, while a difference in current would occur if either of the electrode conductors has a ground fault or open circuit condition. 	***Pros*** • Simple and cheap. • Does not require any equipment at electrode site • Does not require any communications equipment between converter station and electrode station. ***Cons*** • It is doubtful that this type of protection could reliably detect line to ground faults over most of the line either in bipolar or monopolar mode. • May not be able to detect line-to-ground faults on both conductors at the same location or open circuits occurring simultaneously on both conductors. • Useful only as an indication that one of the two conductors has become open circuited. Even this indication would only be possible in monopolar operation.	Has been applied on some systems	Secondary protection
End-to-End Differential Protection **(ETED)**	Measure the current at the both ends of the electrode line. A fault will be indicated if the current difference exceeds a specified current level. As with the conductor unbalance, the sensitivity of this protection is limited by current transducer tolerances, high tower footing resistances and the need to provide margins against nuisance tripping. 	***Pros*** Reliably detect open circuited conductors in monopolar mode. ***Cons*** • More expensive than conductor unbalance current fault detection. • Requires installation of equipment at the electrode site and the installation of communications between the electrode sites and the converter station • Does not provide reliable detection of conductor ground faults during bipolar operation and may not detect line-to-ground faults on large portions of the line even in monopolar operation.	Has been applied on some systems	Secondary protection

Table 8-1 Summary of Electrode Line Fault Detection and Protection Method/Schemes

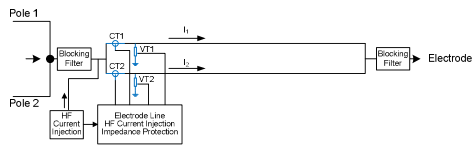
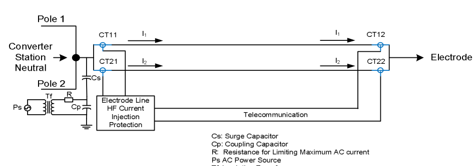
Method/Scheme	Principle	Pros & Cons	Application	Recommendation
High Frequency Line Impedance Measuring Method **(HFLI)**	A high frequency (about 1 kHz) signal is injected into electrode line and the voltage and current are monitored to determine the impedance. The calculated impedance will be used to discriminate if there is a fault on the line.  	***Pros*** • Operation and sensitivity do not depend on HVdc electrode current or operation mode • The protection covers the full line • End to end communication between the converter station and electrode is not required ***Cons*** • Requires a blocking filter at each end of the electrode line. As the blocking equipment must be rated to carry the maximum HVdc monopolar current, it is relatively expensive and would also increase overall HVdc transmission losses in monopolar operation. • There are very few suppliers of the impedance measuring equipment at the high frequency (about 1 kHz) and it tends to be of laboratory quality rather than relay system quality and reliability. • The signal levels injected on the line are generally low and thus system may not reliably detect high impedance ground faults.	Has been installed on at least one HVdc transmission system but generally only for monitoring not protection	Primary protection
High Frequency Current Differential System **(HFCD)**	A high frequency (Hundred to thousand Hz) signal is injected into electrode line and current is monitored at both injecting point and receiving end. The difference in current in the two line conductors measured at receiving end (electrode end) is used to detect the fault along the electrode line except close to receiving end which will be picked up by the injecting end (converter end) current change.  	***Pros*** • Should be able detect a fault on the electrode line during both monopolar and bipolar operation. • Possible to detect faults on the whole line if the signal level is large enough ***Cons*** • Requires end-to-end communications between the converter station and electrode station • Requires more power to inject the high frequency current signal than the impedance measuring system. • It may not be possible to inject sufficient current into a long electrode line for reliable operation. A significant signal	Has been used as neutral line protection system for Hokkaido-Honshu HVdc Link (124kV OH and 44km cable) in Japan with satisfactory performance [1].	Primary protection

Table 8-1 Summary of Electrode Line Fault Detection and Protection Method/Schemes

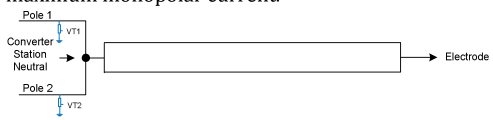
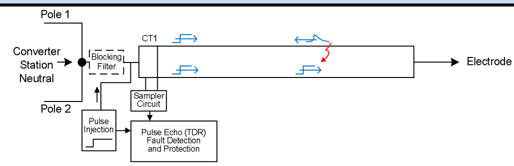
Method/Scheme	Principle	Pros & Cons	Application	Recommendation
		level would be required for long electrode lines taking into account the tolerances of the measuring transducers, normal conductor unbalance and margins against nuisance tripping		
Neutral Bus Voltage Measurement **(NBV)**	Measure neutral bus voltage on each pole. If electrode line conductor is opened circuited, a high neutral bus voltage would be measured. The setting needs to be higher than the maximum voltage drop in the electrode line at maximum monopolar current.  	***Pros*** • Very simple and can reliably detect if both electrode line conductors are open circuited. • The equipment needed for voltage measuring would already be installed and thus no new equipment needs to be installed. • Does not require communications or equipment at the electrode sites. ***Cons*** • Cannot detect line-to-ground faults. • Cannot detect a single open conductor.	Universally used	Primary protection
Pulse Echo using Single Pulse Time-domain Reflectometry **(PE-TDR)**	TDR echo method injects a single HF pulse from one end of the line and the injected pulse travels down the line at the velocity with attenuation as determined by the transmission line propagation characteristics. Part of the pulse energy will be reflected at the electrode or any other impedance discontinuity along the line and will travel back towards the injection point where it can be detected and analyzed. Injected and reflected pulses would be recorded and compared. The location of the impedance discontinuity (ground fault, open circuit or dropped conductor) can be estimated based on the time interval between two pulses, while the magnitude, polarity and shape of the reflected pulse will be used to diagnose the nature of the discontinuity.	***Pros*** • Relatively insensitive to line characteristics. • Cost effective as it only requires the pulse echo equipment and blocking filter equipment to be installed at converter station. No equipment is needed at the electrode site. • Can detect both ground faults and open circuit conditions on the each conductor of the line. ***Cons*** • As TDR relies on a single pulse echo strategy, the measurement accuracy can be affected by attenuation with fault distance and phase change distortion with frequency as well as resolution error due to noise pickup [3]. This will be more problematic for long lines.	Developed by Siemens and has been used in HVdc links in China. It has not been used for protection of very long electrode lines.	Suppliers should be consulted to establish whether it is practical to apply this type of protection on electrode lines of the length proposed on this project. Any limitations should be identified. If it is practical it could be applied as a primary fault detection system.

Table 8-1 Summary of Electrode Line Fault Detection and Protection Method/Schemes

Method/Scheme	Principle	Pros & Cons	Application	Recommendation
				
Pulse Echo using Pseudorandom Binary Sequences **(PE-PRBS)**	The PRBS pulse echo scheme injects a bipolar coded pulse train (PRBS) rather than a single pulse. The PRBS will be reflected if there is a line impedance discontinuity/mismatch and a conditioned waveform containing both the input and reflected waveshape components would be captured for analysis. A sustained pulse echo response containing the characteristic signature of the fault will be obtained when the input PRBS and reflected fault responses are cross-correlated (CCR).	***Pros*** • Relatively insensitive to line characteristics and provides sensitive detection all fault types. • Can detect both ground fault and open circuit conditions on the each conductor of the line. • Cost effective as it only requires the pulse echo equipment to be installed at converter station. • PRBS method has been validated experimentally to provide more accurate and reliable identification of fault location and type than TDR method as it averages out the noise pickup. ***Cons*** • No known experience for this type of protection • As there are few suppliers of this type equipment, and it would be a special design by the supplier.	It has been tested and proven in the lab to be an effective method for transmission line fault detection. Further work would be needed to establish if the method can be applied for protection of actual electrode lines.	Suppliers should be consulted to establish whether this fault detection principle is practical on actual electrode lines and, if so, whether it is possible to apply this type of protection on electrode lines of the length proposed on this project.

Appendix A
Electrode Line Information

Labrador - Metallic Return

```
DATE : 11-24-2008

PROBLEM TITLE        :       LAB_META
CABLE DESIGNATION    :       800-A2#S3A-84#7
TITLE FOR SAG TABLE :

CABLE DATA :
-----------
           DIA                  (MM) =  41.1
           AREA                (MM2) =  997.5
           MASS               (KG/M) =  3.142
           TEMPERATURE COEFF   (C) =  .0000216
           RTS                  (KN) =  383.6
           EVERY DAY TEMP.     (C) =  20

NUMBER OF LINEAR SEGMENTS FOR INITIAL MODULUS =   2

           MODULUS  (GPA)      LIMIT STRESS  (MPA)
      1        48.50              77.00
      2        32.00             200.00

FINAL AND CREEP MODULUS (GPA) :  62.5      35


NUMBER OF CONSTRAINING LOADS =   5

           ICE(MM)  R.DEN  VENT(KPA)  TEMP(C)  %LIMIT  SAG TYPE
                                                  1=INIT & 2=FINAL

      1       0.0    0.00    0.00       -5.0    23.40    1
      2      74.0    0.90    0.21       -5.0    75.00    2
      3     147.0    0.50    0.00       -5.0    75.00    2
      4     147.0    0.50    0.21       -5.0    75.00    2
      5       0.0    0.00    4.07      -10.0    75.00    2

TEMPERATURE RANGE (C) :   MIN. =-30    MAX. = 80    RATE OF CHANGE = 10


NUMBER OF RULING SPANS =  1
RULING SPANS (M) :
   300.00
```

Appendix B
Preliminary HVdc Facility Locations

nalcor energy	Labrador - Island Transmission Link: Project Overview

Figure B-1 Location plan of the proposed Gull Island and Soldiers Pond stations and Shoreline Electrodes

Appendix G

Suggested Modeling Scenarios

Gull Island

(AMEC)

Revised

Strait of Belle Isle

Ground Potential Simulation

Modelling Scenarios

Hugh G. Miller, P.Geo.

September, 2010

Objective : To develop scenarios incorporating the resistivity structure of the geology to enable simulation of the Ground Potential readings (GPR) which occur at sites along the Strait of Belle Isle from currents injected into electrodes located at various possible sites along the Strait.

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

Input Data

Geology

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

- **Surficial sediments**. The surficial sediments consist, in the Strait of Belle Isle area on land and beneath the Strait, of spatially limited deposits of glaciofluvial and marine sediments restricted to the major valleys on land and the major seabed depressions beneath the waters of the Strait and very thin, poor till, deposits on the higher ground, both on land and subsea. The actual thickness varies from place to place. The surficial cover on the Labrador coast is so thin in the case of the poor till unit and very limited in area, and hence in effect, in the case of the glacio-marine unit that these units can be omitted in modelling. Similarly, on the Newfoundland side of the Strait the surficial cover is poor. Similar conditions are found beneath the water of the Strait. Thus the surficial sediments can be, and have been, omitted in modelling.
- **Bedrock sediments**. The bedrock sediments in the area under consideration consist of Late Precambrian sandstone and limestone on the Labrador Coast and a carbonate platform along with the Dunnage ophiolite suite on the Northern Peninsula of the Island of Newfoundland. Underlying the Strait of Belle Isle are the Precambrian limestones and sandstones which are in turn overlain by the Carbonate rocks.
- **Bedrock Basement**. Throughout the rest the area of interest on the Labrador side of the strait are Granitoid rocks which underlie the sandstone and sediments and are exposed extensively elsewhere. On the Newfoundland side of the Strait,

similar granitoid rocks provide the basement to the Carbonates and the Dunnage rocks. Similar granitoid rocks underlie the sediments in the Strait of Belle Isle.

Electrical resistivity

There is very little information on the electrical resistivity of the geological units in the Strait of Belle Isle area. Magnetotelluric (MT) investigations in Labrador have been confined to deep investigations (Kurtz and Garland, 1976) conducted along the Quebec North Shore distant from the present study area. This 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 provides evidence that the resistivities are most likely > 10 000 ohm-m to depths of the order of 50 km.

Shallower audio-magnetotelluric (AMT) work has been conducted as part of exploration programs in Central and Northern Labrador (NL Natural Resources Exploration files). 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 <1000 ohm-m, but the size of these zones 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 Labrador data suggest it is appropriate to use larger resistivities.

The Statnet study used resitivities of 50 ohm-m for the limestone on the coast of Labrador, 20 ohm-m for the sandstone, 3000 ohm-m for the basement rocks and 0.25 ohm-m for the seawater. These rock resitivities seem to be derived from petroleum geology based references, and are considered to be very low for the age and tightly cemented nature of both the carbonates and sandstone in the area. Similarly, the basement resistivity of 3000 ohm-m is considered low for Labrador and for the island.

Using the rock property data presented in Woodworth-Lynas et al. (1992) for two relatively deep drill holes on either side of the Strait of Belle Isle, an estimate can be made of the porosity of the various units and from this using the standard Archies Law relating porosity and the resistivity of the pore fluids to the bulk rock resistivity, a resistivity estimate can be calculated for five samples in the consolidated sediments of the Hawke Bay, Bradore and Forteau formations. The results are highly variable, ranging from approximately 40 ohm-m to in excess of 1600 ohm-m. Furthermore, these results are highly dependent on the nature of the small samples from which they were derived, so they are used only to suggest the range of resitivities possible in these rocks. The lower values are consistent with those used by Statnet and the higher ones are consistent with those expected for rocks of this age and compaction.

The McNeice (1998) thesis reports that resistivities for the crustal rocks on the Island of Newfoundland varied in the 1000 ohm-m to 5000 ohm-m range, especially for Dunnage rocks of central Newfoundland.

Accordingly, for modelling, the following resistivities are recommended:

- Labrador Sediments 300 -1000 ohm-m
- Northern Newfoundland Carbonates 300 -1000 ohm-m
- Dunnage Zone rocks in northern Newfoundland 2000 - 5000 ohm-m
- Sediments above basement in Strait of Belle Isle 300 -1000 ohm-m.
- Basement Granitoid rocks throughout the area 5000-10000 ohm-m

A separate analysis of the resistivity of the seawater in the Strait of Belle Isle was undertaken by an AMEC oceanographer. This report is as follows:

Estimates of resistivity in Strait of Belle Isle

1. Circulation and Hydrology in the Strait of Belle Isle

The Strait of Belle Isle connects the northern part of the Gulf of St. Lawrence to the Labrador shelf and northern Newfoundland shelf. As a result, both tidal (astronomical forcing) and low frequency circulation (driven by large scale density gradients between various water masses and large scale atmospheric processes) in the Strait of Belle Isle are largely controlled at the western end by flows in the Gulf and at the eastern end by the presence of the Labrador current that flows south on the Labrador and Newfoundland shelf.

1. Tidal currents

Tidal analysis performed on current records from the Strait of Belle Isle that are available from DFO reveals the following characteristics:

- Tides are dominated by the semi-diurnal constituents which represent roughly slightly less than 2/3 of the energy, while the diurnal constituents are slightly less than 1/3 of the energy. The remaining energy being distributed among other constituents each with a very small portion of the energy.
- Tidal ellipses are very elongated along the Strait which means that tidal currents are mainly along the Strait with very small excursion across the Strait.
- Maximal tidal currents vary from 1.3 m/s to 2 m/s near the surface and in the top 20 m and from 1.2 m/s to 1.7 m/s around 50 m and deeper.

As a result, relatively strong tidal currents along the Strait alternate into and out from the Gulf of St. Lawrence, changing direction about every 6 ½ hours, with only very short periods of time of weak cross Strait currents in between ("slack waters")

2. General circulation

Two main processes influence the mean or low frequency currents in the Strait.

The first one is the Labrador Current that flows southward from Davis Strait and Hudson Strait along the Labrador coast over the shelf and upper slope. The Labrador Current is the continuation of the West Greenland current with the addition of cold and fresh water outflows through Davis Strait and Hudson Strait that result from spring and summer river runoff and sea ice melt in Baffin Bay and the Arctic Archipelago. However, it is the additional sea ice melt that takes place on the Labrador shelf that affects the most the properties (salinity and temperature) of the Labrador Current when it reaches the area to the east of the Strait of Belle Isle. Although there is no information on the flow rate of Pinware River (A substantial effort was spent looking for information on flow rates of rivers on the Labrador side of the Strait to no avail. Environment Canada was contacted and confirmed that Pinware River was never gauged), it is expected to have an insignificant overall effect on the properties of the water in the Strait because 1) the length of the Strait and associated drainage basin is small compared to those that precede it on the course of the Labrador Current (West Greenland, Baffin Island, Labrador so that the fresh water input in the Strait is extremely small compared to that taking place along Greenland/Baffin

Island/Labrador combined with sea ice melt on the Greenland and Labrador shelves, Baffin bay and the Arctic Archipelago; 2) the fresh water at the mouth of Pinware river (or smaller streams along the strait) would be quickly mixed and entrained into the large volumes of Strait water moved back and forth along the Strait by the strong tidal currents. As a result, the signature of the Pinware River fresh water inflow is under most conditions expected to be, not only very localized at the mouth of the River right at the coast, but also result in salinity and temperature anomalies of very small amplitude.

The maximum flow of the Labrador Current in the region of the Strait of Belle Isle occurs late summer and early fall, the minimum in early spring. A portion of the Labrador Currents branches off to the west and enters the Strait between Belle Isle and the Newfoundland Coast. This results in an inflow of relatively cold and fresh water into the Gulf of St. Lawrence along the Labrador side of the Strait of Belle Isle. The strength of this inflow varies seasonally, reflecting the river runoff and sea ice melt cycle. Even at its peak, the currents associated with this portion of the Labrador Current flowing in the Strait are an order of magnitude weaker than tidal currents.

The second processes that results in low frequency currents in the Strait are slowly varying large scale atmospheric pressure gradients and associated persistent winds (on a time scale of a few days to a few weeks). These can result in relatively strong flows in the Strait of Belle Isle either into or out of the Gulf of St. Lawrence. Current records from the DFO database shows several instances at various depths when such currents from the southwest occurred that were strong enough to over compensate tidal currents when in the opposite directions. During such events, the total flow remained from the southwest over several days, with minimal strength when tidal currents opposed the atmospheric driven current and peaks of the order of 2.5 m/s when tidal currents were also out of the Gulf.

3. Combined currents

Because of the overall predominance of the tidal currents over the Labrador Current contribution flowing into the Gulf along the Labrador side of the Strait, currents are expected to be alternating into and outside of the Gulf every 6 ½ hours with speeds between about 1 m/s to 2 m/s, except for some periods of time of a few days when currents forced by atmospheric processes are strong enough for the combined flow to remain in one direction. During these periods peak current speeds of about 2.5m/s can be expected when both atmospheric driven and tidal currents are in the same direction.

4. Hydrology

Profiles from the DFO data base indicate fairly well vertically mixed conditions in the winter and some stratification in the summer. They also indicate some slight differences in the surface layer between the Labrador and Newfoundland sides in late summer early fall. These reflect the presence of a portion of the Labrador Current flowing into the Gulf along the Labrador side with lower salinities and temperatures than on the Newfoundland side. These differences (of up to about 0.4PSU and 1.5℃) are of significance only in the determination of relatively weak mean flows in and out of the Gulf on either side of the Strait that play an important role in the heat, salt and fresh water budget of the Gulf , but lead to very small resistivity differences.

In winter temperature is about -1.8℃ and salinity 32.5 PSU. In summer, the Strait can be approximated by a 2 layer system with a surface layer about 30 m thick. In the surface layer, average temperature is about 7℃ and the salinity 31 PSU. In the bottom layer, the average temperature is about 3℃ and the salinity 32 PSU.

2. Resistivities

Based on the salinities and temperatures above, resistivities can be estimated:

Winter:		0.39 Ohm x m
Summer:	Top 30m:	0.32 Ohm x m
	Bottom layer	0.35 Ohm x m

The slight differences in salinity and temperature in the late summer/early fall for the surface layer between the Labrador and Newfoundland sides result in a difference of only 0.01-0.02 Ohm x m (resistivity of 0.33 Ohm x m on Labrador side (over 2/3 of total width of the Strait) and 0.31 Ohm x m on the Newfoundland side (over 1/3 of total width of the Strait).

As explained in Section 1, the anomaly at the mouth of Pinware River is expected to be much localized along the coast and very small in amplitude: based on minimum expected turbulent mixing with Labrador Current due to the strong tidal currents along the coast, the resistivity is expected to be at most 0.5 Ohm x m at the mouth of the river and rapidly decrease to 0.32 Ohm x m over a distance of a few hundreds of meters.

Summary for Modelling

Based on this analysis, the seawater of the Strait of Belle Isle has been assigned a resistivity of 0.39 ohm-m for its entire depth in the modelling scenarios presented below. This is the maximum value for the resistivity found in the deeper water during the winter. Use of this value will produce the most conservative estimate of the calculated Ground Potential Rise (GPR).

Tidal Variation

The tidal variation along the Strait of Belle Isle coast is very limited in its range. The highest tidal range is associated with the Spring and Neap tides. Based on the 2010 Canadian Hydrographic Tides tables for St. Anthony, the Spring tide has the greatest range and occurred on April 1 and 2. Examination of the tidal range ie the height of water difference between lowest, low water and highest, high water for West St. Modeste, Forteau, and Red Bay which are the three sites closest to the investigated proposed Electrode Sites, shows this range is less than 1.5 m. For the rest of the year the range is less than this. This means that the maximum variation in water depth due to simple tides, unaffected by severe wind conditions, is of the order of 0.8m above or below Mean Sea Level. As long as the tops of the electrodes are more than 0.8m below MSL (1.5 m below Highest High Water), they should remain covered by water under normal water conditions unaffected by wind-driven surges.

Seasonal Variations – Other variables

The Strait of Belle Isle experiences considerable seasonal variation in sea ice conditions, shore ice freezing and iceberg movements. In the coves and embayments the seawater can freeze to a thickness of approximately 1 -1.5 m and be fastened to the shore. Sea ice can be driven into coves by prevailing winds and tides. The recommended electrode sites have been chosen to minimize the impact of moving ice, however there may be some rafting of local ice broken up by winds and tides.

The recommended electrode sites have been chosen such that no iceberg incursion is expected. As noted in the site visit pictures, small pieces of ice broken from foundering, nearby, icebergs can be driven into the coves by wind and tide action. The breakwater emplaced at the mouth of the cove to protect the electrodes will mitigate against any impact these bergy bits could have on the electrodes.

Recommended Model Scenarios

Two scenarios were developed in accordance with NALCOR's request, a Most Likely Case and a Worst Case, or Least Likely Case. The second case, the Worst Case, is based on extreme assumptions for both resistivity and thickness while the values for the Most Likely Case are based on average values, assumed based on textbook data and experience where no specific data are available. The recommended model parameters, incorporating all the points raised above, are summarized in the following table for each of the Most Likely and Worst Case scenarios:

Strait of Belle Isle
GPR Modelling Scenarios 2010

Unit		Most Likely	Worst Case
Labrador sediments	Thickness (m)	150 m	50 m
	Resistivity (ohm-m)	1000 ohm-m	300 ohm-m
Labrador Basement	Thickness (m)	Infinite	infinite
	Resistivity (ohm-m)	5000 ohm-m	10000 ohm-m
SOBI Water	Thickness (m)	Per bathymetry data	Per bathymetry data
	Resistivity (ohm-m)	0.39 ohm-m	0.39 ohm-m
SOBI Sediments	Thickness (m)	300 m	500 m
	Resistivity (ohm-m)	300 ohm-m	1000 ohm-m
SOBI Basement	Thickness (m)	Infinite	infinite
	Resistivity (ohm-m)	5000 ohm-m	10000 ohm-m
NL Carbonates	Thickness (m)	500 m	1000 m
	Resistivity (ohm-m)	300 ohm-m	1000 ohm-m
NL Dunnage	Thickness (m)	2000 m	5000 m
	Resistivity (ohm-m)	2000 ohm-m	5000 ohm-m

NL Basement	Thickness (m)	Infinite	infinite
	Resistivity (ohm-m)	5000 ohm-m	10000 ohm-m

The Model Polygons

The spatial extents of the various units have been extracted from a 1:1,000,000 provincial digital geology file using a point interval of 100m and presented as a series of polygons for each feature. The data are presented as point ID #, X coordinate, Y coordinate. 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 21 Datum NAD 83. All files except the Dunnage file contain a single polygon. The Dunnage file contains the four polygons needed to depict that area. For ease in modelling, these Dunnage polygons could be combined into a single polygon if deemed necessary

The thickness of each unit is provided in the modelling scenario table presented above, except for the Strait of Belle and adjoining area water file for which the digital bathymetric data should be used.

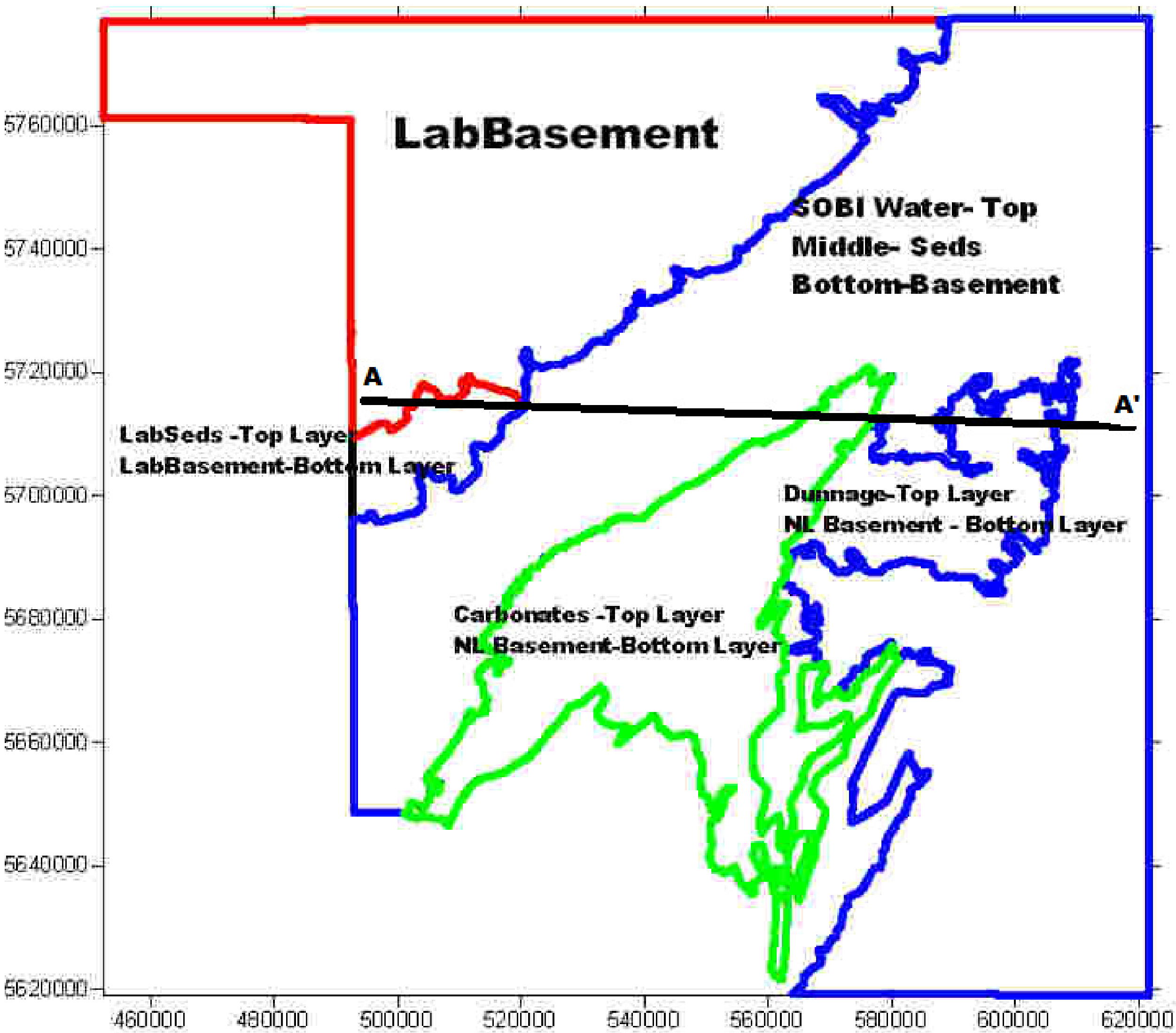
The files are:

- Labrador Sediments file contains the single polygon for the sandstone/limestone sediments found on the coast of Labrador.
- Labrador Basement file for the granitoids on land in Labrador. The limits of this polygon include the limits of the Labrador Sediments polygon, so the Labrador sediments must lie on top of this polygon in modelling.
- Strait of Belle Isle water for the seawater of the Strait and adjoining Atlantic Ocean out to the area of Belle Isle and south to the southern limit of the Dunnage rocks on land in the Northern Peninsula area.
- Strait of Belle Isle sediments which are the sediments similar to the Labrador Sediments and the Carbonates which underlie the seabed and sit atop the basement beneath the Strait of Belle Isle. The limits of this polygon are the same as the limits of the Strait of Belle Isle seawater polygon.
- Strait of Belle Isle Basement consists of the granitoid rocks beneath the Strait of Belle Isle sediments. The limits of this polygon are the same as the limits of the Strait of Belle Isle seawater polygon.
- Carbonates for the Carbonate rocks found on the southern, Newfoundland, side of the Strait.

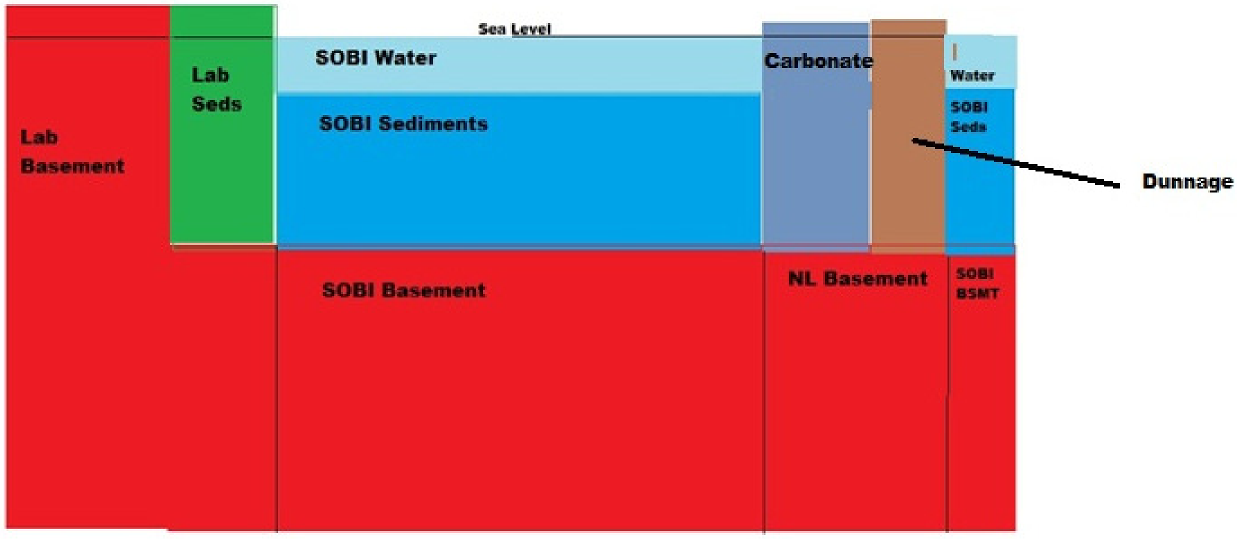
- Dunnage Rocks for the Dunnage ophiolite sequence of northern Newfoundland. This file contains four polygons.
- NL Basement for the basement rocks underlying the Carbonate and Dunnage rocks on the Island of Newfoundland near the Strait of Belle Isle. The limits of this polygon encompass the limits of the Carbonates and Dunnage polygons.

  The file format for the spatial extent files is as follows
  - Unit Name
  - Point ID #, Xcoord(Easting), Y coord(Northing)- coordinates in meters
  - Polygon # 1
  - Point #, x-coordinate, y-coordinates of point 1
  - Coordinates of remaining points
  - Coordinates of last point is same as first to close polygon
  - Polygon #2 (if necessary)
  - Point #, x-coordinate, y-coordinates of point 1
  - Coordinates of remaining points
  - Coordinates of last point is same as first to close polygon
  - Repeat for each polygon in file

The spatial relationship of the various polygons is illustrated in the following two diagrams.



The relationship and vertical disposition of the various units is illustrated below for the cross- section along line A-A' (note this is not to scale either vertically or horizontally):



Notes:

- The two modelling scenarios to be simulated have been developed to represent the Most Likely case based on analysis of all the data available and a Worst Case scenario using limiting values for the various parameters. The difference in the output from these two scenarios should present the range in which the GPRs will lie.
- No file has been developed for the electrode locations. These can be chosen and input based on the separate Site Assessment being undertaken. If the results are simulated for these two scenarios for the electrode location closest to the cable crossing site, these results should represent the maximum GPRs to be experienced at the cable crossing location. So it may not be necessary to undertake the simulation for additional electrode locations.
- The maximum depth to which the models are extended using the underlying granitoid resistivities should be 50 km, consistent with the geological knowledge for the area.

Appendix H

Suggested Modeling Scenarios

Soldiers Pond

(AMEC)

REVISED

Dowden's Point Electrode

Ground Potential Simulation

Suggested Models

Hugh G. Miller, P.Geo.

September, 2010

Original Objective in 2009: 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 electrodes located at the Dowden's Point location.

Objective in 2010: To undertake a literature review on the sea water resistivity and to review published bathymetric/oceanographic data to refine the model of the bodies of sea water. Also the impact of seasonal variations and tide will be considered to develop the worst case model.

Required input: A model of the crustal electrical structure based on the known geology and water bodies and the expected electrical resistivities of these bodies.

Input Data- Based on the geology and water bodies within a circle of 3.5 km radius centered on the proposed electrode location. This radius was 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 collected from three separate test pits excavated as part of the field work conducted at Dowden's Point in September 2009. 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^3K)	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 Cove 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.
- There are four water bodies, the ocean of Conception Bay which is salt water, Lance Cove Pond, Seal Cove Pond, and Indian Cove Pond.

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 sediments 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 for 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 (1998). 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.

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 has been 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
  - 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.
  - The Poor Drift Till and the Till Undifferentiated.
  - 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. In the 2009 simulation scenario development, a resistivity was assigned to seawater using the value given in the standard Applied Geophysics (Telford et al, 1976, rev 1990) textbook. This value was 0.2 ohm-m. In 2010, the sea water and pond resistivities have been developed in consultation with oceanographers in AMEC who have reviewed literature and databases pertaining to the oceanographic conditions in Conception Bay as follows:

Estimates of resistivity in Conception Bay and adjacent ponds

1. Conception Bay

Based on climatology from DFO databases for Conception Bay area and hydrographic sections by MUN ("The circulation and hydrography of Conception Bay, Newfoundland" Brad deYoung and Brian Anderson in Atmospheric-Ocean 33 (1) 1995, 135-162) it is possible to represent schematically Conception Bay as a 2 layer basin with average depth of about 200m. The top layer is about 50m thick.

Based on temperature and salinity in each layer for winter and summer conditions:

- Winter: - top layer resistivity: 0.37 Ohm x m
  - bottom layer resistivity: 0.38 Ohm x m
- Summer: - top layer resistivity: 0.29 Ohm x m
  - bottom layer resistivity: 0.37 Ohm x m

2. Lance Cove Pond

Lance Cove Pond is separated from Conception Bay by a narrow beach. It is replenished only by land runoff, without any significant stream feeding it. Lance Cove Pond is not connected to Conception Bay and is not tidal. It is essentially a fresh water pond but for small amount of sea water that may enter the Pond episodically during storms as sea spray and possibly waves overtopping the beach.

Water in Lance Cove Pond is expected to have very different physical properties (salinity, temperature and therefore resistivity) from Conception Bay. As a shallow enclosed pond with significant inflow, we can assume water temperature close to 0℃ in the winter and possibly up to 20℃ in the summer.

At low salinity levels, small salinity variations result in large resistivity variations.

Assuming that Lance Cove Pond has an average salinity of a few PSU, its resistivity would be in the range of:

- 2 Ohm x m to 10 Ohm x m in winter
- 1 Ohm x m to 6 Ohm x m in summer.

To the extreme limit of a purely fresh water pond, resistivity would be as high as

- 700 Ohm x m in winter
- 6000 Ohm x m in summer

3. Seal Cove Pond

Seal Cove Pond is a small tidal inlet fed by Seal Cove Brook and the spillway of a small hydro power station. It is about 700 m long, with an average width of about 100m. It widens towards Conception Bay but is connected to the Bay by a narrow channel under the highway bridge.

When the hydro power plant is operating, the spillway is expected to be the largest fresh water inflow and, based on flow rates of such small hydro power plant (typically a few m^3/s) quite a significant inflow to the relatively small inlet.

Due to the relatively small tidal amplitude in Conception Bay (about 1m), the size and geometry of Seal Cove Pond, and the large fresh water inflow from the spillway, the estuarine Richardson number would be in a range indicating a stratified inlet. However the flow rate of the spillway could be high enough to be the main source of kinetic energy and vertical shear in Seal Cove Pond instead of tidal currents, so that significant vertical mixing may occur, not only as expected at the head of the pond and at the mouth under the highway bridge, but all along the pond.

When the hydro power plant is not operating much less fresh water inflow is expected. The estuarine Richardson number estimated range still indicate a stratified inlet but it is possible that enough vertical mixing occurs under the highway bridge due to increased current speed to result in an overall partially or well mixed inlet.

If mixed conditions prevail, Seal Cove Pond could be represented as a relatively homogeneous body of water with reduced salinity compared to Conception Bay. Reduction in salinity would bring resistivity values in the range of:

- 0.7 Ohm x m in winter
- 0.4 Ohm x m in summer

If stratified conditions prevail, Seal Cove could be represented as a 2 layers inlet with a bottom layer of Conception Bay water and a fresher surface layer a few meters thick. The surface layer would be most different from Conception Bay water when maximum fresh water inflow from hydro power plant spillway occurs. Corresponding resistivity would be:

- Winter: - resistivity in top 5 m : 1.5 Ohm x m
  - resistivity in bottom layer: 0.37 Ohm x m

- Summer: - resistivity in top 5 m : 1 Ohm x m
  - resistivity in bottom layer: 0.29 Ohm x m

4. Indian Pond

Indian pond is a tidal inlet fed by a small fresh water brook. The nearby oil fired power station which operates from September until June has its water intake in Indian Pond with a flow rate relatively large for the size of the pond, which may increase circulation and enhance mixing.

If mixed conditions prevail, Indian Pond could be represented as a relatively homogeneous body of water with slightly reduced salinity compared to Conception Bay. Reduction in salinity would bring resistivity values in the range of:

- 0.4 Ohm x m in winter
- 0.3 Ohm x m in summer

If stratified conditions prevail, Indian Cove could be represented as a 2 layers inlet with a bottom layer of Conception Bay water and a fresher surface layer a few meters thick. Corresponding resistivity would be:

- Winter: - resistivity in top 2 m : 1 Ohm x m
  - resistivity in bottom layer: 0.37 Ohm x m
- Summer: - resistivity in top 2 m : 0.7 Ohm x m
  - resistivity in bottom layer: 0.29 Ohm x m

Summary for Modelling

Based on this analysis, the average resistivity of the sea water in Conception Bay is 0.33 ohm-m, with a variation from this average from summer to winter of approximately 20%. In order to provide the most conservative estimate of the GPR's, the seawater has been assigned a resistivity of 0.38 ohm-m in the modeling scenarios developed.

The resistivities for the ponds are more variable. Values consistent with the mean value of the summer and winter values for a single layer condition have been proposed for the modeling. These ponds are have very limited spatial extent, so their major effect is expected to be a perturbation of the GPR contours.

Tidal Variation

The tidal variation in Newfoundland is very limited in its range. The highest tidal range is associated with the Spring and Neap tides. Based on the 2010 Canadian Hydrographic Tides tables for St. John's in 2010 the Spring tide has the greatest range and occurred on April 1 and 2. Examination of the tidal range ie the height of water difference between lowest, low water and highest, high water for Bell Island, Holyrood and Long Pond which are the three sites closest to the proposed Electrode Site, shows this range is less than 1.5 m. For the rest of the year the range is less than this. This means that the maximum variation in water depth due to simple tides, unaffected by severe wind conditions, is of the order of 0.8m above or below Mean Sea Level. So as long as the top of the electrodes are more than 0.8m below MSL, they should remain covered by water under normal water conditions unaffected by wind-driven surges.

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.

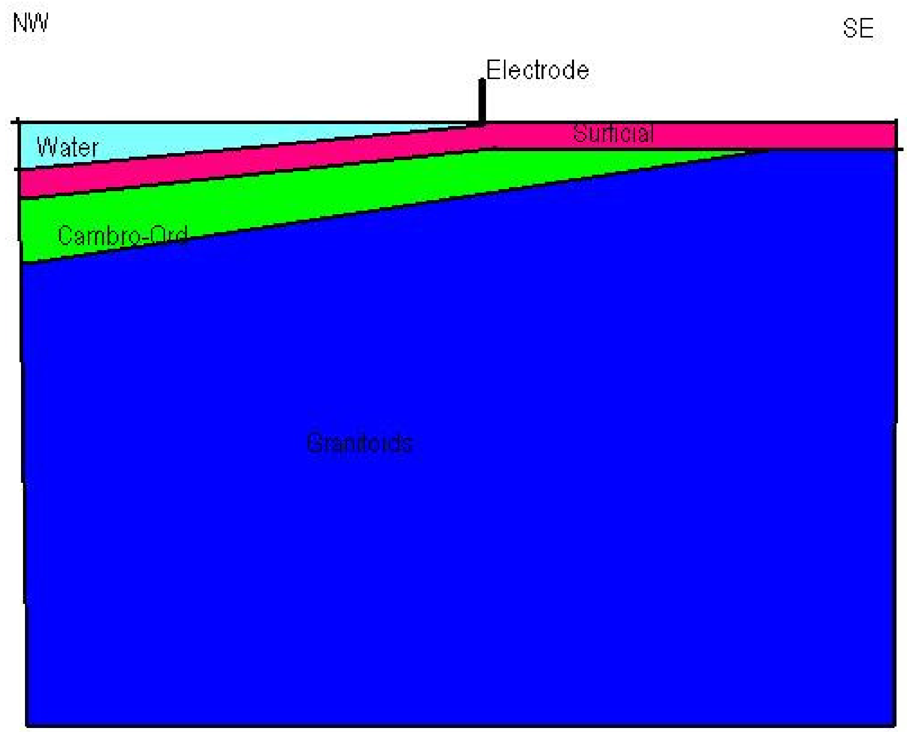
- Solid Rocks: Cambro-Ordovician sediments which underlie the Surficial sediments and overlie granitoid-volcanic bedrock. The thickness and resistivities to be used are given are presented in the Scenario Table. The thickness has been kept fixed and the resistivity varied for the simulation scenarios. Dip shown on diagram is 6^0 to 10^0 to the northwest.
- File format for Water, Surficial and Solid Rock files
    - Unit Name
    - Xcoord(Easting), Y coord(Northing)- coordinates in meters
    - Coords of point 1
    - Coords of point 2, etc
    - Last point coordinate is same as first to close polygon
    - Unit Name for next unit
    - Coords of point 1
    - Coords of point 2, etc
    - Last point coordinate is same as first to close polygon
    - Repeat for each polygon in file

There should be two new models run in 2010 encompassing several scenarios as follows:

- The depth of Conception Bay should be revised from 2009 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 and the most likely and highest value have been suggested for the proposed model scenarios.
- 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 as indicated in the scenarios.
- 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 the cross-section intersects the shoreline.



The scenarios to be modeled in 2010 were developed to give a most likely scenario and two other scenarios. One of the additional scenarios is labeled the Most Likely 2009 LOw Resistivity Seawater 2010 scenario and is the scenario modeled in 2009 so it does not need to be run again. The other two scenarios are designated Most Likely 2010, HighRho Seawater 2010 which incorporates the new seawater resistivity information, and the High Resistivity Land 2010 which uses the highest resistivities for the geological units and the new seawater and pond water resistivities. The three scenarios are presented in the following table:

Modelling Scenarios 2010

Unit		Most Likely 2009 Low Rho Seawater 2010	High Rho Land 2010	Most Likely 2010 HighRho Seawater 2010
Conception Bay				
	Resistivity (Ohm-m)	0.2	0.38	0.38
	Thickness (meters)	100	150	150
Seal Cove Pond				
	Resistivity (Ohm-m)	100	0.55	0.55
	Thickness (meters)	10	10	10
Lance Cove Pond				
	Resistivity (Ohm-m)	10	100	100
	Thickness (meters)	10	10	10
Indian Cove Pond				
	Resistivity (Ohm-m)	0.2	0.35	0.35
	Thickness (meters)	10	10	10
Surficial				
Glacio-marine Top	Resistivity (Ohm-m)	5000	10000	5000

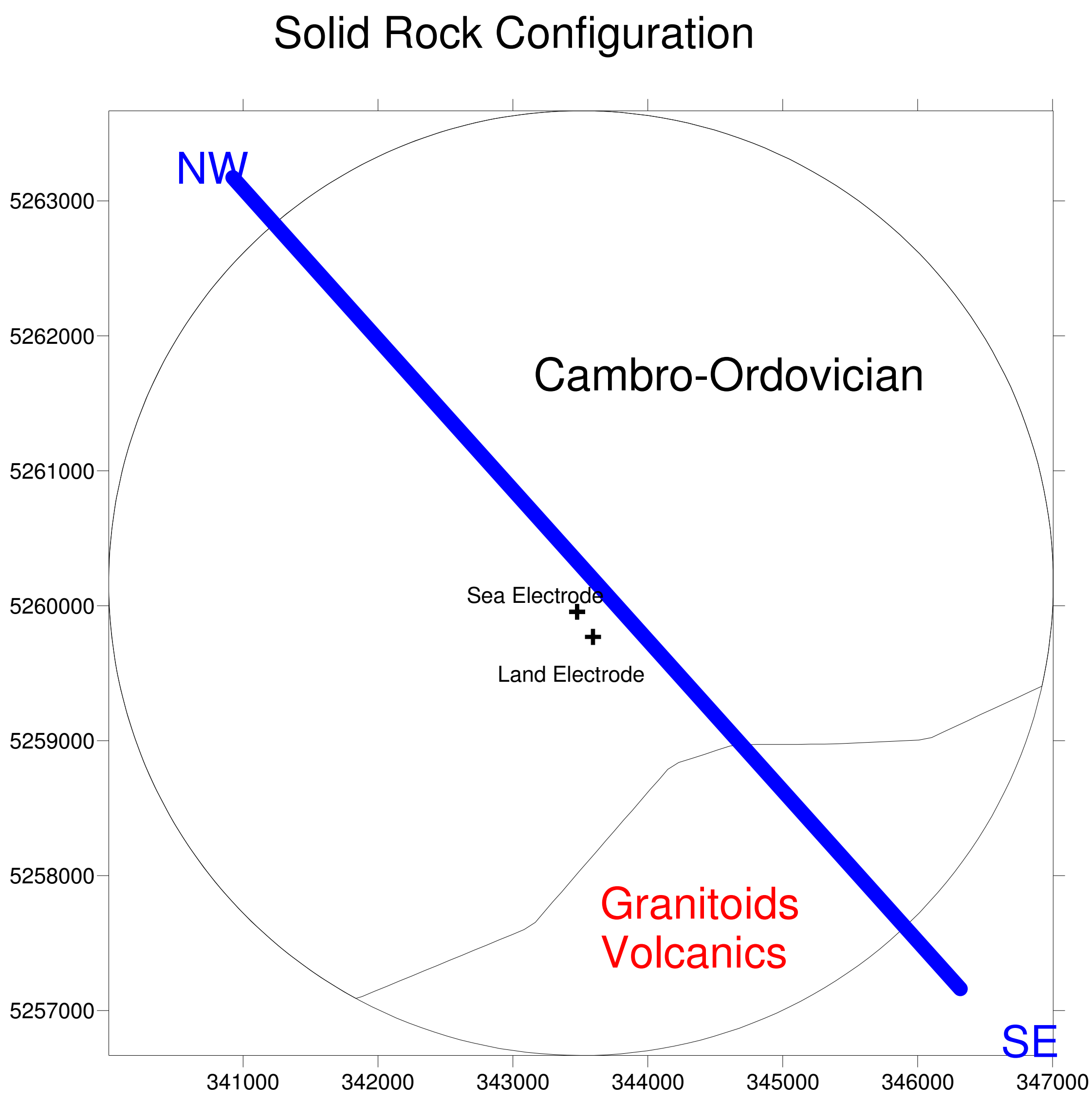
	Thickness (meters)	4	4	4
Surficial				
Glacio-marine Middle	Resistivity (Ohm-m)	300	500	300
	Thickness (meters)	3	3	3
Surficial				
Glacio-marineLower	Resistivity (Ohm-m)	5000	10000	5000
	Thickness (meters)	5	5	5
Surficial				
Till Undifferentiated	Resistivity (Ohm-m)	2000	2000	2000
	Thickness (meters)	5	5	5
Surficial				
Poor Till	Resistivity (Ohm-m)	2000	2000	2000
	Thickness (meters)	5	5	5
Cambro-Ordovician				
	Resistivity (Ohm-m)	500	2000	500
	Thickness (meters)	500	500	500
Granitoid-Volcanics				
	Resistivity (Ohm-m)	5000	10000	5000
	Thickness (meters)	To max depth	To max depth	To max depth

Notes on Scenarios

- The Water features except for Conception Bay are kept constant with the resistivities and thickness as shown for all the simulations. For Conception Bay, the digital bathymetric model should be used for the water depth with a constant resistivity of 0.38 ohm-m.

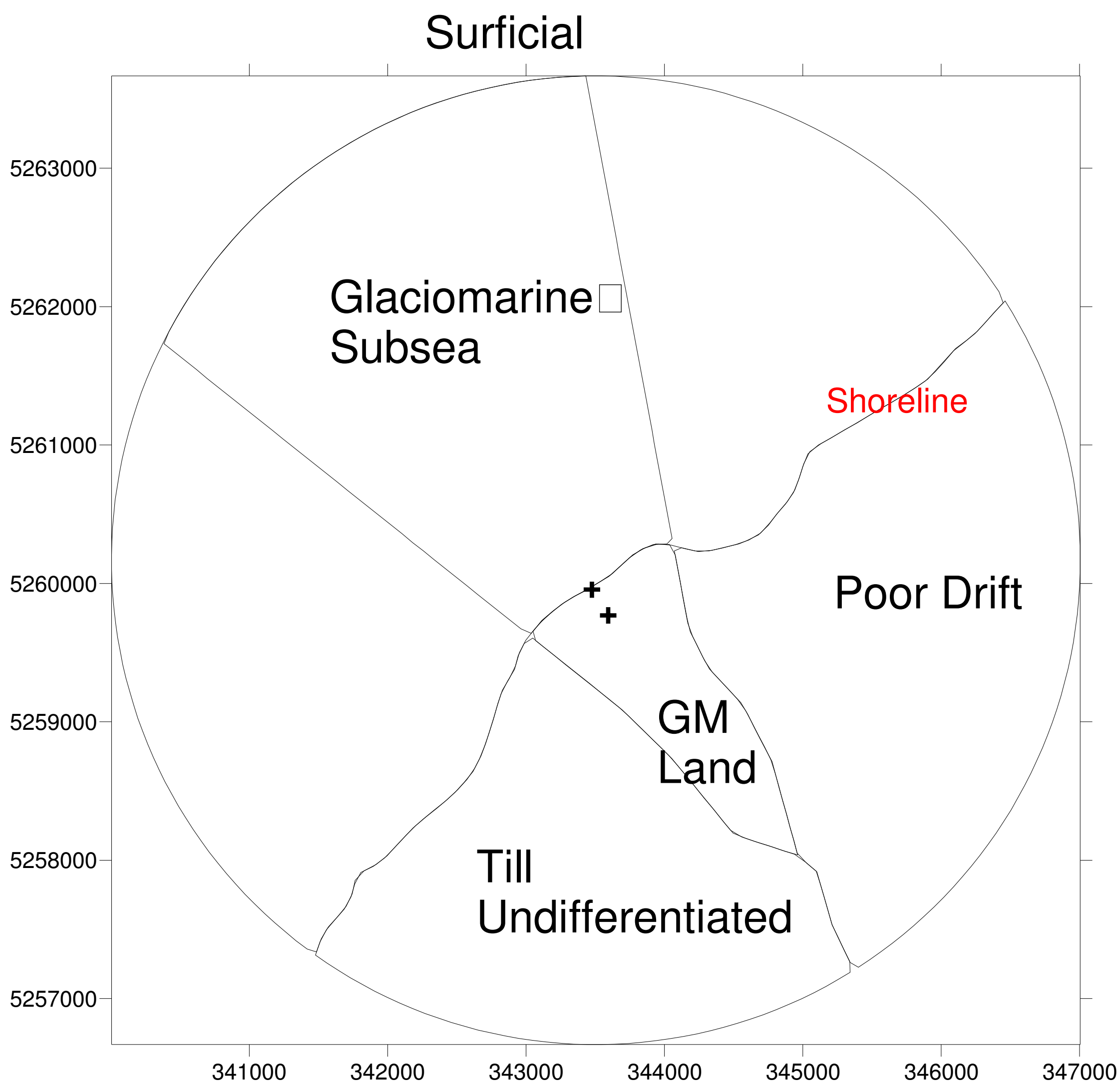
- The Undifferentiated Till and Poor Drift resistivity and thickness are kept constant for all scenarios.
- The thicknesses of the glacio-marine sub-units units are kept constant; the resistivities are varied.
- The thickness of the Cambro-Ordovician unit is kept constant at 500 m and the resistivity 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.
- Using the Kimbark formula for a simple two resistivity model with the resistivity of the seawater 0.2 ohm-m, the land 5000 ohm-m, and the seabed slope 0.015 radians gives a GPR of 1.09 Volts at 2.5 km for a current of 1300 A. When the seawater resistivity is changed to 0.38 ohm-m, the value recommended for the 2010 simulation, this GPR becomes 2.06V. Thus one would expect the simulated GPR's from the Most Likely 2009 simulation to be increased by approximately the same ratio in the 2010 Most Likely scenario.
- All spatial parameters for the various geological units and sea units remain the same from the 2009 models, with the provision that the actual digital bathymetry for Conception Bay and adjoining Atlantic Ocean should be used if possible. Any additional land which needs to be incorporated into the models should be given a resistivity of 5000 ohm-m.
- Two electrode positions were given for 2009, a sea (shoreline) and a land location. For the 2010 modelling only the shoreline position should be considered.
- The maximum depth to which the deep resistivity is assigned should be 50 km, consistent with geological information for the crustal structure for Newfoundland.

Plots of various units NW-SE indicates position of illustrative profile



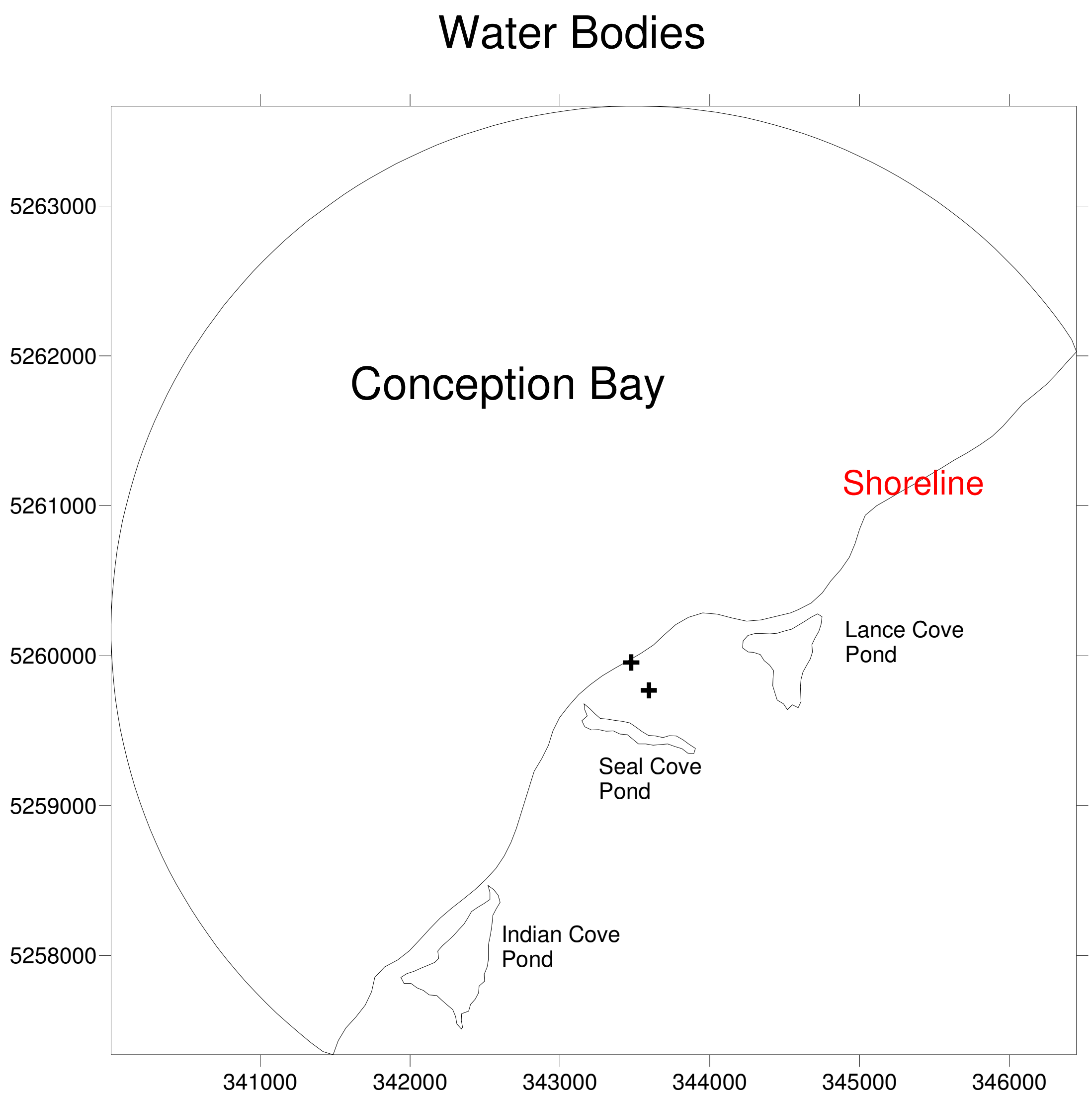
The Granitiods – Volcanics continue throughout the area beneath the Cambro-Ordovician as illustrated in profile

RevisedSept2010DPsimulation2010



The GM Land unit is the glaciomarine unconsolidated sediments on land. The Undifferentiated Till and Poor Drift do not continue beneath Conception Bay.

RevisedSept2010DPsimulation2010



Appendix I

Electric Field Report

L'Anse-au-Diable North

(Teshmont)

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the L'Anse-au-Diable Electrode Site

Prepared by:

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[Rev00: 2010 September 22]

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the L'Anse-au-Diable Electrode Site

Executive Summary

The objective of this investigation is to assess the voltage distribution on the surface for an area surrounding and including the L'Anse-au-Diable HVDC electrode site.

Geotechnical data from L'Anse-au-Diable was used to model the estimated ground resistivity of the site and calculate the ground potential rise in a wide area around the site. These ground potential rise values can be used to assess the effect of the electrode on the surrounding metallic infrastructure and distribution systems.

Due to the effect of the low resistivity sea, the estimated ground potential rise due to the L'Anse-au-Diable electrode falls off quite rapidly.

Disclaimer

This report was prepared under the supervision of Teshmont Consultants LP ("Teshmont"), whose responsibility is limited to the scope of work as shown herein. Teshmont disclaims responsibility for the work of others incorporated or referenced herein.

Revision Number	Date Released	Prepared by	Reviewed by	Comment
Rev00	2010 September 22	BVD	NATD	
Rev01	2010 October 14	NATD	NATD	Removed Appendix A (Resistivity Models)

Contents

Appendixes

Figures

Tables

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the L'Anse-au-Diable Electrode Site

1. Introduction

In March 2010, Hatch contracted Teshmont to continue studies for the ground electrodes for the Lower Churchill project. During these studies the previously established model was refined.

The purpose of the consulting services was to determine the estimated worst case ground potential rise at the electrode site and surrounding area.

2. Methodology

This study was carried out using Teshmont's GRELEC program. This program is used to calculate voltages and potential gradients within a 3-Dimensional model of non-homogeneous material when a current is applied at one point or a number of points.

The volume under study is divided into layers, rings and sectors as shown in Figure 2-1 .

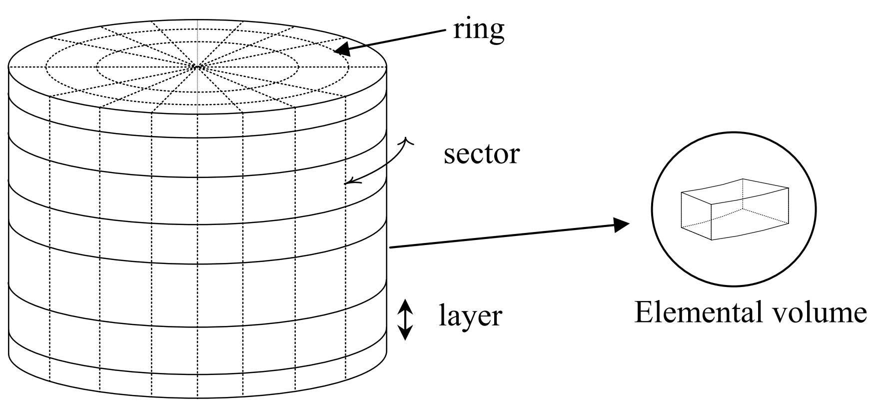


Figure 2-1: GRELEC Model

The program calculates the resistances of and between the elemental volumes from the geometry and resistivity given in the input data. The admittance matrix is formulated from the resistances. It then calculates the voltages at all nodes and the potential gradients given a vector of currents injected at any or all of the nodes.

3. System data

The inputs to the study are as follows:

- Soil and seawater resistivity
- Electrode current
- Electrode geometry

3.1. Soil and Seawater Resistivity

Teshmont was provided with the approximate resistivity data and bathymetric maps for the L'Anse-au-Diable electrode site and surrounding area. This AMEC report by Hugh Miller, P.Geo. is titled: *Strait of Belle Isle Ground Potential Simulation Modeling Scenarios* [1].

The AMEC report contained most likely and worst case resistivities for each of the modeling parameters. The model (SB_03) was created using a combination of most likely and worst case resistivity parameters. For the sediments, carbonates, dunnage, and basement components the most likely resistivities were used. For the Strait of Belle Isle water the more conservative worst case resistivity was used as the majority of the current will pass through the water.

3.2. Electrode current data

In this study an electrode current of 2320 A was considered.

3.3. Electrode Geometry

The electrode was modelled as electrode elements attached to the pond side of a breakwater as shown in Figure 3-1.

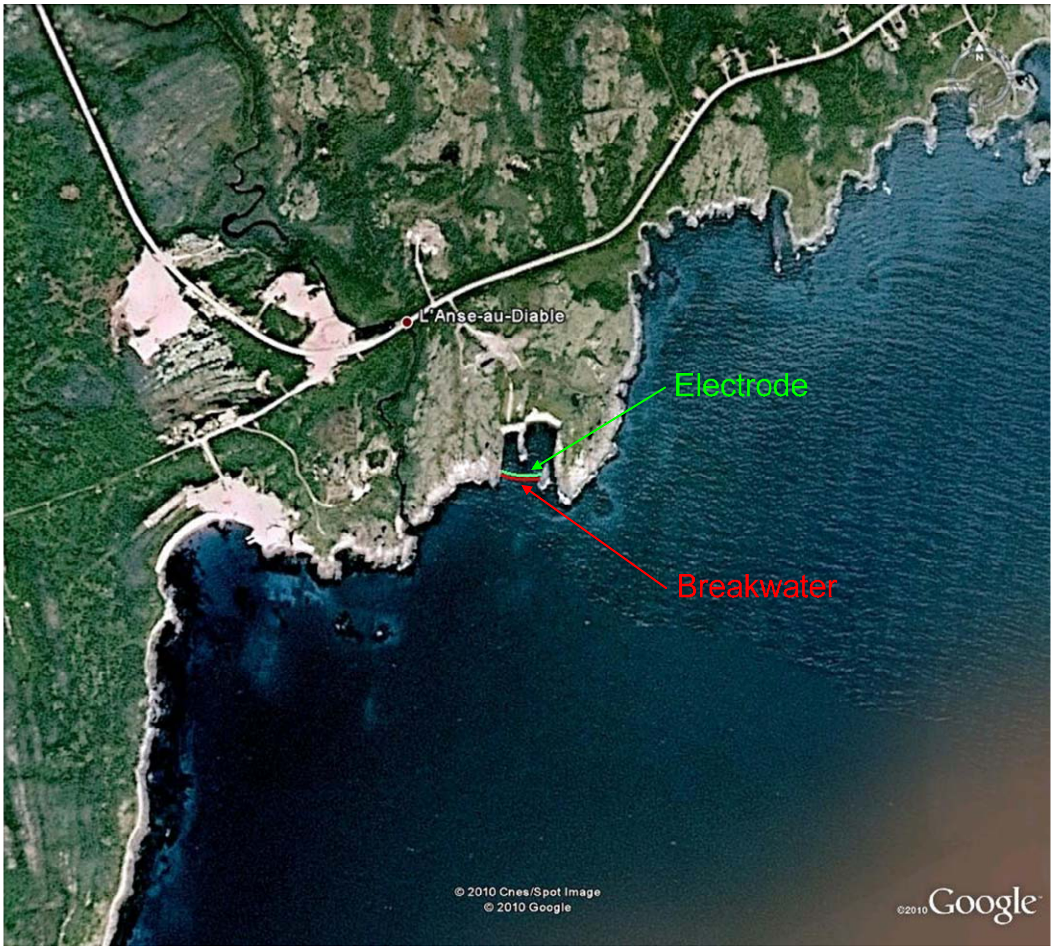


Figure 3-1: Electrode & Breakwater

See Figure 3-2 for the electrode and breakwater elements with reference to the rings and sectors.

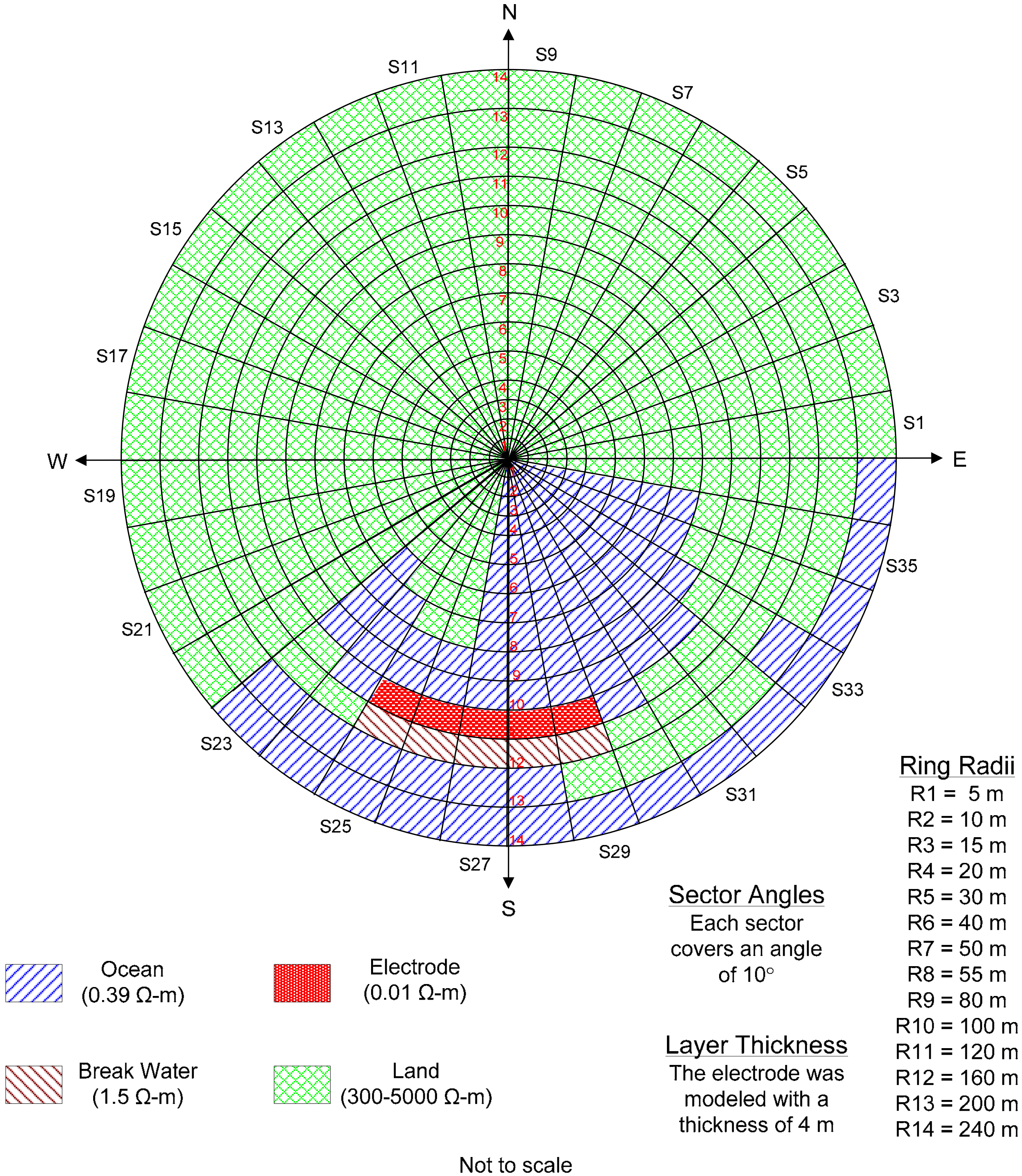


Figure 3-2: Electrode & Breakwater Location with Rings & Sectors

3.4. Assumptions

- Beyond 600 km radius from electrode and below 50 km depth was considered to be the remote ground with zero voltage.
- The provided resistivity data was approximate conditions for the area of the electrode. By extrapolating the available data and the geophysical conditions of the site, an estimated resistivity was assumed for the regions for which no data was provided.

4. Development of the electrode model (SB_03)

In this section the study results are provided. Specific features of the site are discussed followed by the description of the input to the GRELEC program. The output of the program along with detailed analysis of the results is provided in the next section.

4.1. Data and Assumptions

This site is located at the north end of the dc transmission scheme, on the shore line of The Strait of Belle Isle, as shown Figure 4-1.

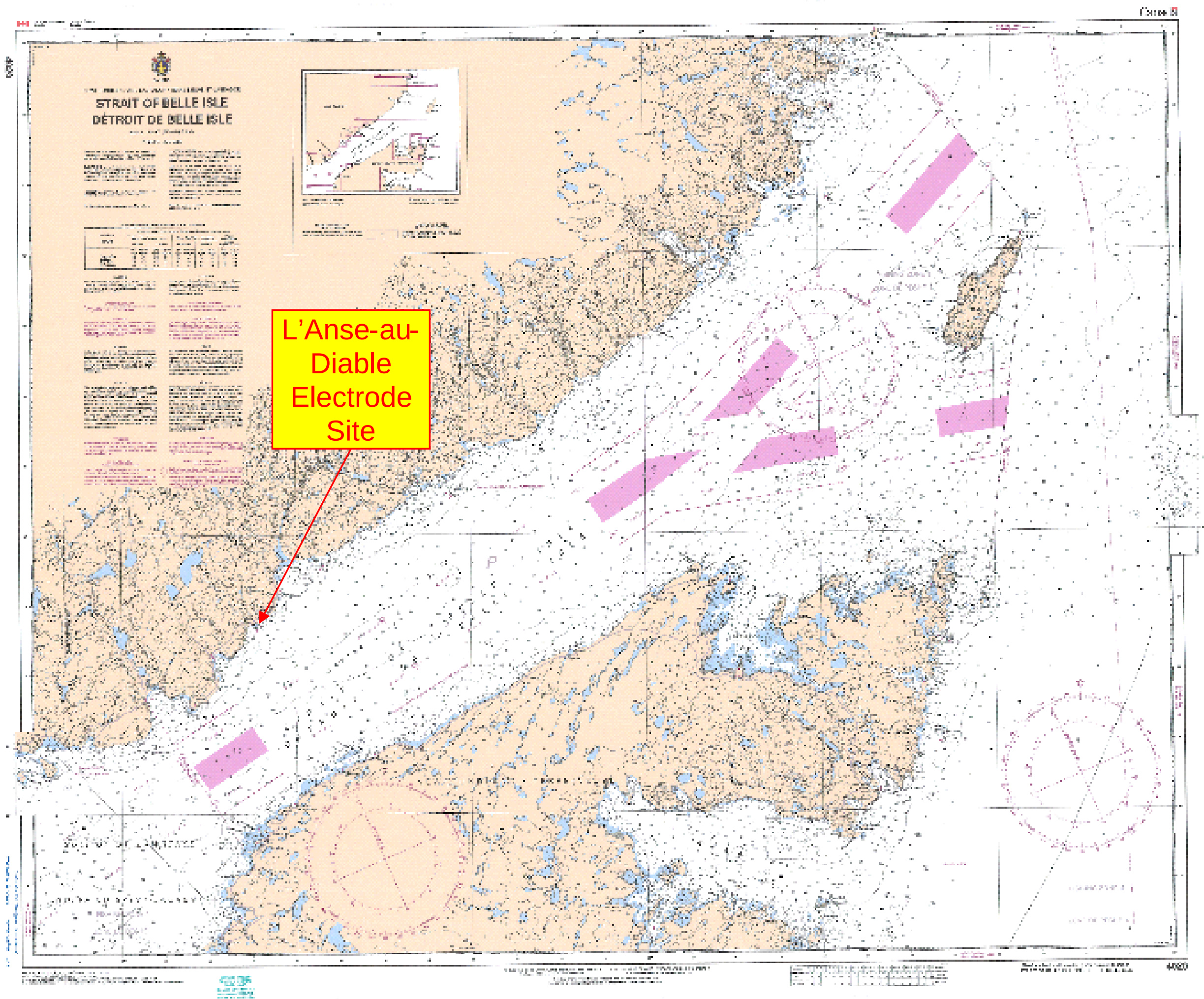


Figure 4-1: L'Anse-au-Diable Electrode Site

For this site the estimated resistivity data, provided by AMEC, is shown in Table 1.

Table 1: L'Anse-au-Diable Resistivity Data

	Resistivity (ohm-m)	Thickness (m)
SOBI Seawater	0.39	Per bathymetry data
Labrador sediments	1000	150
Labrador Basement	5000	Infinite
SOBI Sediments	300	300
SOBI Basement	5000	Infinite

NL Carbonates	300	500
NL Dunnage	2000	2000
NL Basement	5000	Infinite

The regions defined by the above resistivity data are shown in Figure 4-2.

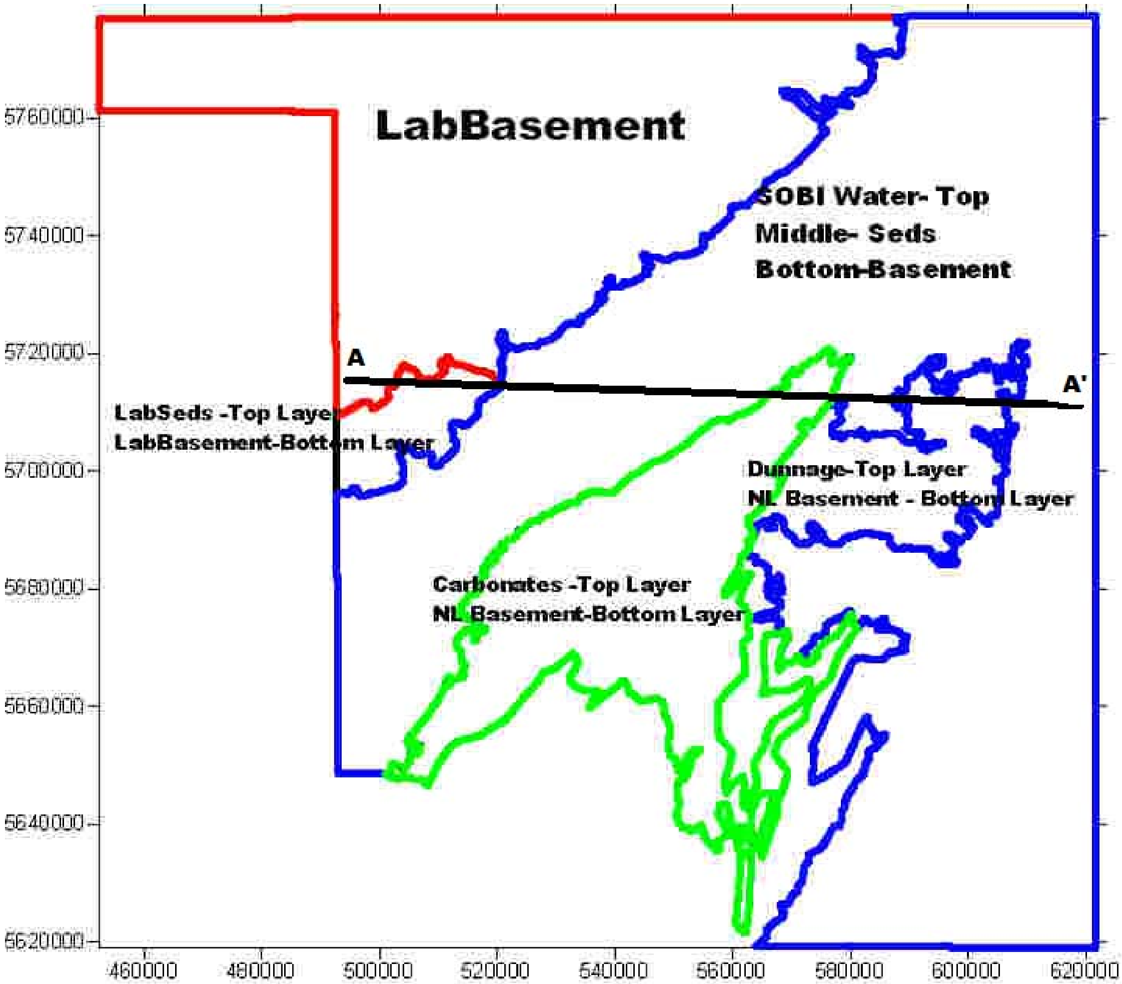


Figure 4-2: Strait of Belle Isle Resistivity Regions

This data as well as the bathymetric chart (sea depth) was used to revise previously developed resistivity models.

4.2. Input resistivity data to GRELEC program

The estimated electrode model (SB_03) was developed by dividing the area around the electrode site into 10° sectors as shown in Figure 4-3. East has been defined as 0°, Sector 1 covers

0° to 10° and the rest of the sectors progress in a counter clockwise fashion around the circle. The results are reported according to these same sectors.

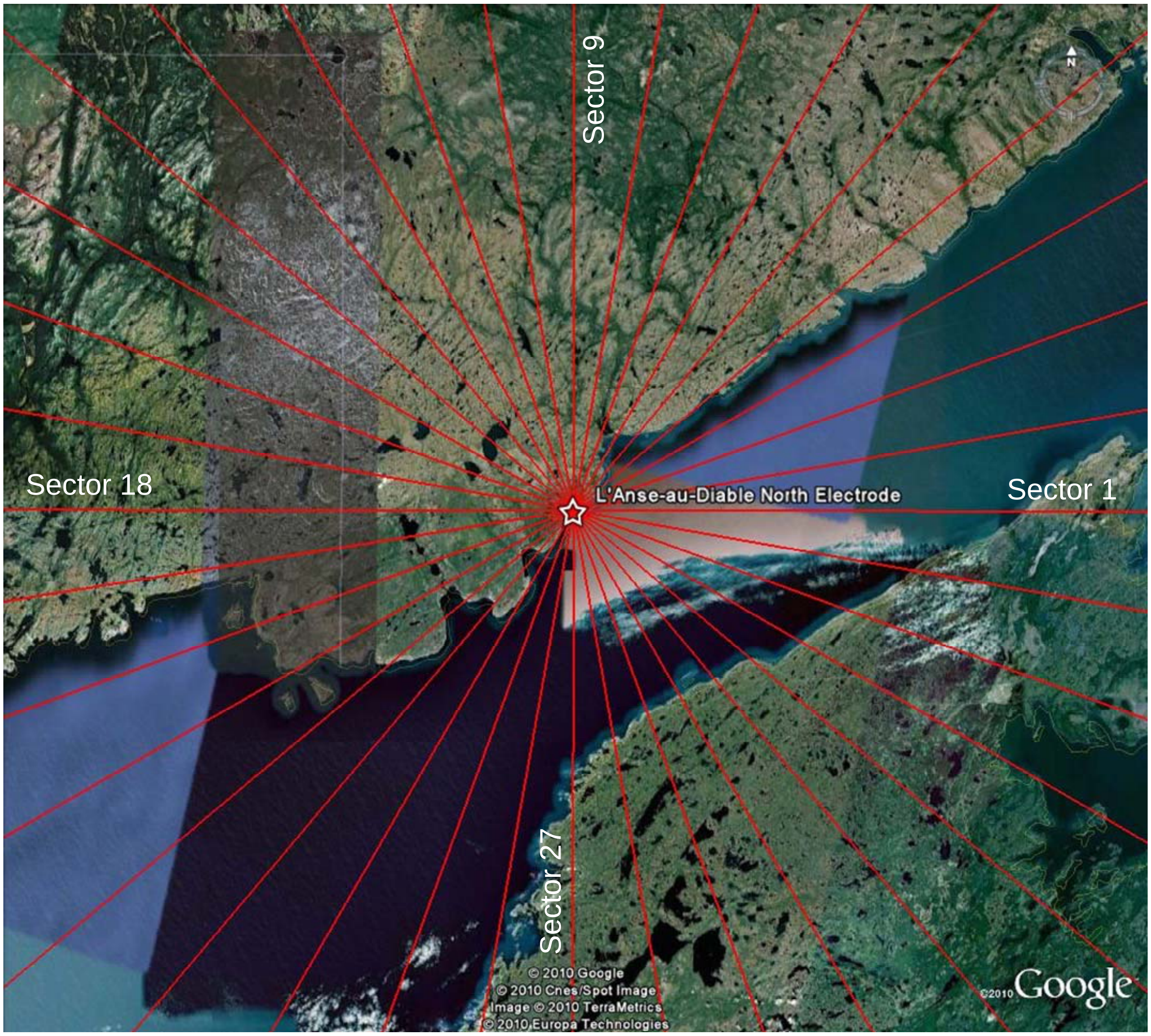


Figure 4-3: Electrode Model Sectors

A depiction of the resistivities modeled in the first layer is shown in Figure 4-4. The model has been developed out to 600 km, however, for the sake of clarity, rings with radii greater than 40 km have been omitted.

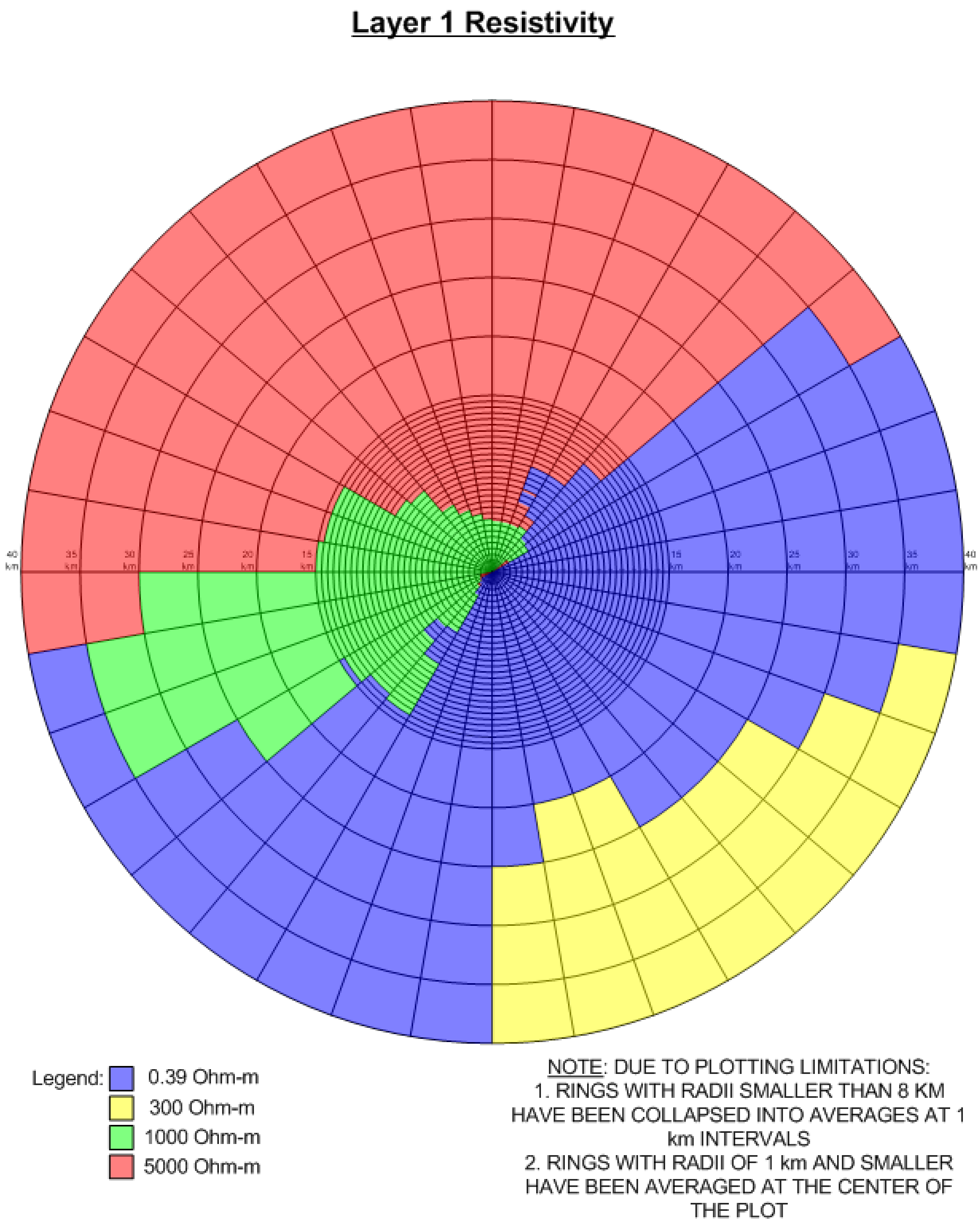


Figure 4-4: Layer 1 (1m Depth) Resistivity to 40km Radius

5. Study Results

The GRELEC program was used to calculate the voltage induced due to the operation of the electrode. The estimated ground potential rise (GPR) and gradient (GRD) for are provided below.

Figure 5-1 shows the estimated ground potential rise and Figure 5-2 shows the estimated voltage gradient on the surface versus distance from the electrode. Further results, including equipotential contours, are included in Appendix A.

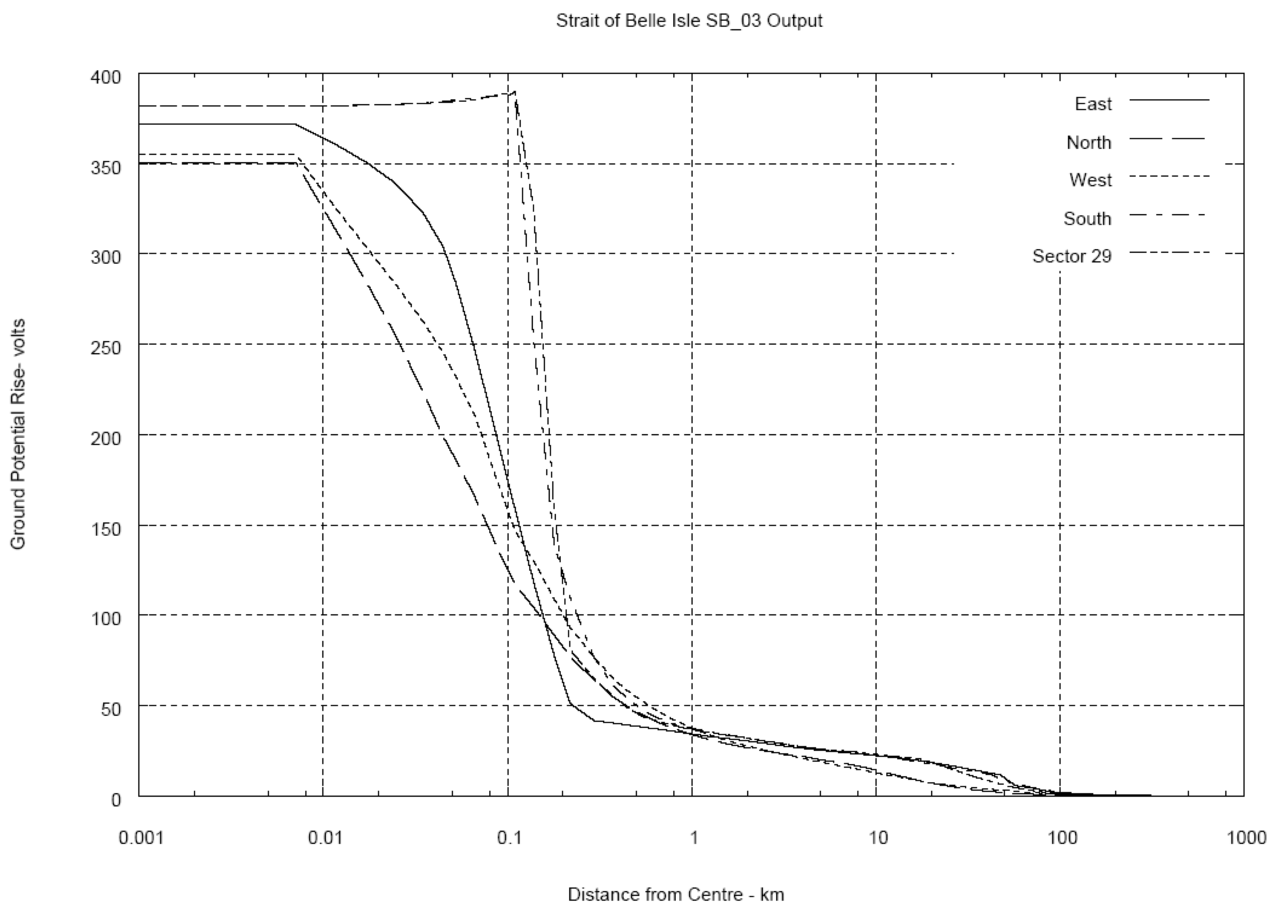


Figure 5-1: Estimated Ground Potential Rise

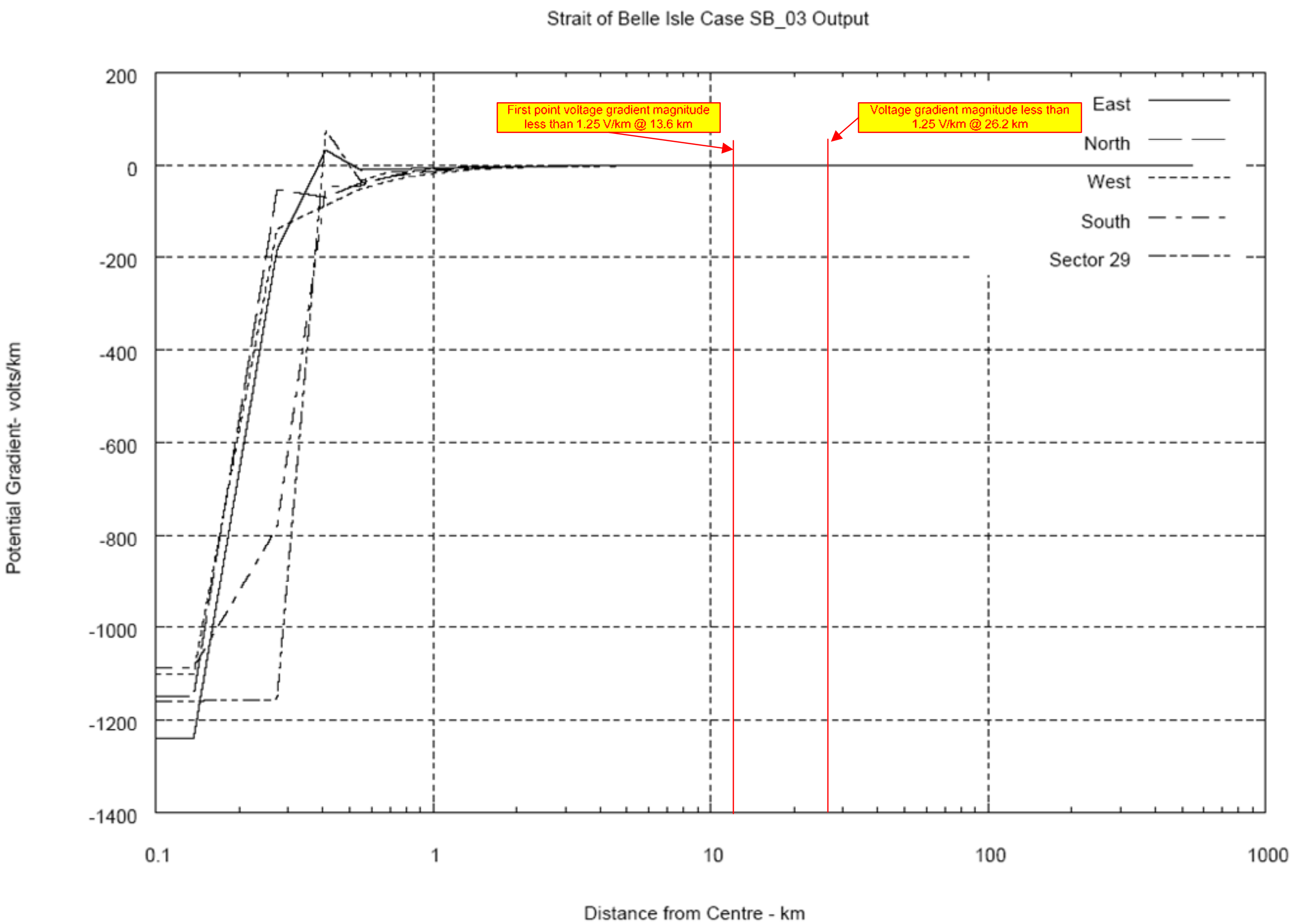


Figure 5-2: Estimated Voltage Gradient

The estimated ground potential rise shows a higher distribution of current towards the Strait of Belle Isle (South & Sector 29 specifically) as shown in Figure 5-3 and an earlier reduction of estimated ground potential rise towards the land (North). The estimated voltage gradient for all sectors is below -1.25 V/km at distances greater than 26.2 km from the electrode.

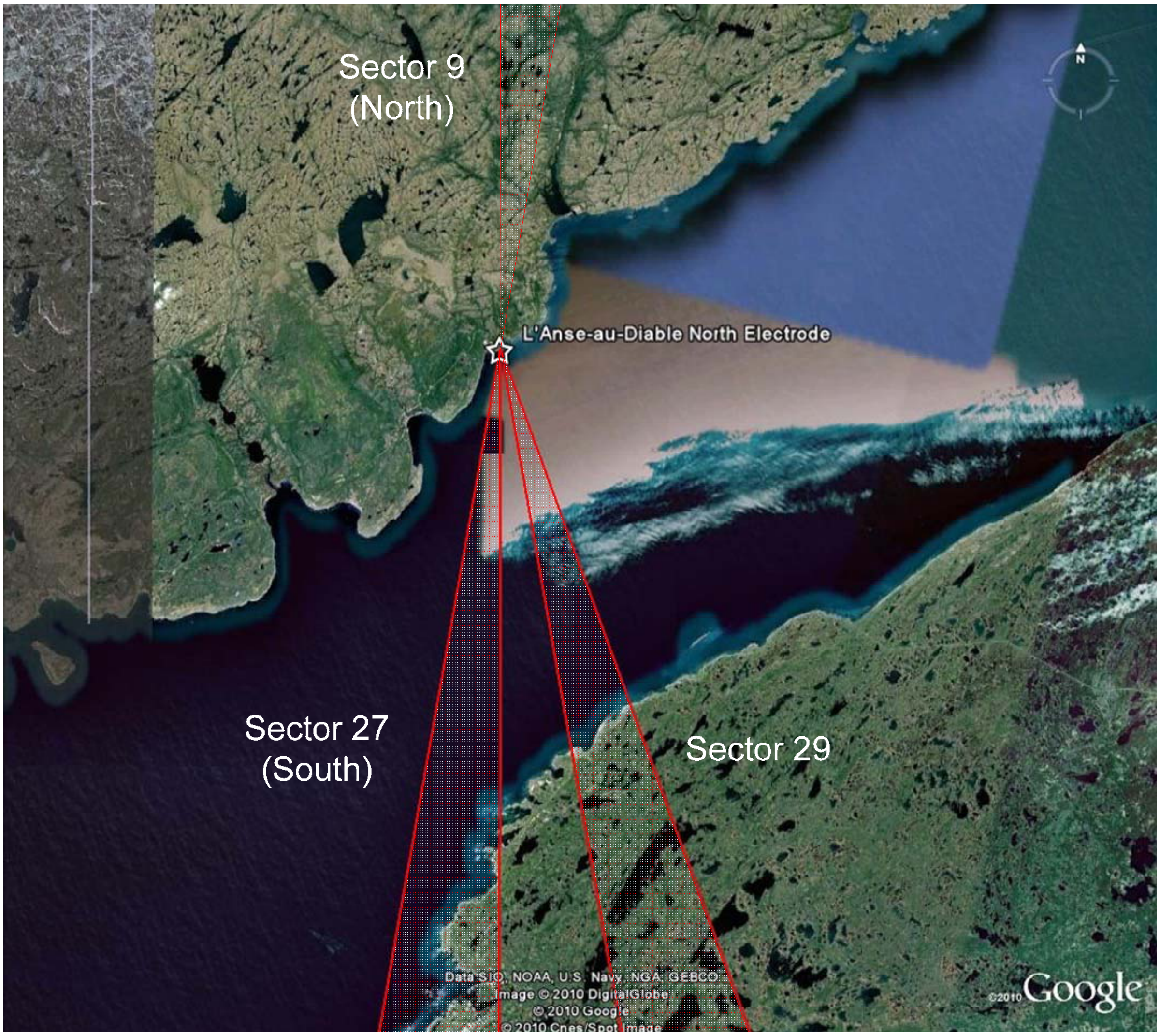


Figure 5-3: Sectors 9 (North), 27 (South) & 29

Summary of results are given in Table 2. The maximum and minimum estimated ground potential rise is given at various distances from electrode

Table 2: Estimated Ground Potential Rise

Distance (km)	Voltage (V)
0.1 (electrode)	390
1	43 - 33
10	23 - 12
50	10.3 – 1.4
200	2.44 – 0.02

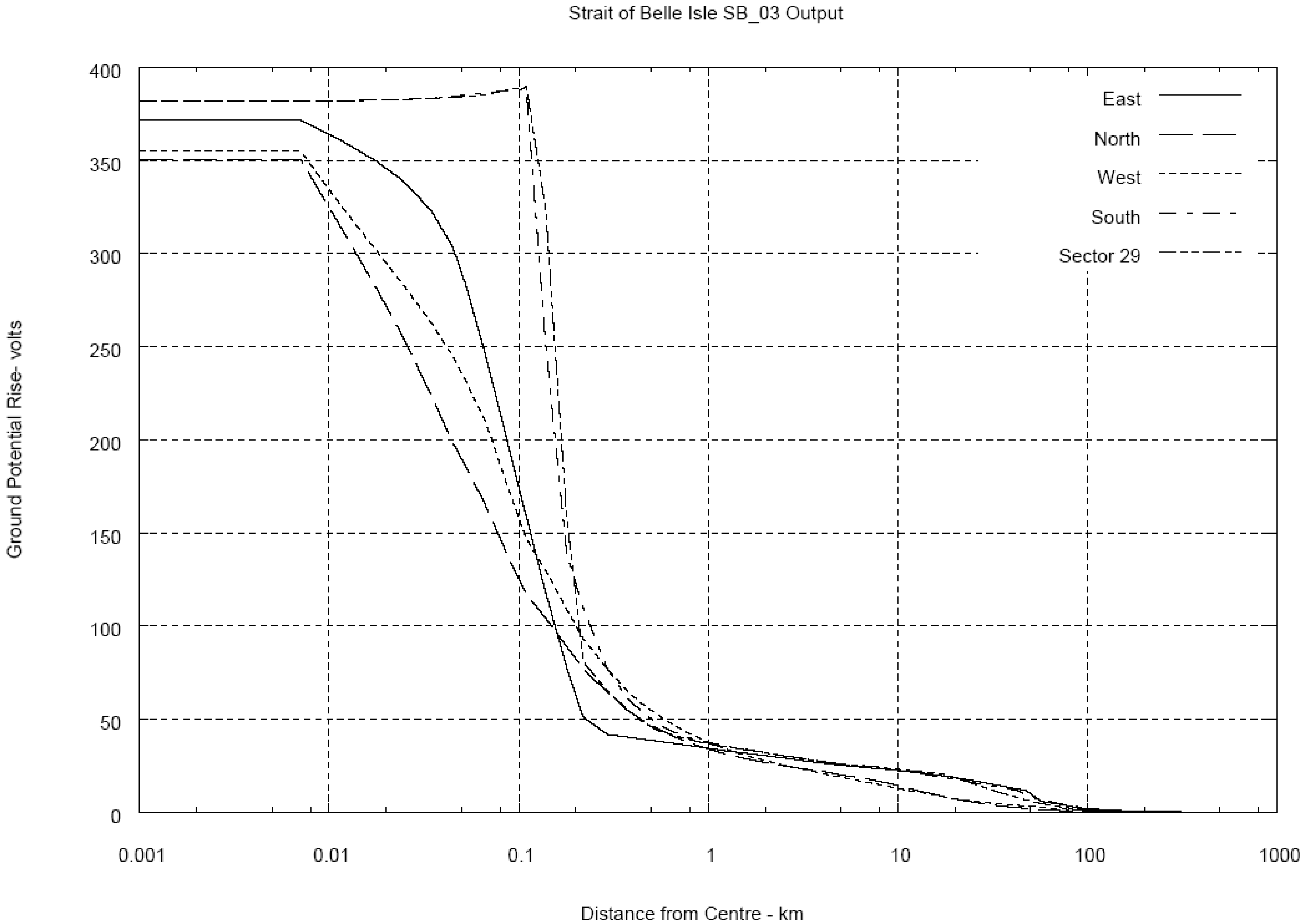
$$\text{Electrode resistance to the remote earth} = \frac{390\ \text{V}}{2320\ \text{A}} = 0.17\ \Omega .$$

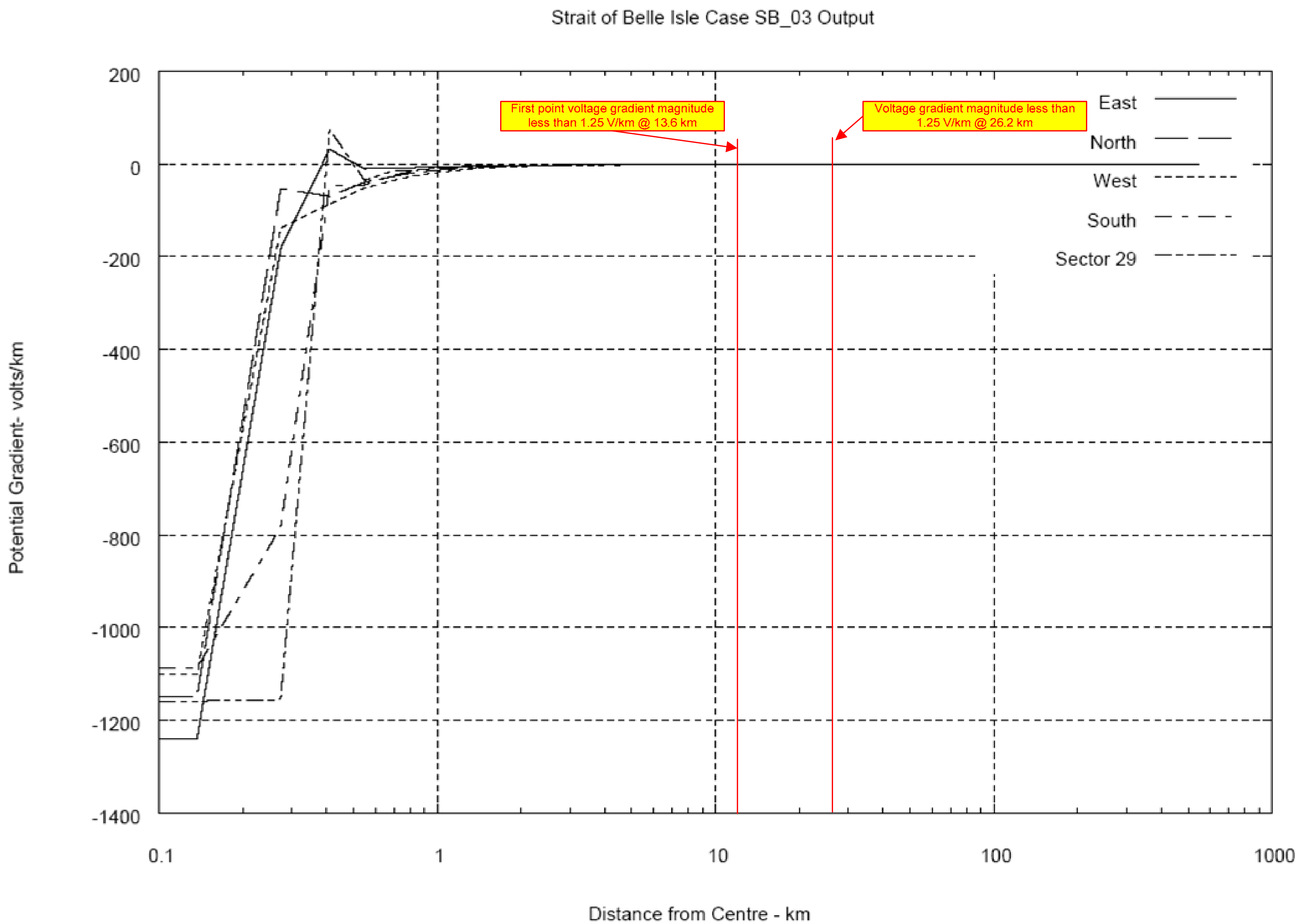
6. References

[1] H. G. Miller, "Strait of Belle Isle Ground Potential Simulation Modeling Scenarios," AMEC, St. John's, NL, September 2010.

Appendix A

Results


Strait of Belle Isle SB_03 Output
Ground Potential Rise- volts
400
350
300
250
200
150
100
50
0
0.001
0.01
0.1
1
10
100
1000
Distance from Centre - km
East
North
West
South
Sector 29


Strait of Belle Isle Case SB_03 Output
First point voltage gradient magnitude less than 1.25 V/km @ 13.6 km
Voltage gradient magnitude less than 1.25 V/km @ 26.2 km
East
North
West
South
Sector 29
200
0
-200
-400
-600
-800
-1000
-1200
-1400
0.1
1
10
100
1000
Potential Gradient- volts/km
Distance from Centre - km

L'Anse-au-Diable Equipotential Contours (to 4 km) - SB_03 0.39 ohm-m sea, 50 km depth

0 4km

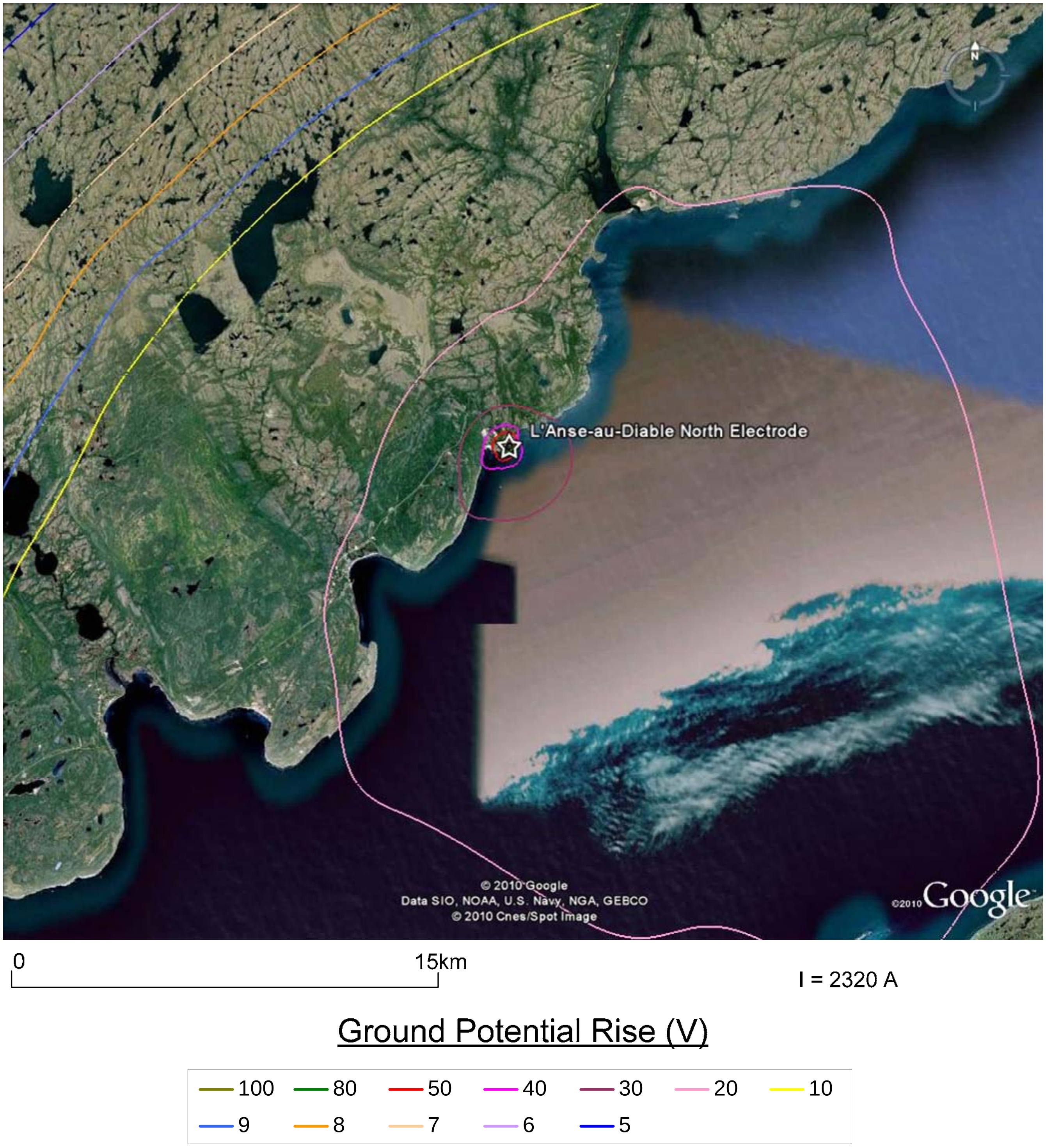
I = 2320 A

Note: Highest Voltage Calculated: 389.8V

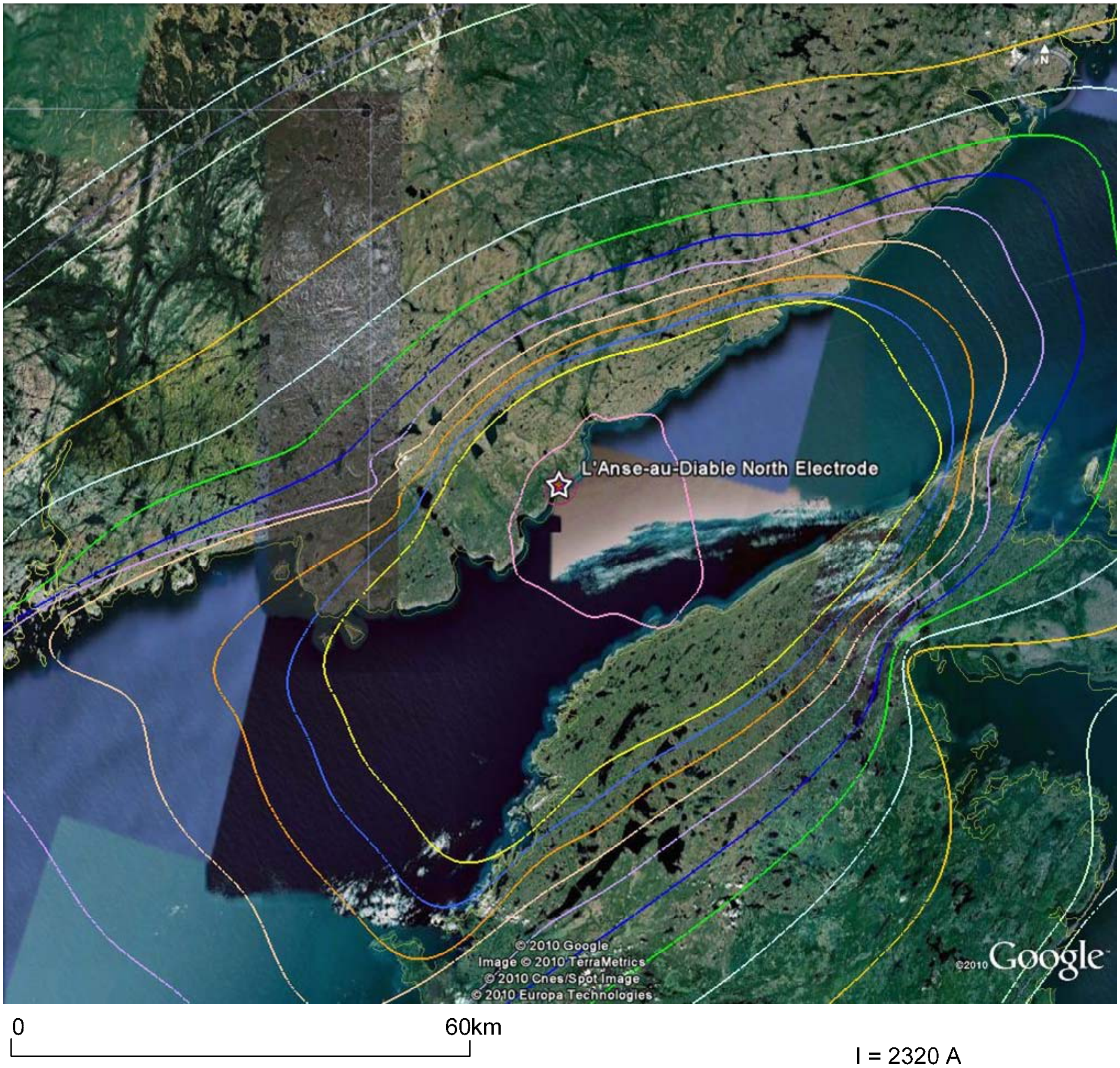
Ground Potential Rise (V)

100	80	50	40	30	20

L'Anse-au-Diable Equipotential Contours (to 15 km) - SB_03
0.39 ohm-m sea, 50 km depth



L'Anse-au-Diable Equipotential Contours (to 60 km) - SB_03
0.39 ohm-m sea, 50 km depth

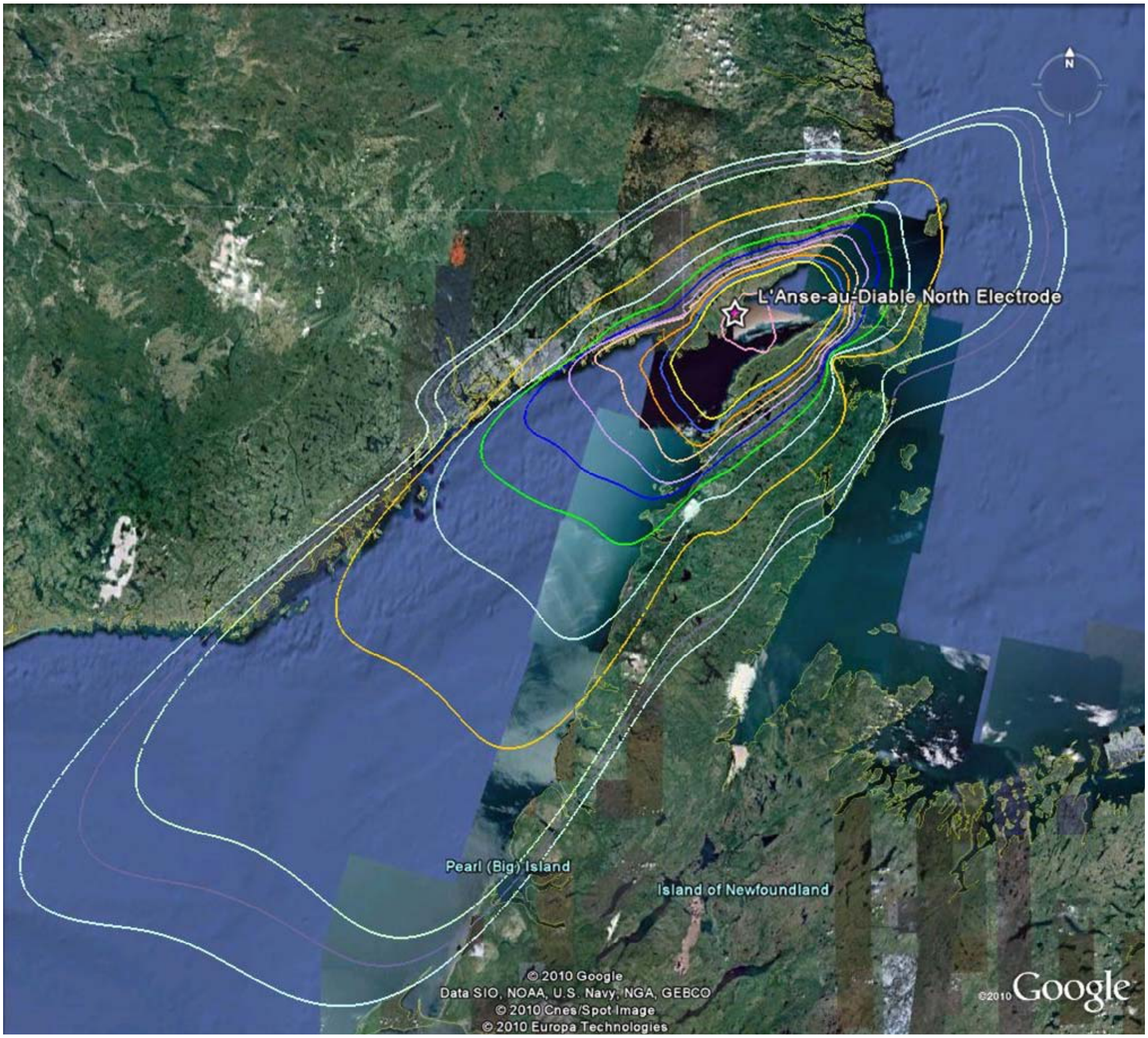


I = 2320 A

Ground Potential Rise (V)

100	80	50	40	30	20	10
9	8	7	6	5	4	3
2	1	0.9	0.8			

L'Anse-au-Diable Equipotential Contours (to 430 km) - SB_03 0.39 ohm-m sea, 50 km depth



0 150km

I = 2320 A

Ground Potential Rise (V)

100	80	50	40	30	20	10
9	8	7	6	5	4	3
2	1	0.9	0.8			

Appendix J

Electric Field Report

Dowden's Point

(Teshmont)

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the Dowden's Point Electrode Site

Prepared by:

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Teshmont

2112-002-0001-Rev02
2010 October 14
[Rev01: 2010 September 22]

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the Dowden's Point Electrode Site

Executive Summary

The objective of this investigation is to assess the voltage distribution on the surface for an area surrounding and including the Dowden's Point HVDC electrode site.

Geotechnical data from Dowden's Point was used to model the estimated ground resistivity of the site and calculate the ground potential rise in a wide area around the site. These ground potential rise values can be used to assess the effect of the electrode on the surrounding metallic infrastructure and distribution systems.

Due to the effect of the low resistivity sea, the estimated ground potential rise due to the Dowden's Point electrode falls off quite rapidly.

Disclaimer

This report was prepared under the supervision of Teshmont Consultants LP ("Teshmont"), whose responsibility is limited to the scope of work as shown herein. Teshmont disclaims responsibility for the work of others incorporated or referenced herein.

Revision Number	Date Released	Prepared by	Reviewed by	Comment
Rev00	2010 July 23	NATD	DLG	
Rev01	2010 September 22	BVD	NATD	
Rev02	2010 October 14	NATD	NATD	Removed Appendix A (Resistivity Models)

Contents

Appendixes

Figures

Tables

Nalcor Energy

Lower Churchill Project

Calculation of the Ground Potential Rise for the Dowden's Point Electrode Site

1. Introduction

In March 2010, Hatch contracted Teshmont to continue studies for the ground electrodes for the Lower Churchill project. During these studies the previously established model was refined.

The purpose of the consulting services was to determine the estimated worst case ground potential rise at the electrode site and surrounding area.

2. Methodology

This study was carried out using Teshmont's GRELEC program. This program is used to calculate voltages and potential gradients within a 3-Dimensional model of non-homogeneous material when a current is applied at one point or a number of points.

The volume under study is divided into layers, rings and sectors as shown in Figure 2-1 .

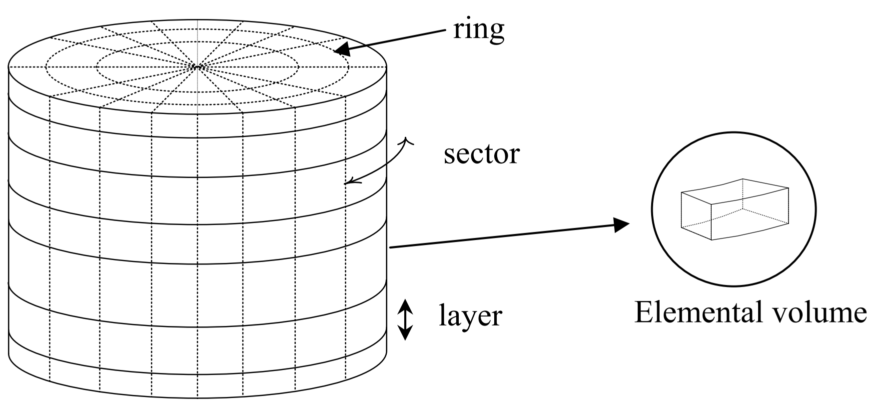


Figure 2-1: GRELEC Model

The program calculates the resistances of and between the elemental volumes from the geometry and resistivity given in the input data. The admittance matrix is formulated from the resistances. It then calculates the voltages at all nodes and the potential gradients given a vector of currents injected at any or all of the nodes.

3. System data

The inputs to the study are as follows:

- Soil and seawater resistivity
- Electrode current
- Electrode geometry

3.1. Soil and Seawater Resistivity

Teshmont was provided with the approximate resistivity data and bathymetric maps for the Dowden's Point electrode site and surrounding area. This AMEC report by Hugh Miller, P.Geo. is titled: *REVISED Dowden's Point Electrode Ground Potential Simulation Suggested Models* [1].

The AMEC report contained most likely and worst case resistivities for each of the modeling parameters. The model (DP_15) was created using a combination of most likely and worst case resistivity parameters. For the ponds, till, cambro-ordovician, granitoid-volcanic, and glacio-marine levels the most likely resistivities were used. For the Conception Bay water the more conservative worst case resistivity was used as the majority of the current will pass through the water. To determine the sensitivity of the results to the resistivity of the seawater a model (DP_13) using the most likely Conception Bay water resistivity was made. The results can be found in Appendix A along with a comparison between the high and most likely resistivity model's results.

3.2. Electrode current data

In this study an electrode current of 1340 A was considered.

3.3. Electrode Geometry

The electrode was modelled as electrode elements attached to the pond side of a breakwater as shown in Figure 3-1.

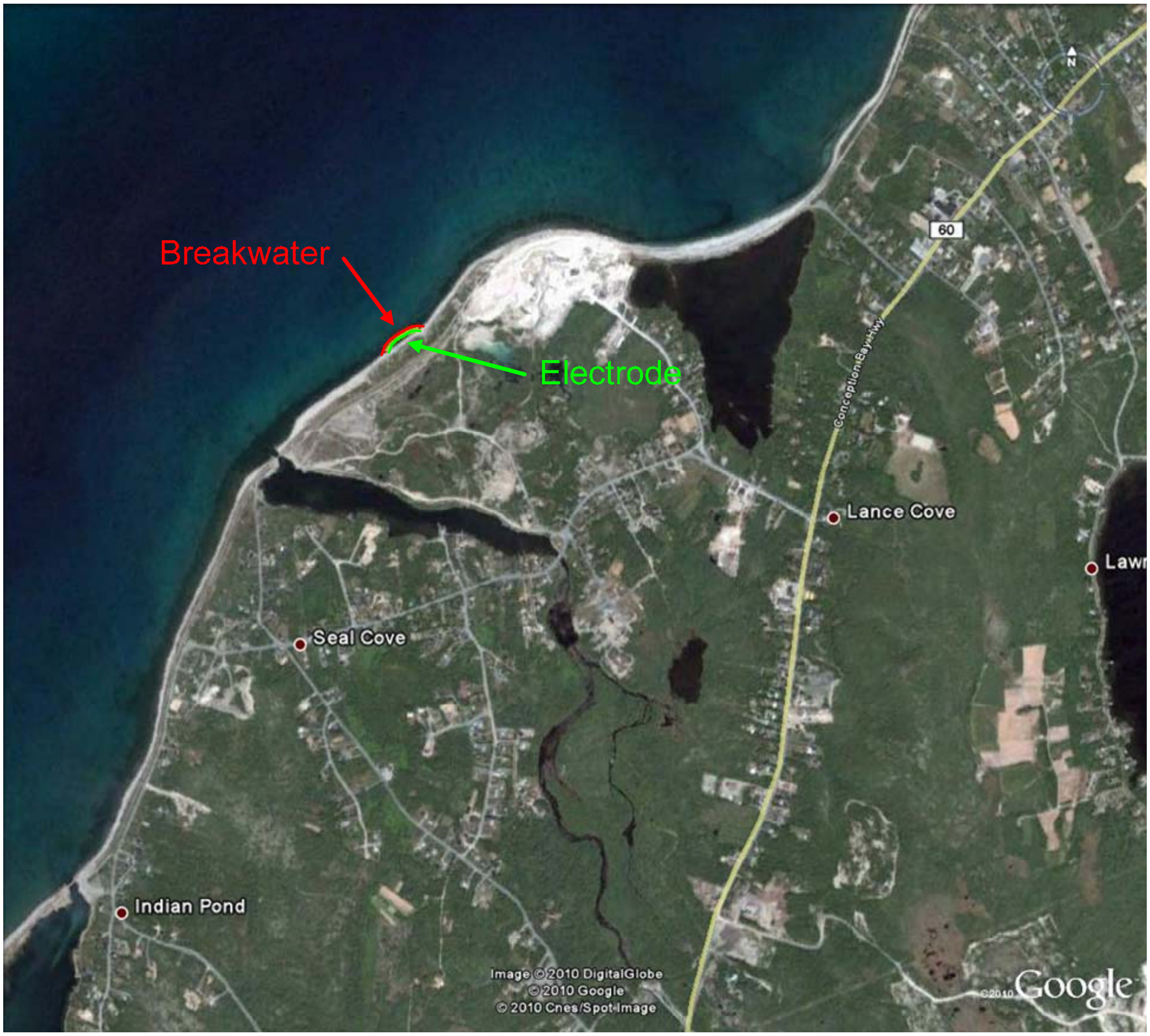


Figure 3-1: Electrode & Breakwater

See Figure 3-2 for the electrode and breakwater elements with reference to the rings and sectors.

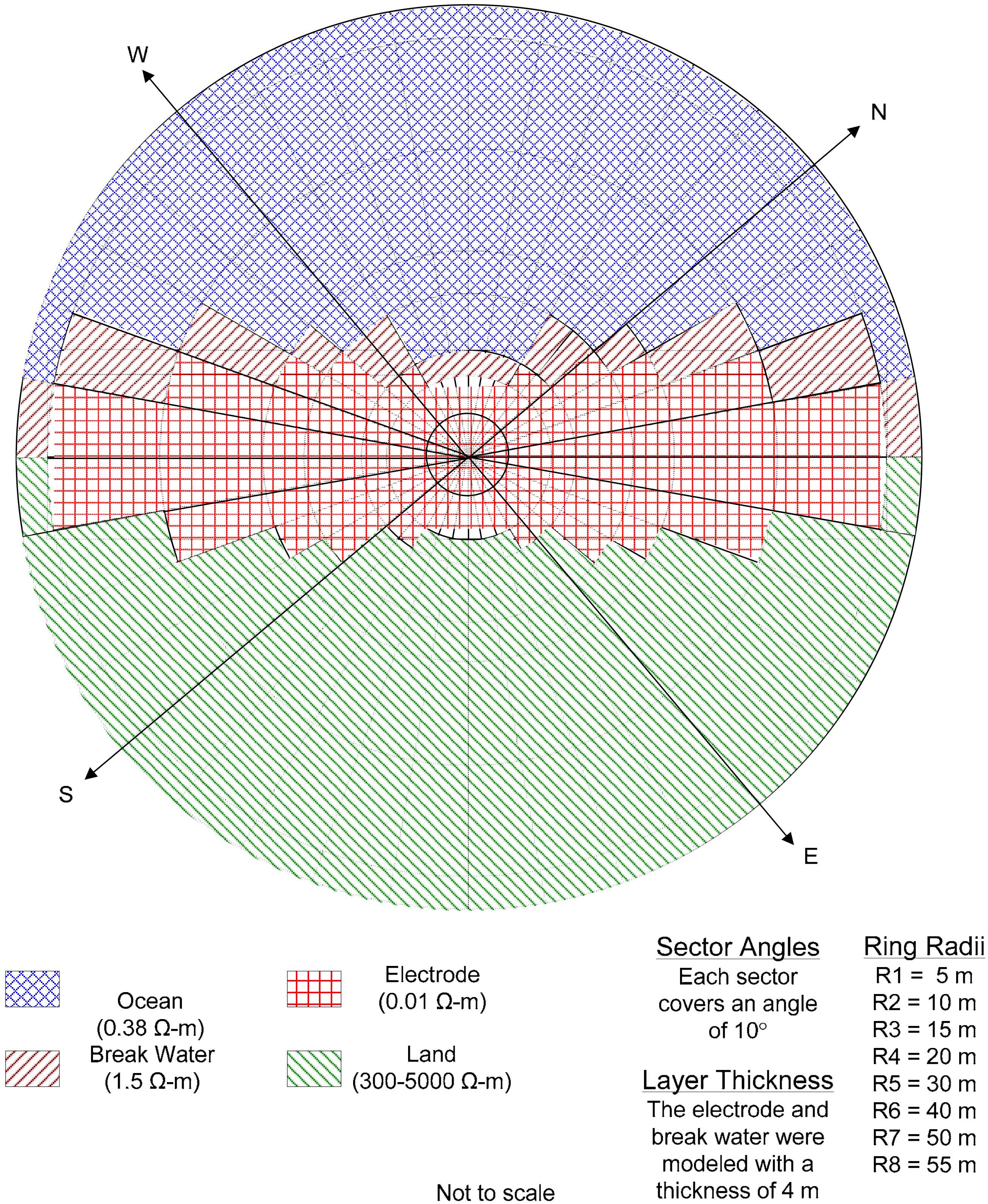


Figure 3-2: Electrode & Breakwater Location with Rings & Sectors

3.4. Assumptions

- Beyond 600 km radius from electrode and below 50 km depth was considered to be the remote ground with zero voltage.
- The provided resistivity data was approximate conditions for the area of the electrode. By extrapolating the available data and the geophysical conditions of the site, an estimated resistivity was assumed for the regions for which no data was provided.

4. Development of the electrode model (DP_15)

In this section the study results are provided. Specific features of the site are discussed followed by the description of the input to the GRELEC program. The output of the program along with detailed analysis of the results is provided in the next section.

4.1. Data and Assumptions

This site is located at the south end of the dc transmission scheme, on the shore line of Conception Bay, as shown in Figure 4-1.

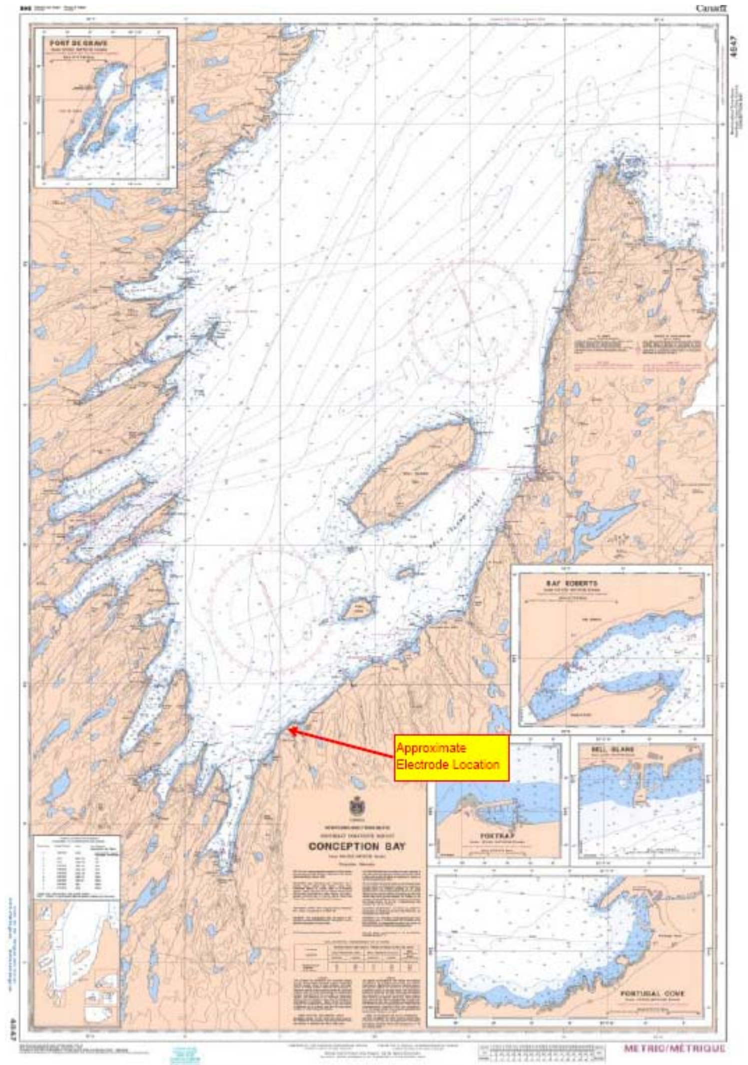


Figure 4-1: Dowden's Point Electrode Site

For this site the estimated resistivity data, provided by AMEC, is shown in Table 1.

Table 1: Dowden's Point Resistivity Data

	Resistivity (ohm-m)	Thickness (m)
Conception Bay	0.38	Per bathymetry data
Seal Cove Pond	0.55	10
Lance Cove Pond	100	10
Indian Cove Pond	0.35	10

Glacio-marine Top	5000	4
Glacio-marine Middle	300	3
Glacio-marineLower	5000	5
Till Undifferentiated	2000	5
Poor Till	2000	5
Cambro-Ordovician	500	500
Granitoid-Volcanics	5000	To max depth

The regions defined by the above resistivity data are shown in Figure 4-2 and Figure 4-3.

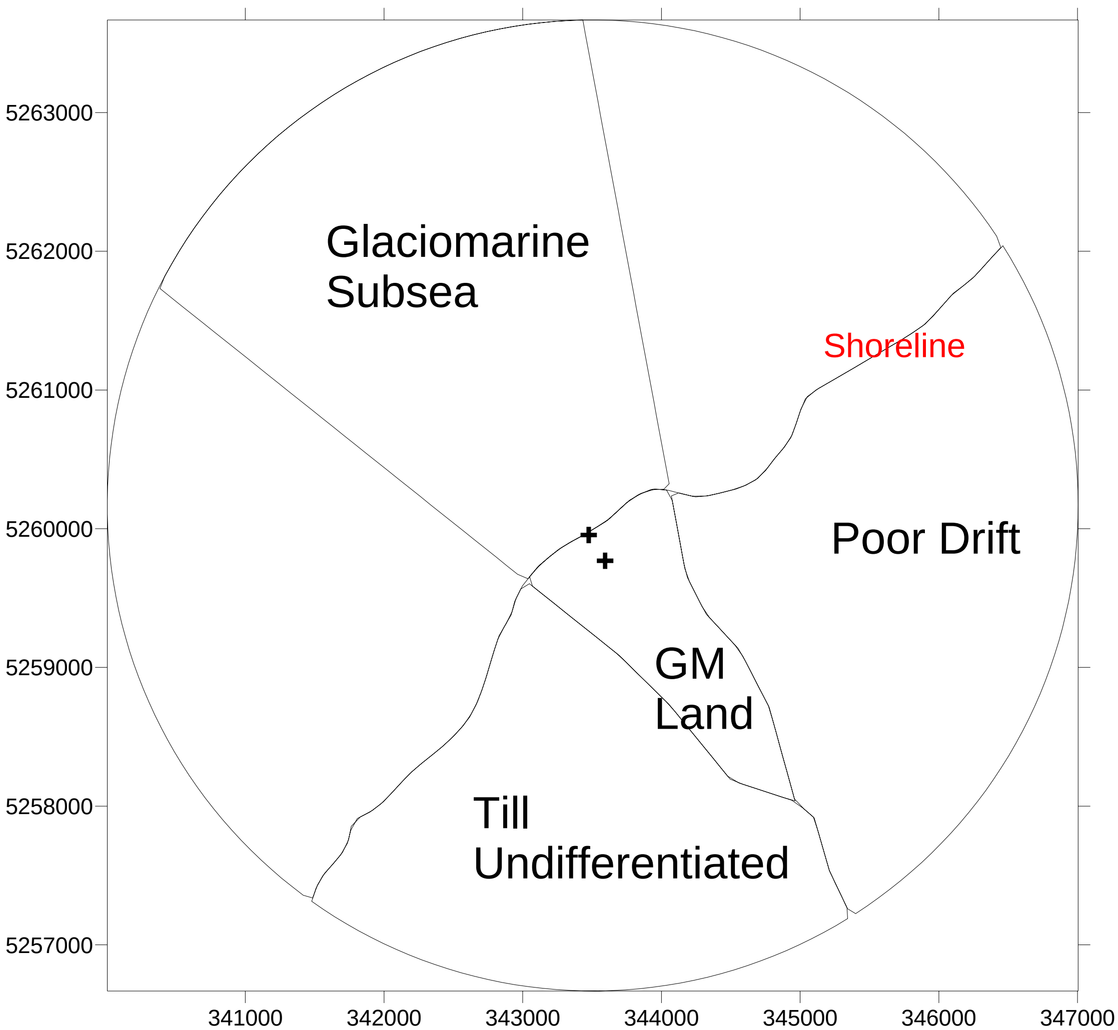


Figure 4-2: Conception Bay Resistivity Regions (Surficial)

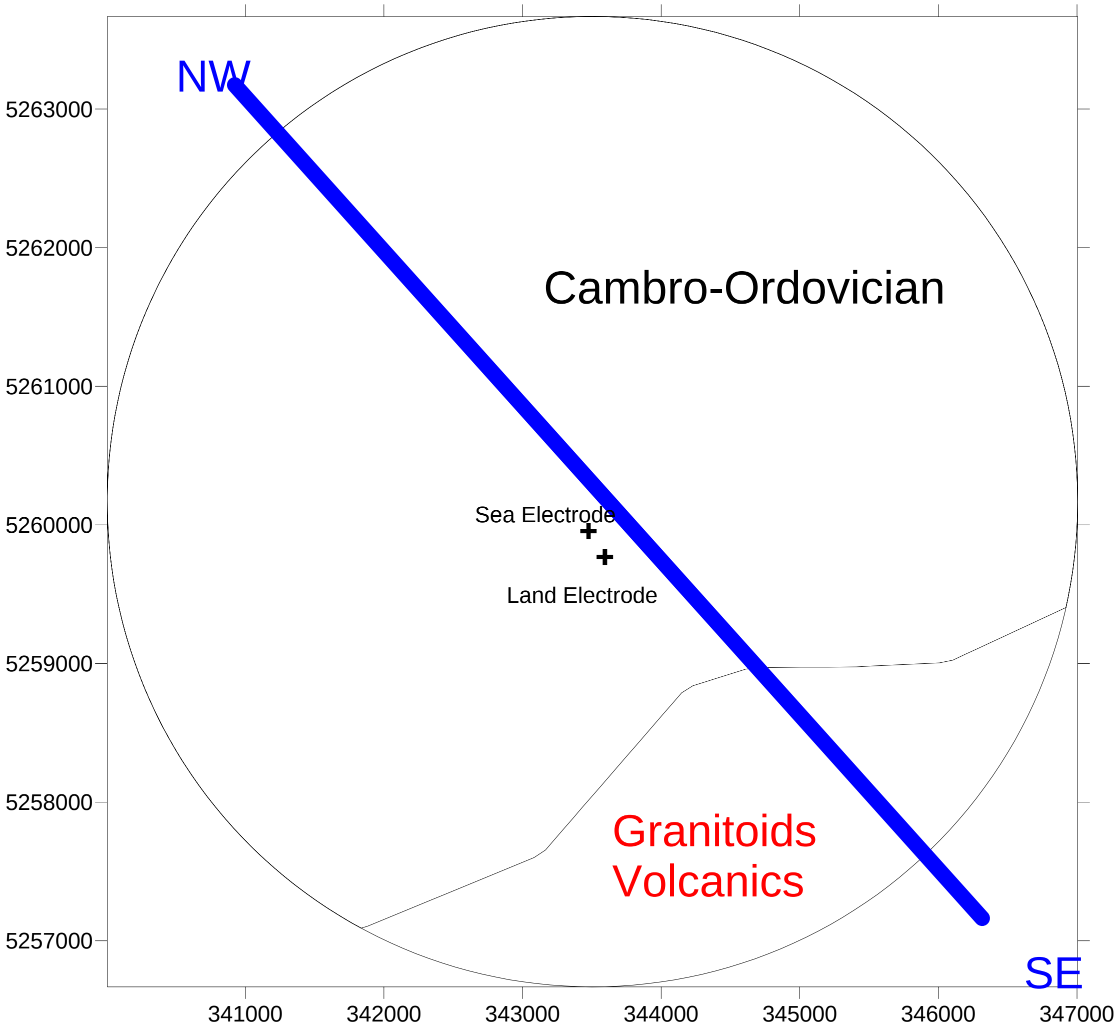


Figure 4-3: Conception Bay Resistivity Regions (Solid Rock Configuration)

This data as well as the bathymetric chart (sea depth) was used to revise previously developed resistivity models.

4.2. Input resistivity data to GRELEC program

The estimated electrode model (DP_15) was developed by dividing the area around the electrode site into 10° sectors as shown in Figure 4-4. East has been defined as 0°, Sector 1 covers 0° to 10° and the rest of the sectors progress in a counter clockwise fashion around the circle. The results are reported according to these same sectors. Complete resistivity models are included in Appendix A.

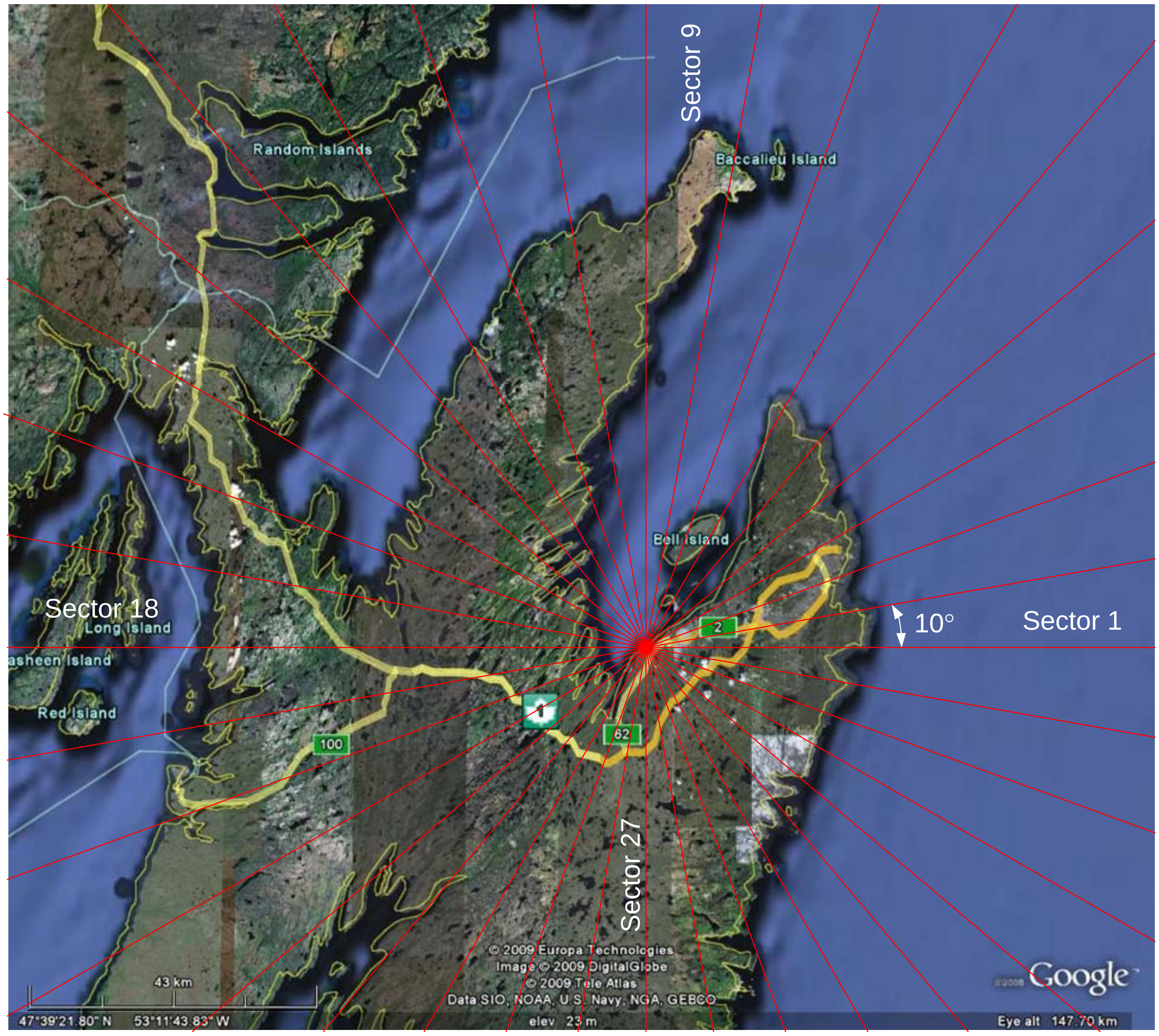


Figure 4-4: Electrode Model Sectors

A depiction of the resistivities modeled in the first layer is shown in Figure 4-5. The model has been developed out to 600 km, however, for the sake of clarity, rings with radii greater than 40 km have been omitted.

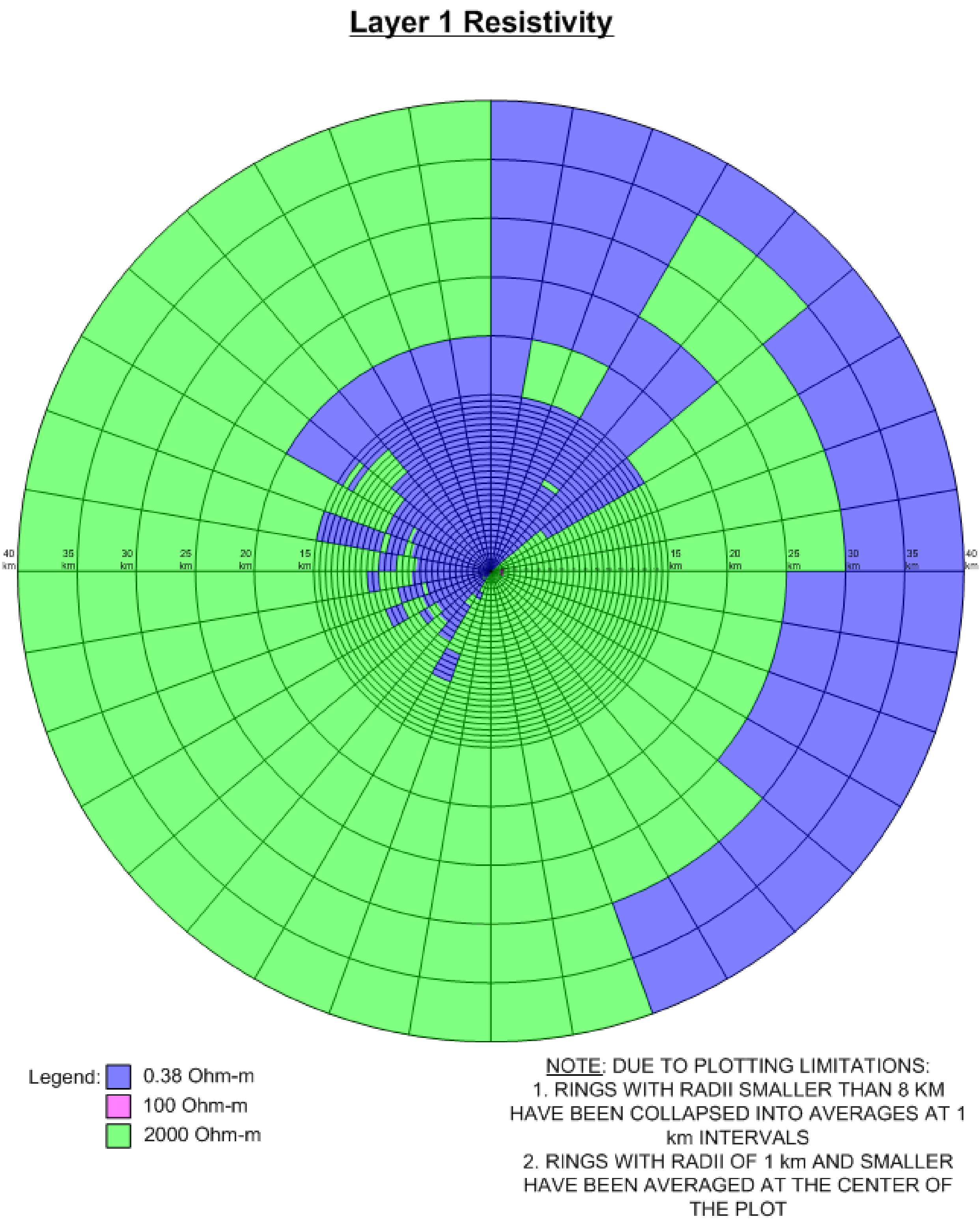


Figure 4-5: Layer 1 (1m Depth) Resistivity to 40km Radius

5. Study Results

The GRELEC program was used to calculate the voltage induced due to the operation of the electrode. The estimated ground potential rise (GPR) and gradient (GRD) for are provided below.

Figure 5-1 shows the estimated ground potential rise and Figure 5-2 shows the estimated voltage gradient on the surface versus distance from the electrode. Further results, including equipotential contours, are included in Appendix A.

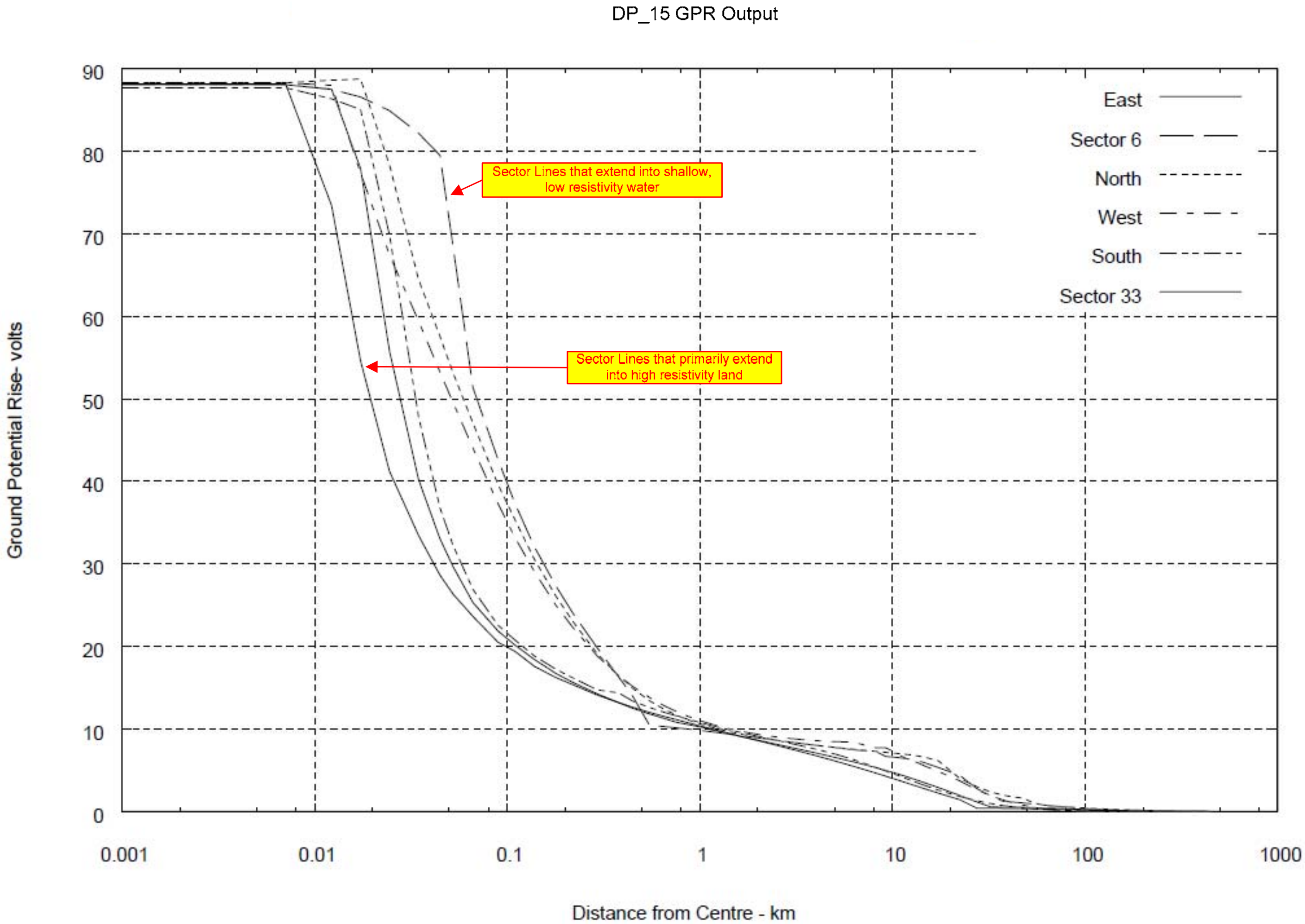


Figure 5-1: Estimated Ground Potential Rise

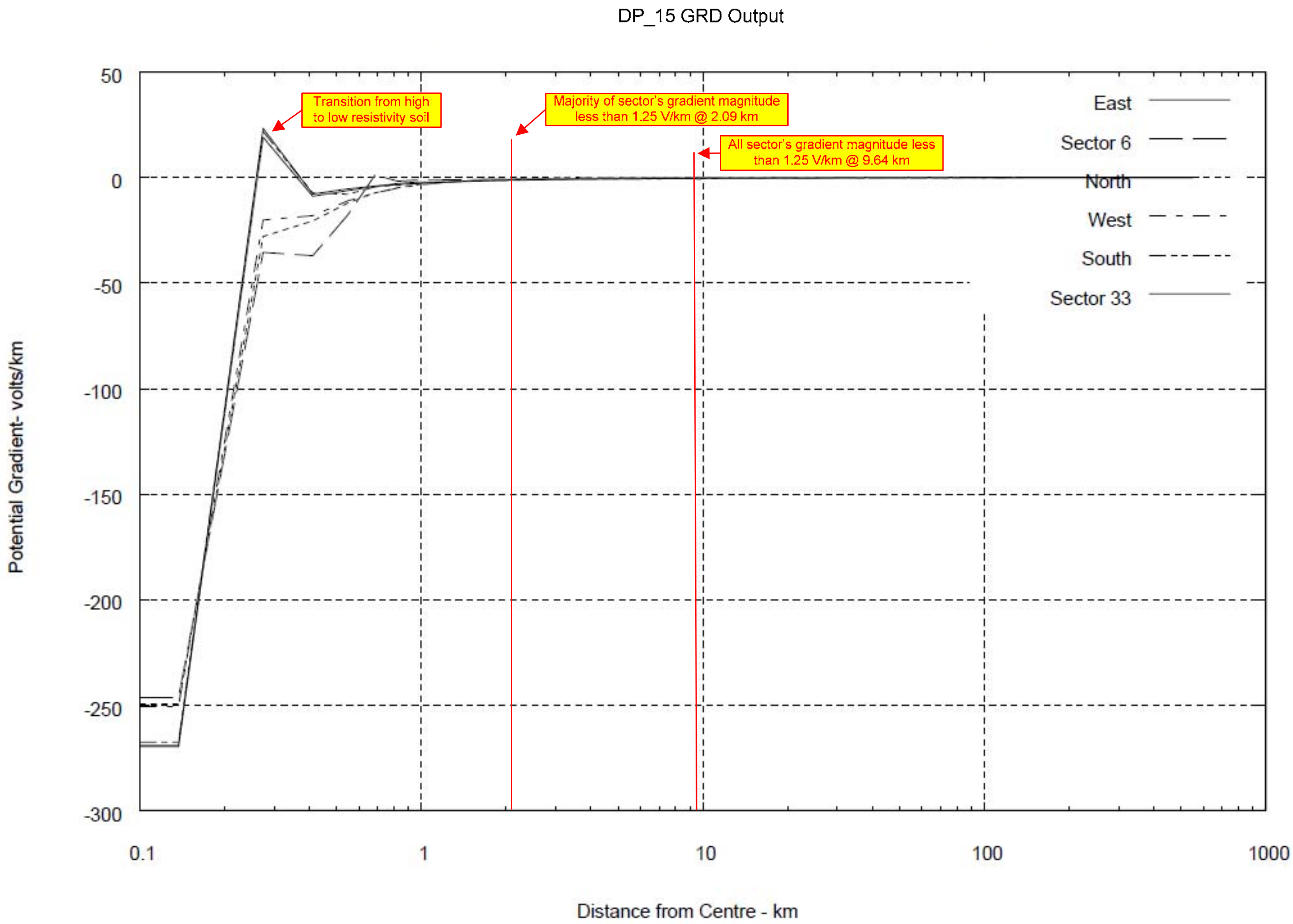


Figure 5-2: Estimated Voltage Gradient

The estimated ground potential rise shows a higher distribution of current towards Conception Bay (North, West & Sector 6 specifically) as shown in Figure 5-3 and an earlier reduction of estimated ground potential rise towards the land (South, East, & Sector 33 specifically). The estimated voltage gradient for all sectors is below -1.25 V/km at distances greater than 9.64 km from the electrode.

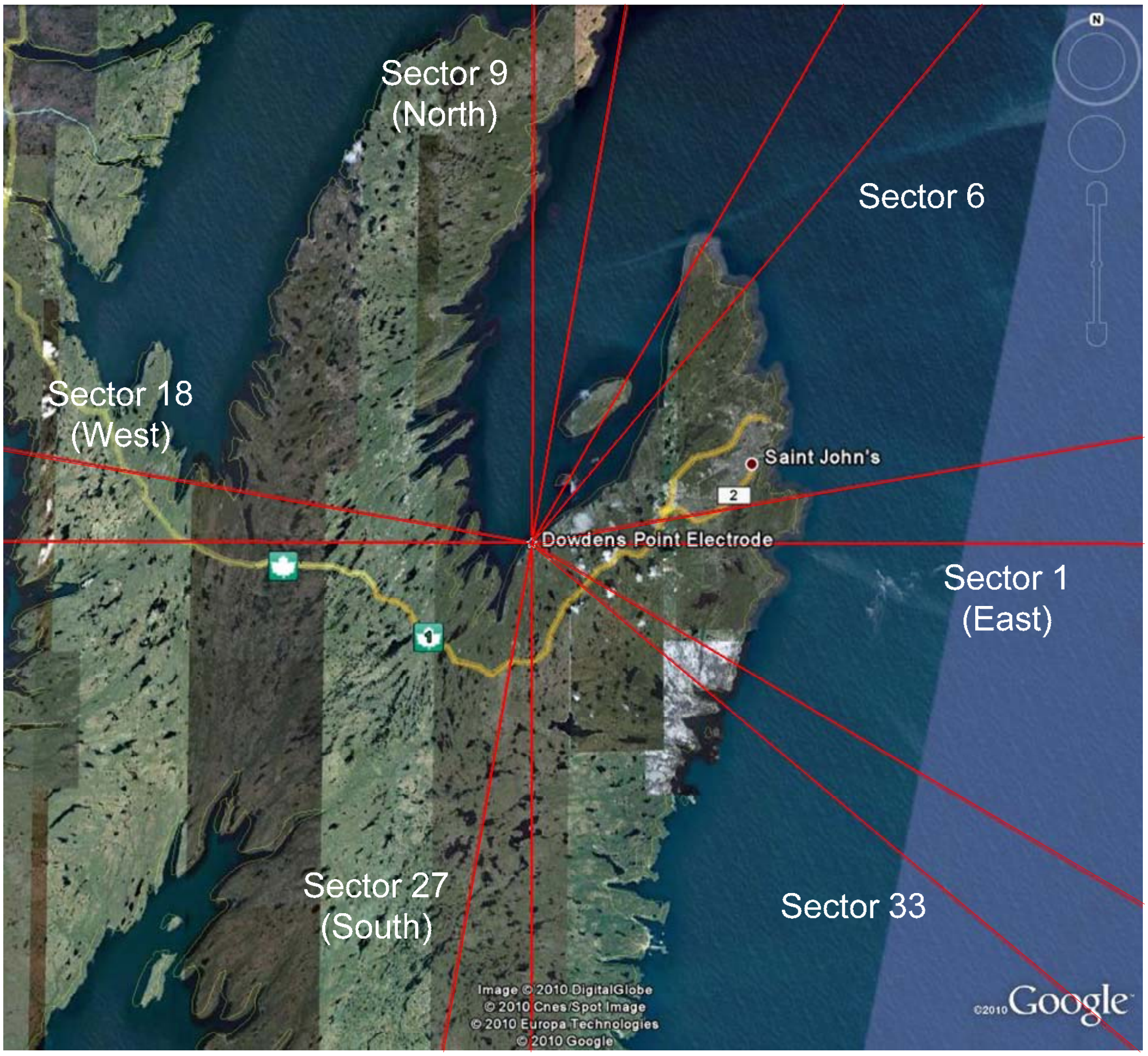


Figure 5-3: Sectors 1(East), 6, 9(North), 18(West), 27(South), & 33

Summary of results are given in Table 2. The maximum and minimum estimated ground potential rise is given at various distances from electrode

Table 2: Estimated Ground Potential Rise

Distance (km)	Voltage (V)
0.01 (electrode)	88.8 – 78.7
1	11.0 – 9.8
10	10.0 – 4.0
50	1.4 – 0.3
100	0.45 – 0.02

$$\text{Electrode resistance to the remote earth} = \frac{88.8\ \text{V}}{1340\ \text{A}} = 0.066\ \Omega\,.$$

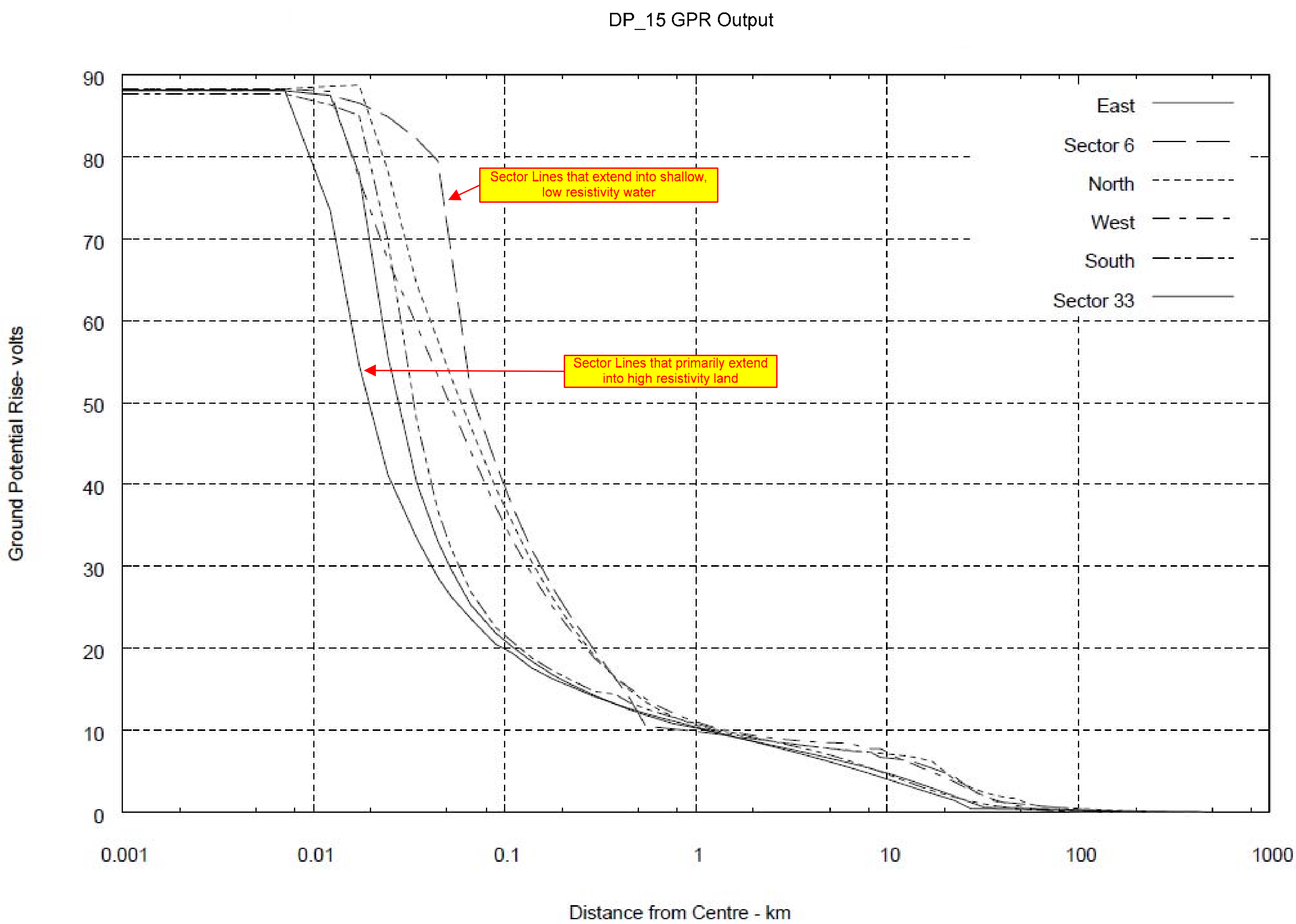
6. References

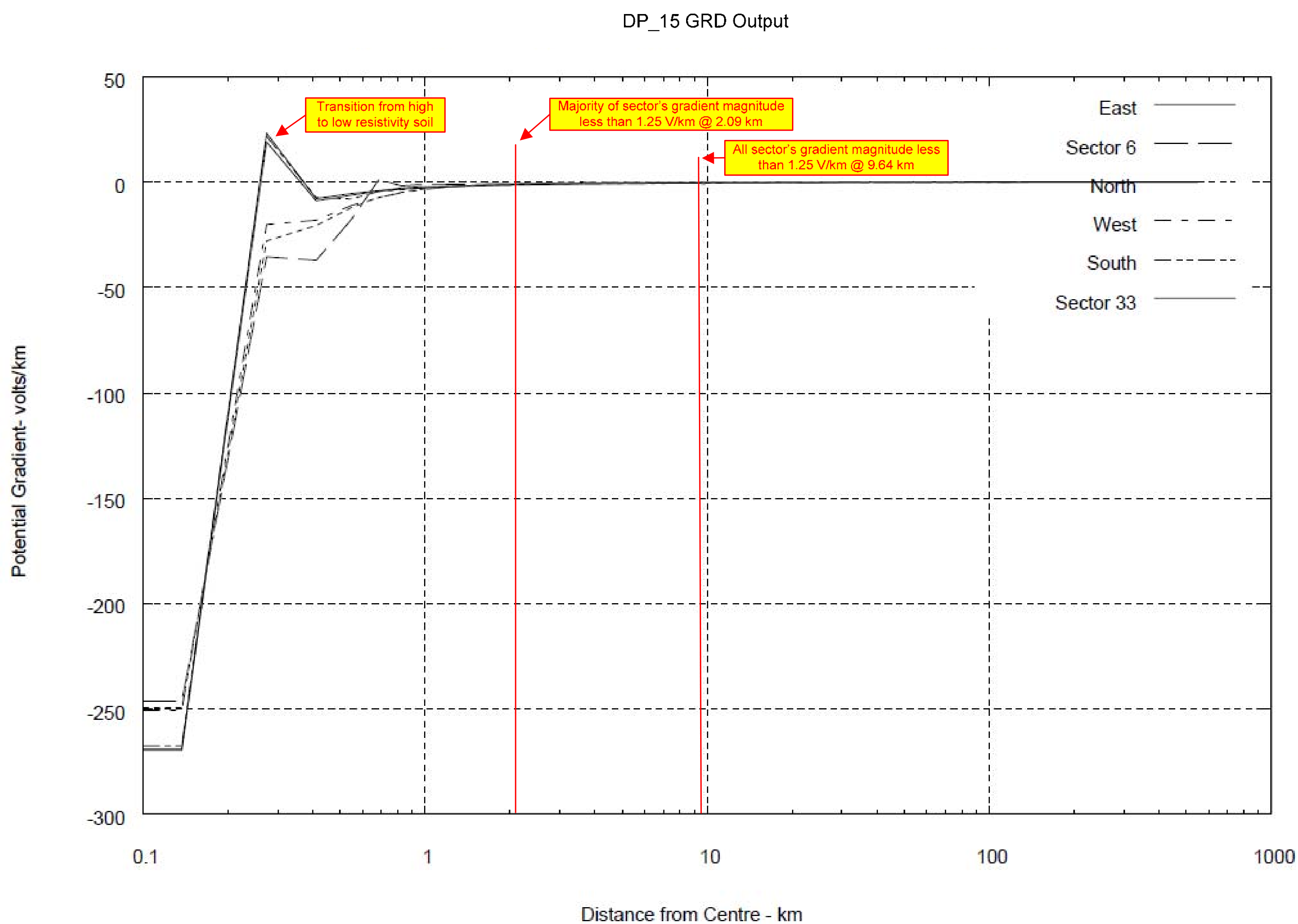
[1] H. G. Miller, "REVISED Dowden's Point Electrode Ground Potential Simulation Suggested Models," AMEC, St. John's, NL, September 2010.

Appendix A

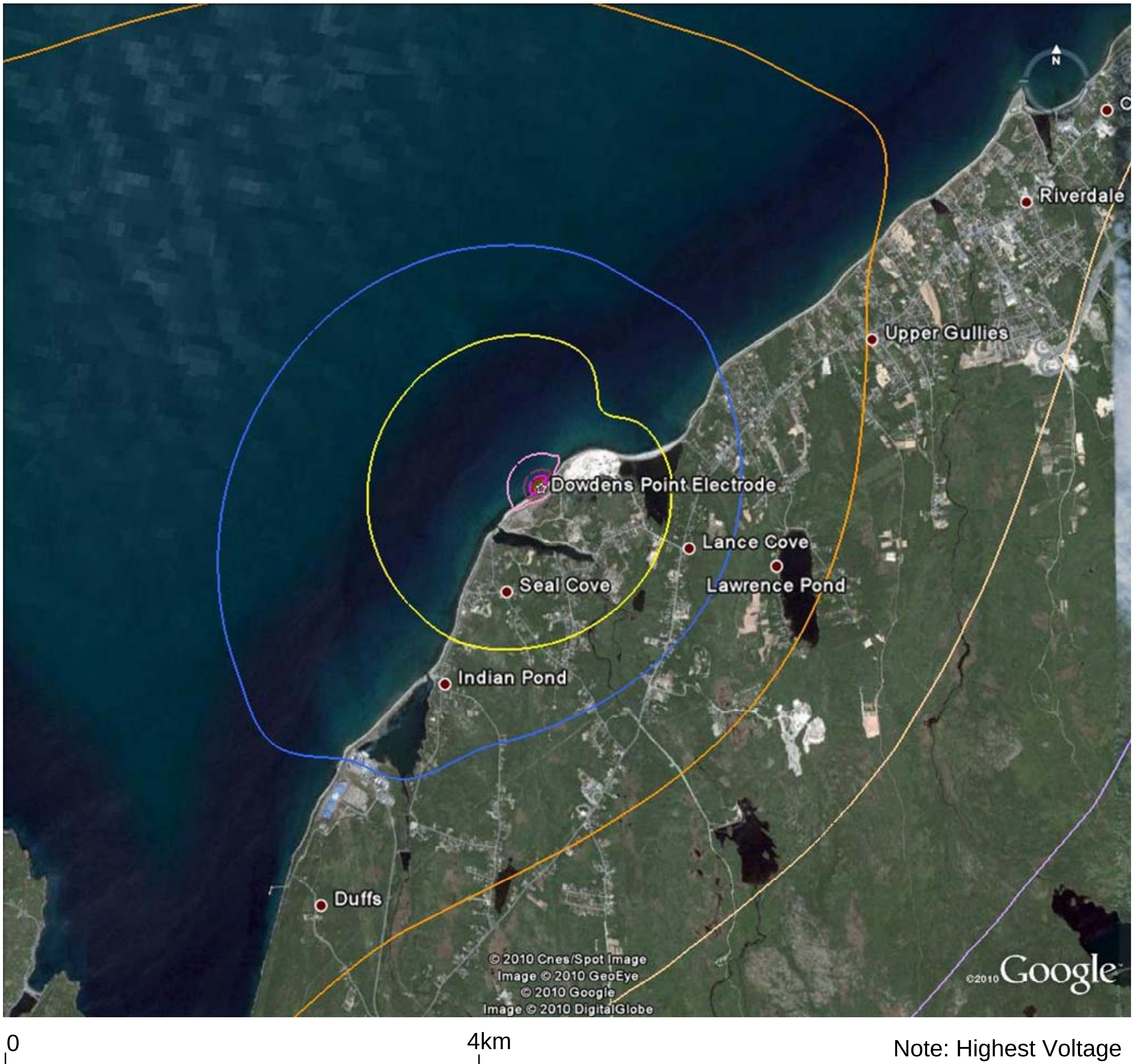
Results

DP_15 Results


DP_15 GPR Output
Ground Potential Rise- volts
Distance from Centre - km
0
10
20
30
40
50
60
70
80
90
0.001
0.01
0.1
1
10
100
1000
East
Sector 6
North
West
South
Sector 33
Sector Lines that extend into shallow, low resistivity water
Sector Lines that primarily extend into high resistivity land


DP_15 GRD Output
Transition from high to low resistivity soil
Majority of sector's gradient magnitude less than 1.25 V/km @ 2.09 km
All sector's gradient magnitude less than 1.25 V/km @ 9.64 km
East
Sector 6
North
West
South
Sector 33
50
0
-50
-100
-150
-200
-250
-300
Potential Gradient- volts/km
0.1
1
10
100
1000
Distance from Centre - km

Dowden's Point Equipotential Contours (to 4 km) – DP_15 0.38 ohm-m sea, 50 km depth

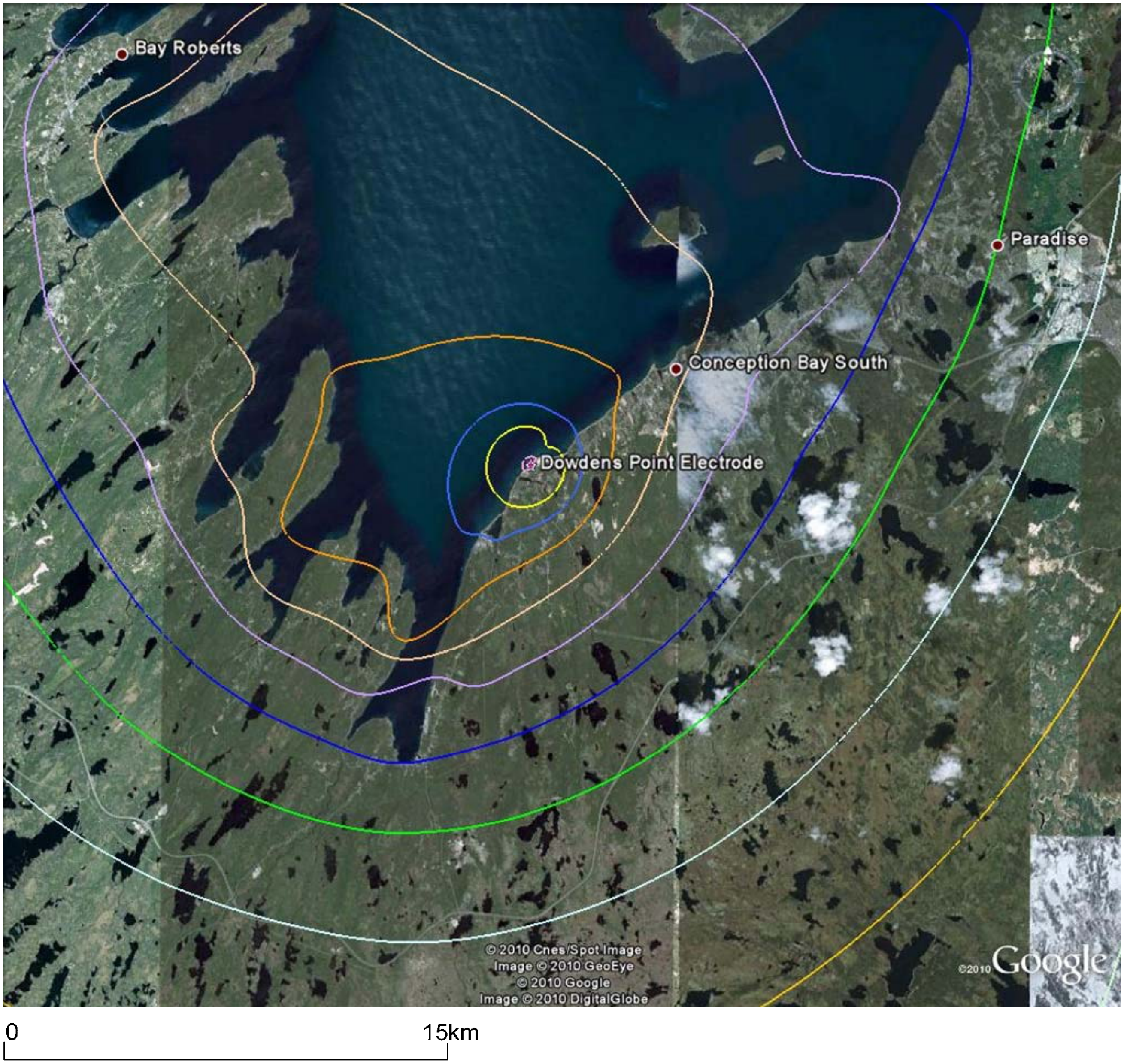


Note: Highest Voltage Calculated: 88.8V

Ground Potential Rise (V)

78 — 70 — 60 — 50 — 40 — 30 — 20 — 10 — 9 — 8 — 7 — 6

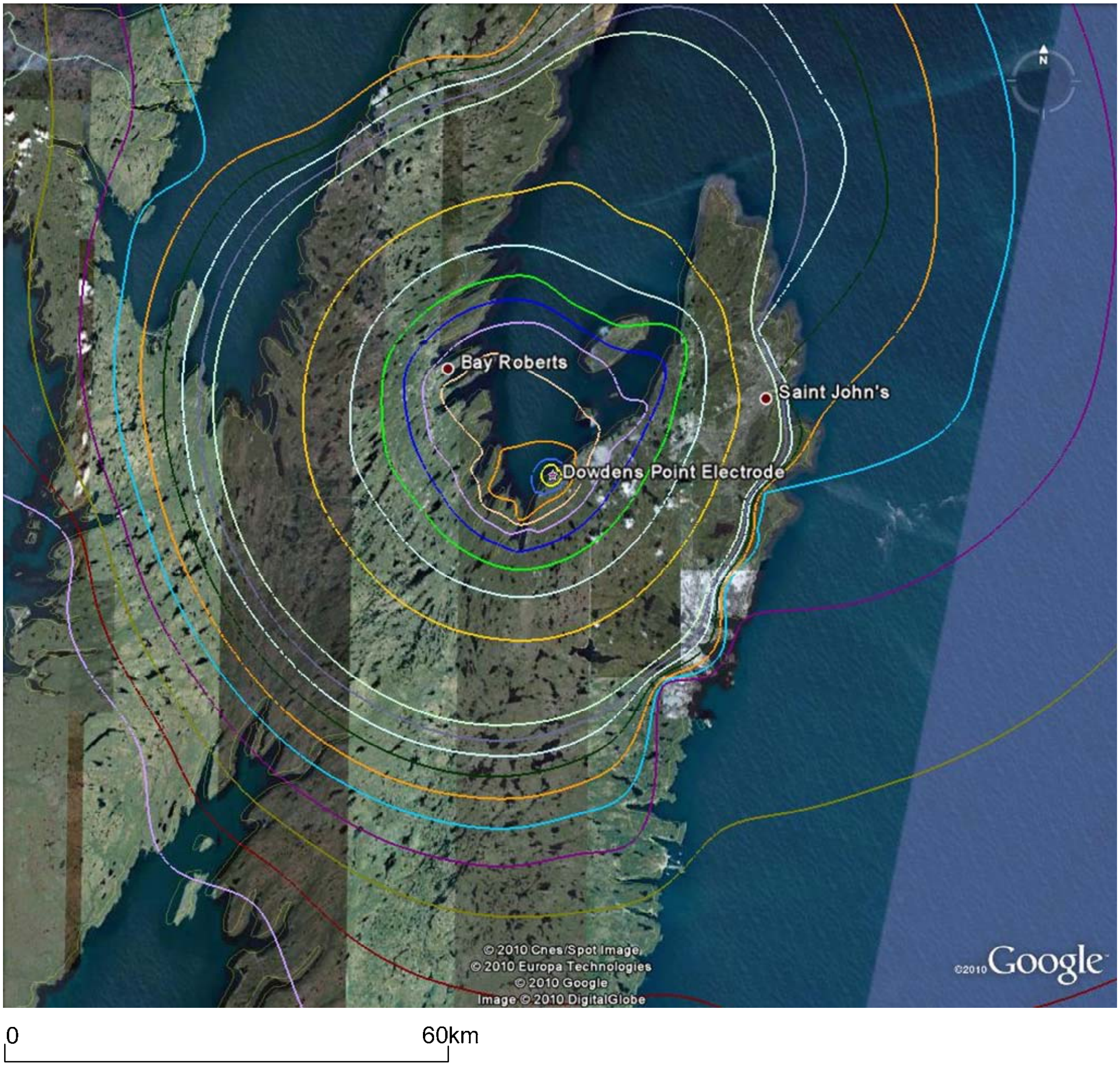
Dowden's Point Equipotential Contours (to 15 km) – DP_15 0.38 ohm-m sea, 50 km depth



Ground Potential Rise (V)

78	70	60	50	40	30	20	10	9	8	7
6	5	4	3	2						

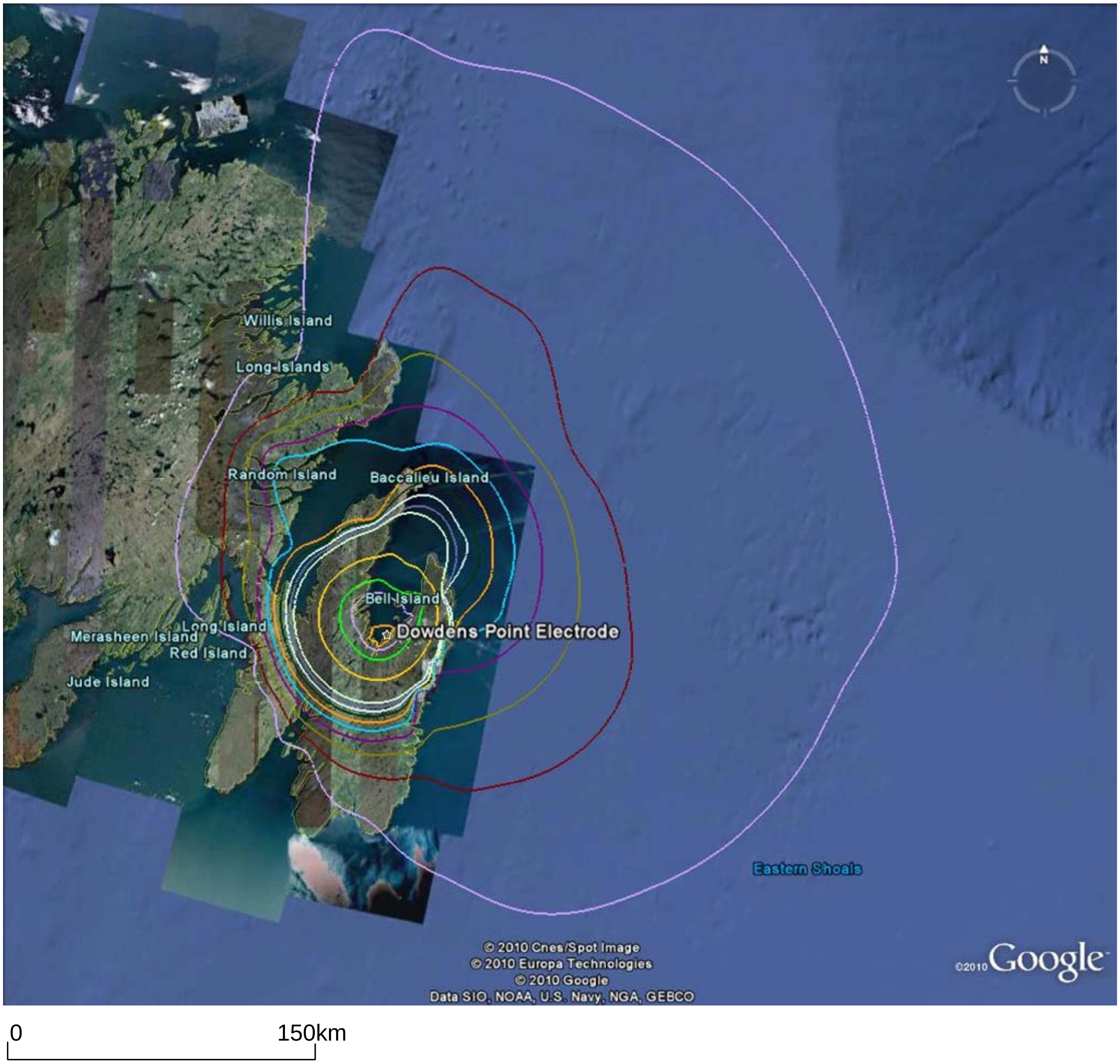
Dowden's Point Equipotential Contours (to 60 km) – DP_15 0.38 ohm-m sea, 50 km depth



Ground Potential Rise (V)

10	9	8	7	6	5	4	3	2	1
0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	

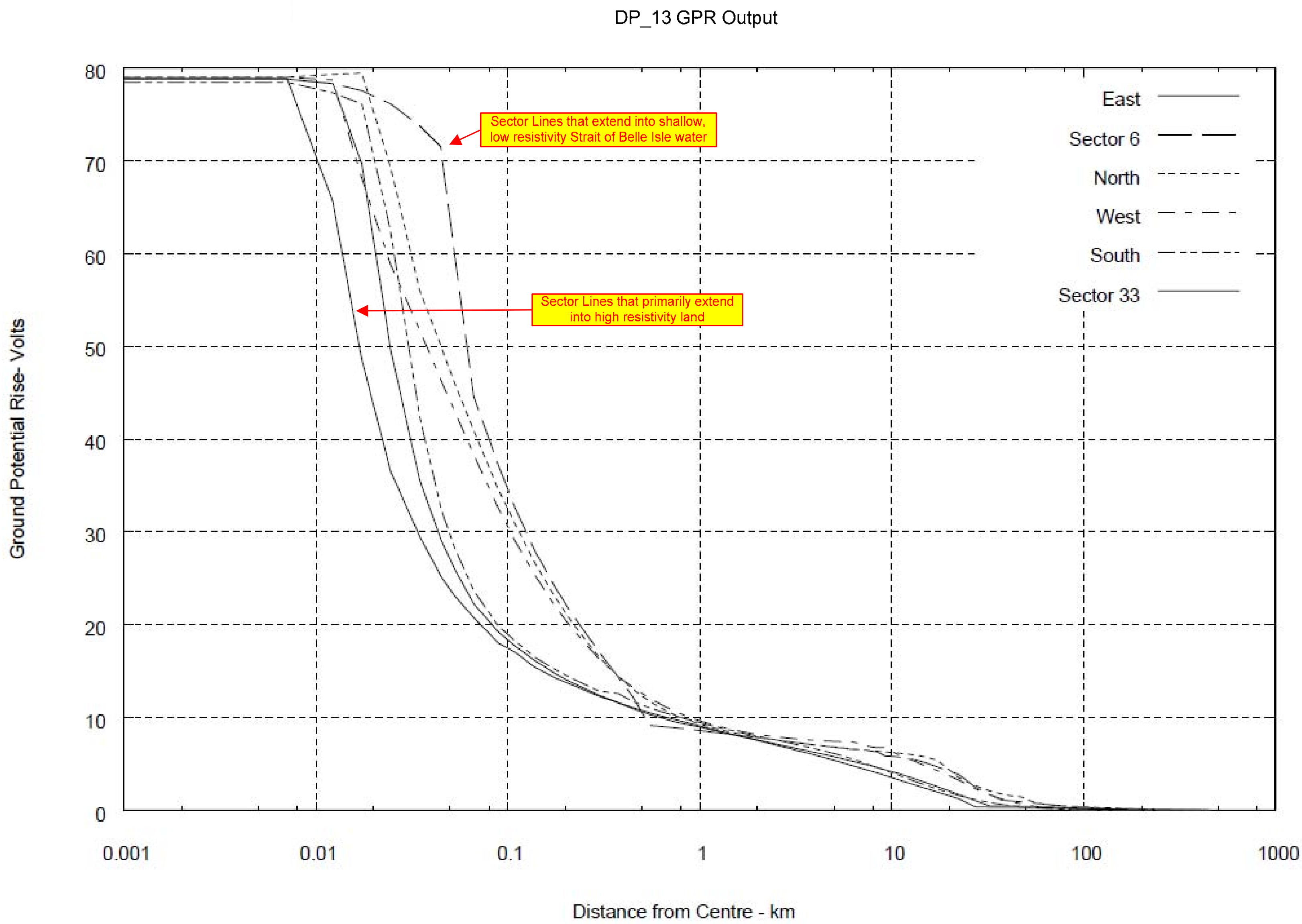
Dowden's Point Equipotential Contours (to 285 km) – DP_15 0.38 ohm-m sea, 50 km depth

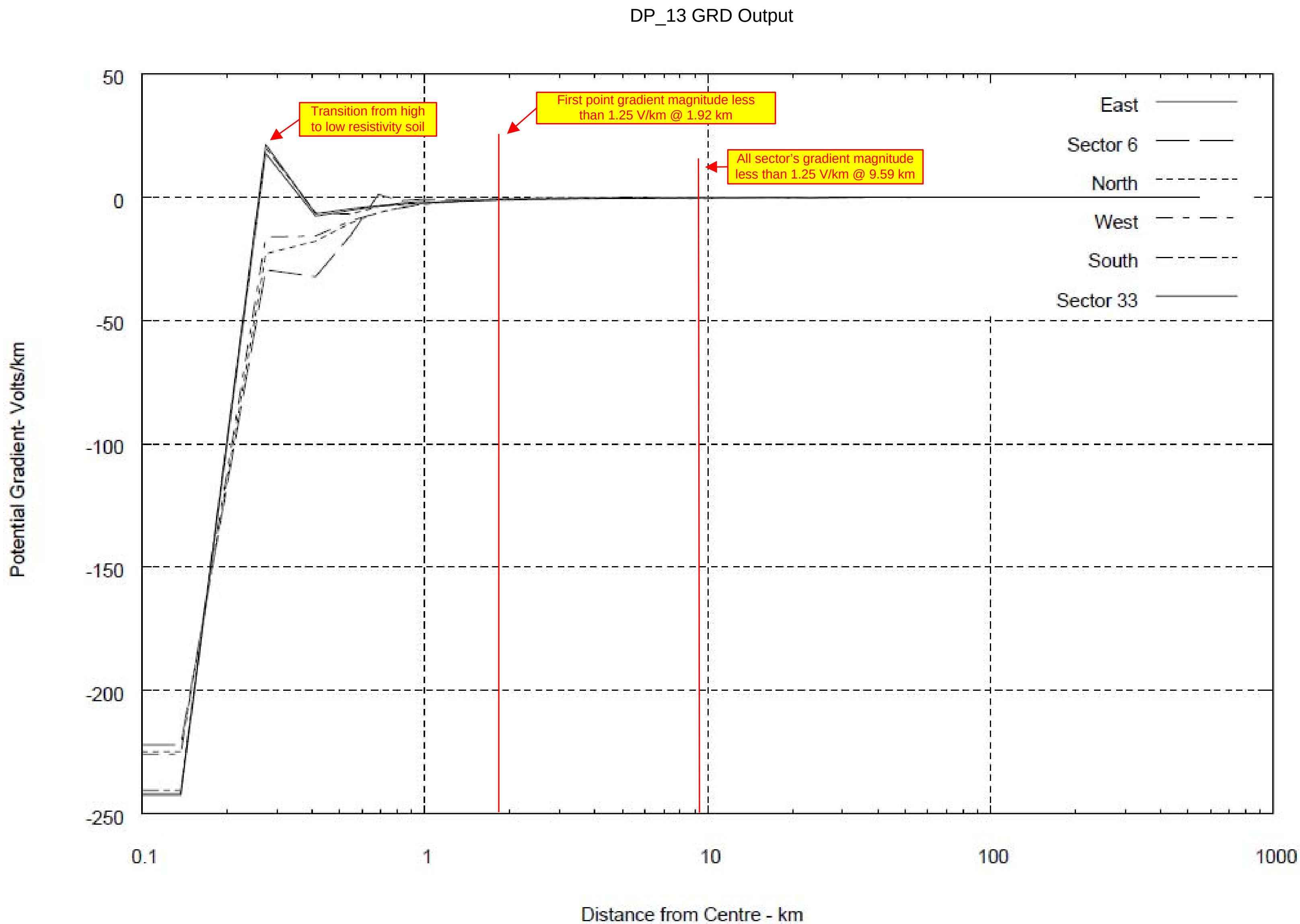


Ground Potential Rise (V)

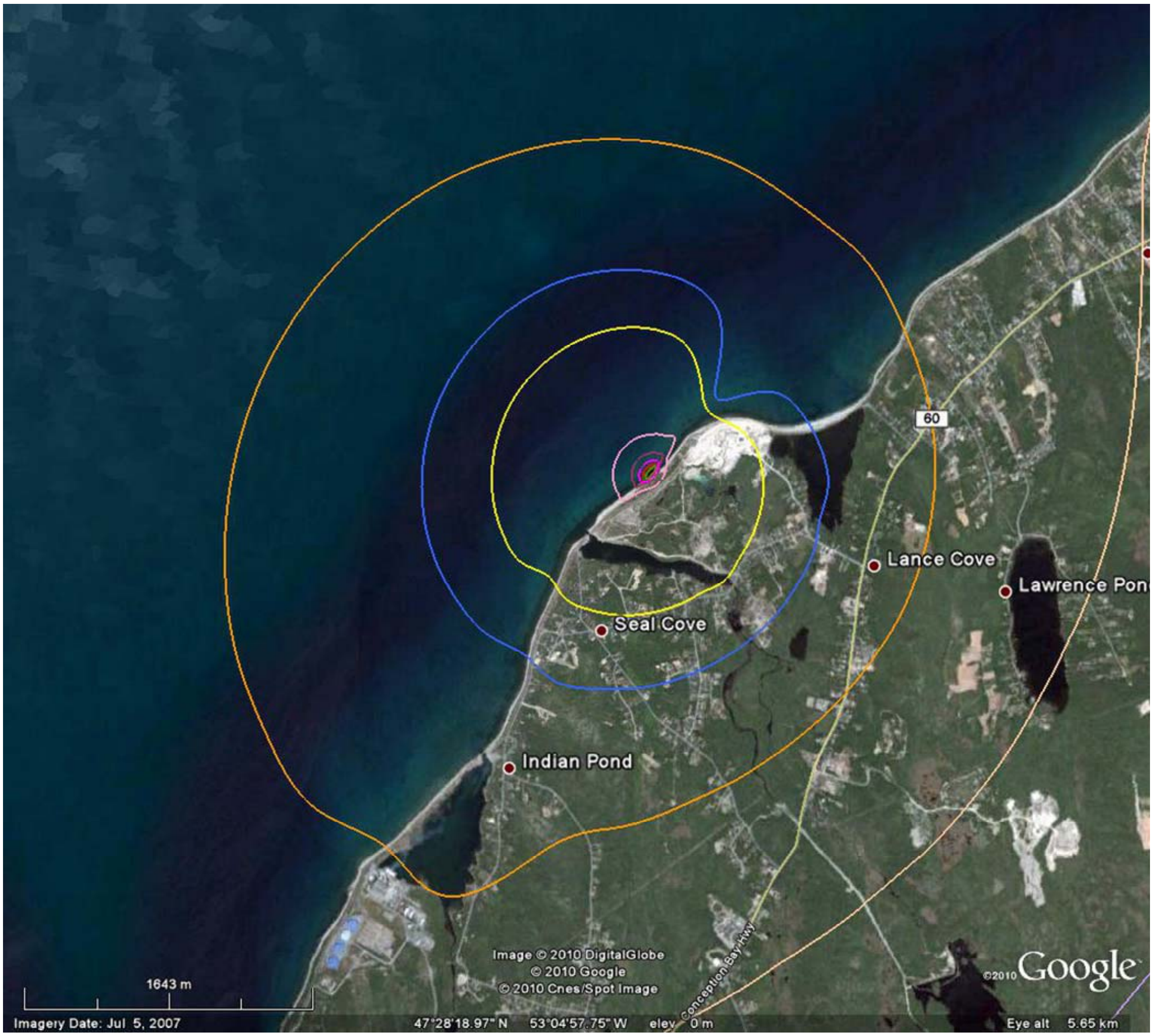
10	8	6	4	2	1	0.9	0.8	0.7
0.6	0.5	0.4	0.3	0.2	0.1			

DP_13 Results (Most Likely Conception Bay Water Resistivity, 0.33 Ohm-m)


DP_13 GPR Output
Ground Potential Rise- Volts
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
1000
Distance from Centre - km
East
Sector 6
North
West
South
Sector 33
Sector Lines that extend into shallow, low resistivity Strait of Belle Isle water
Sector Lines that primarily extend into high resistivity land


DP_13 GRD Output
Transition from high to low resistivity soil
First point gradient magnitude less than 1.25 V/km @ 1.92 km
All sector's gradient magnitude less than 1.25 V/km @ 9.59 km
East
Sector 6
North
West
South
Sector 33
Potential Gradient- Volts/km
50
0
-50
-100
-150
-200
-250
0.1
1
10
100
1000
Distance from Centre - km

Dowden's Point Equipotential Contours (to 4 km) – DP_13 0.33 ohm-m sea, 50 km depth



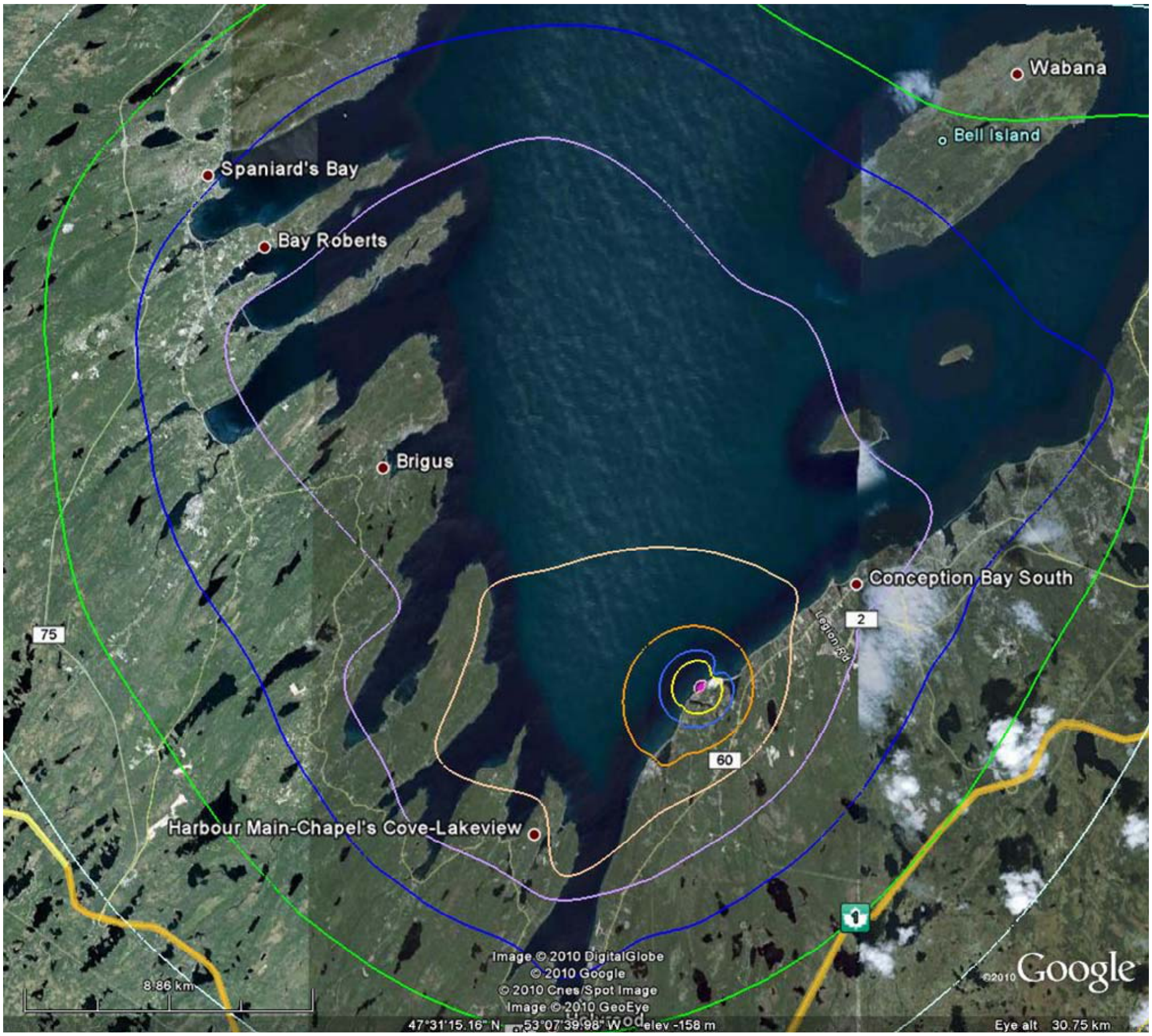
0 4km

Note: Highest Voltage Calculated: 79.5V

Ground Potential Rise (V)

78	70	60	50	40	30	20	10	9	8	7

Dowden's Point Equipotential Contours (to 15 km) – DP_13 0.33 ohm-m sea, 50 km depth

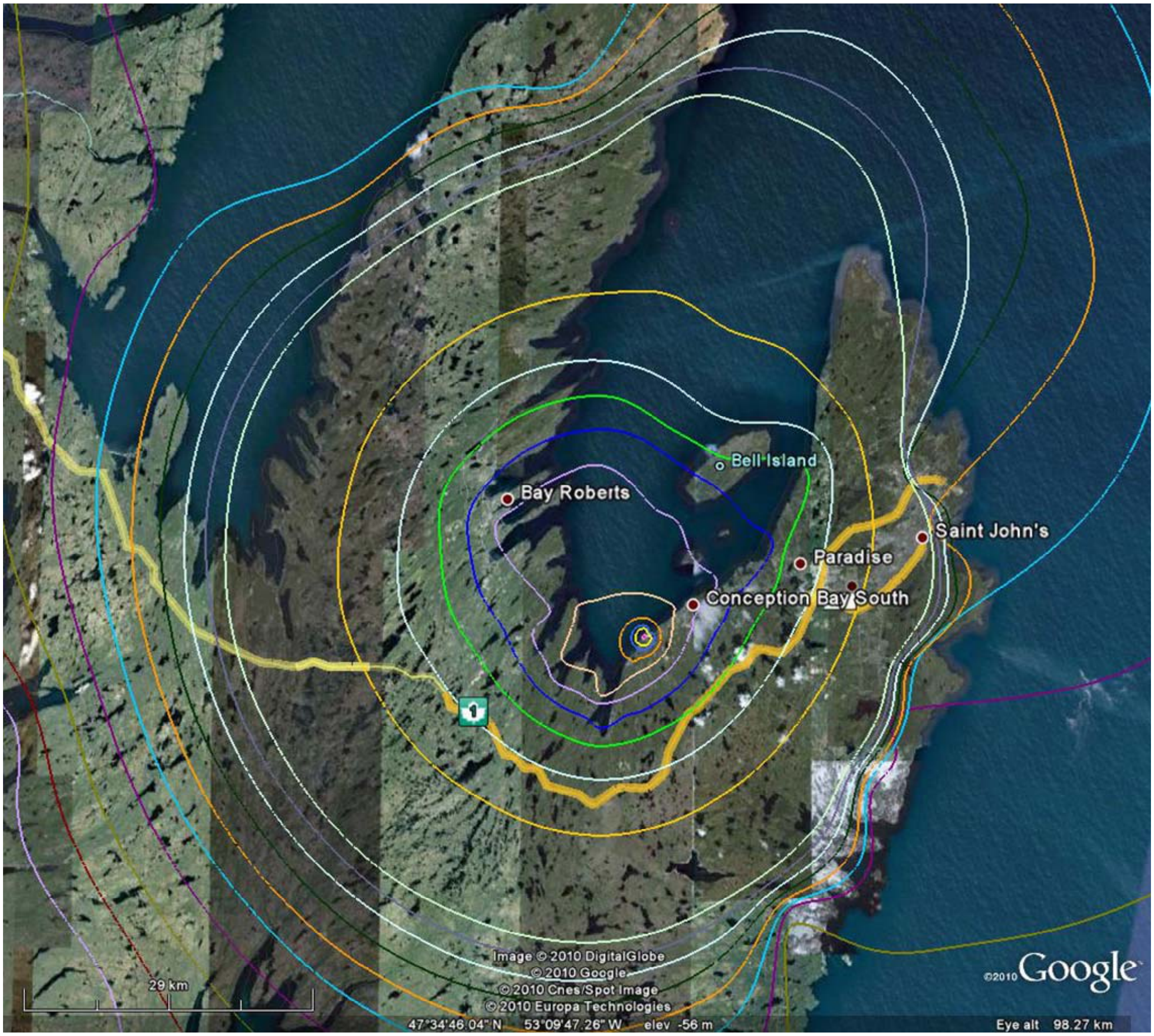


0 15km

Ground Potential Rise (V)

78, 70, 60, 50, 40, 30, 20, 10, 9, 8, 7, 6, 5, 4, 3

Dowden's Point Equipotential Contours (to 60 km) - DP_13 0.33 ohm-m sea, 50 km depth

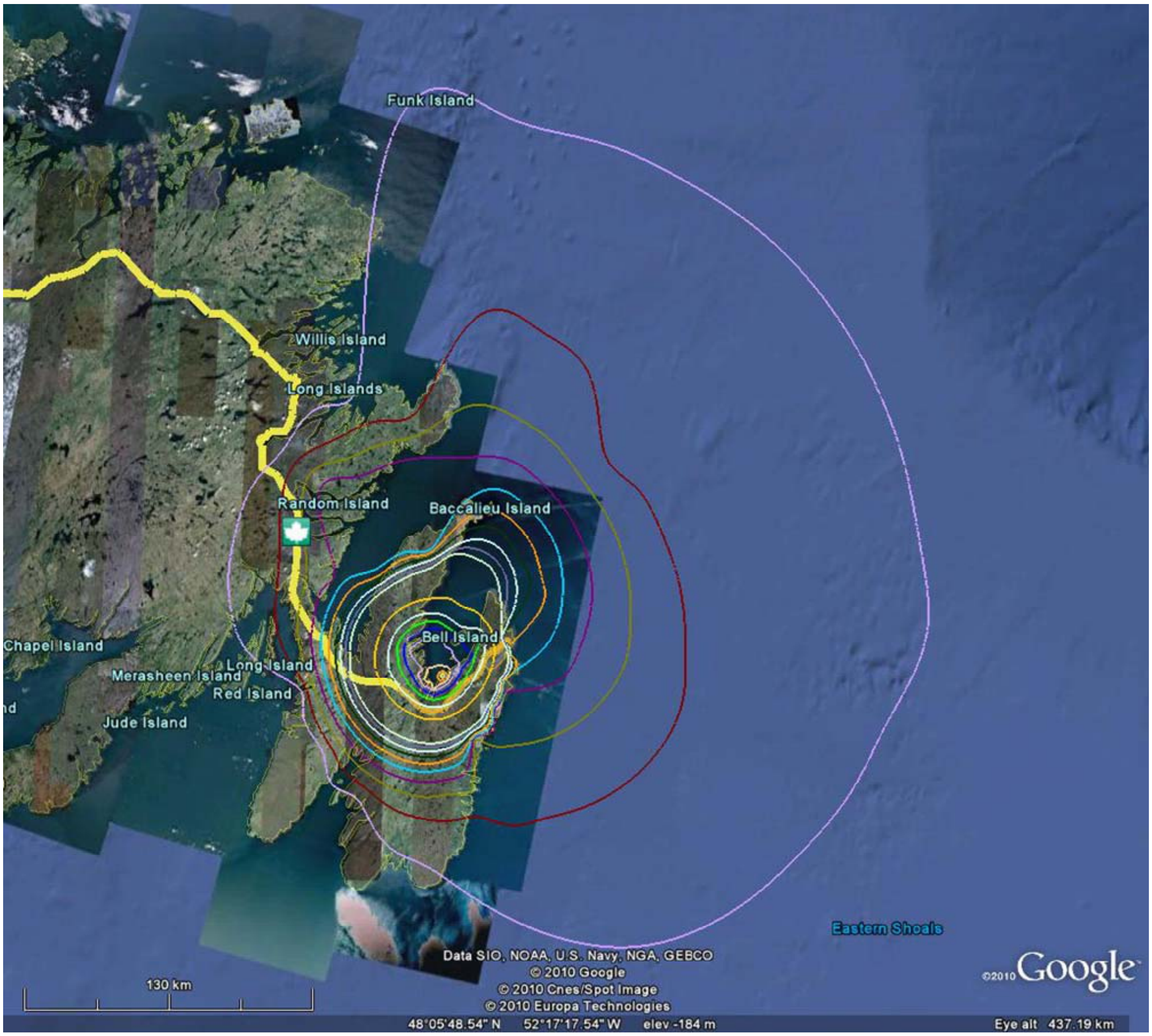


0 60km

Ground Potential Rise (V)

10, 9, 8, 7, 6, 5, 4, 3, 2, 1
0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1

Dowden's Point Equipotential Contours (to 260 km) – DP_13 0.33 ohm-m sea, 50 km depth

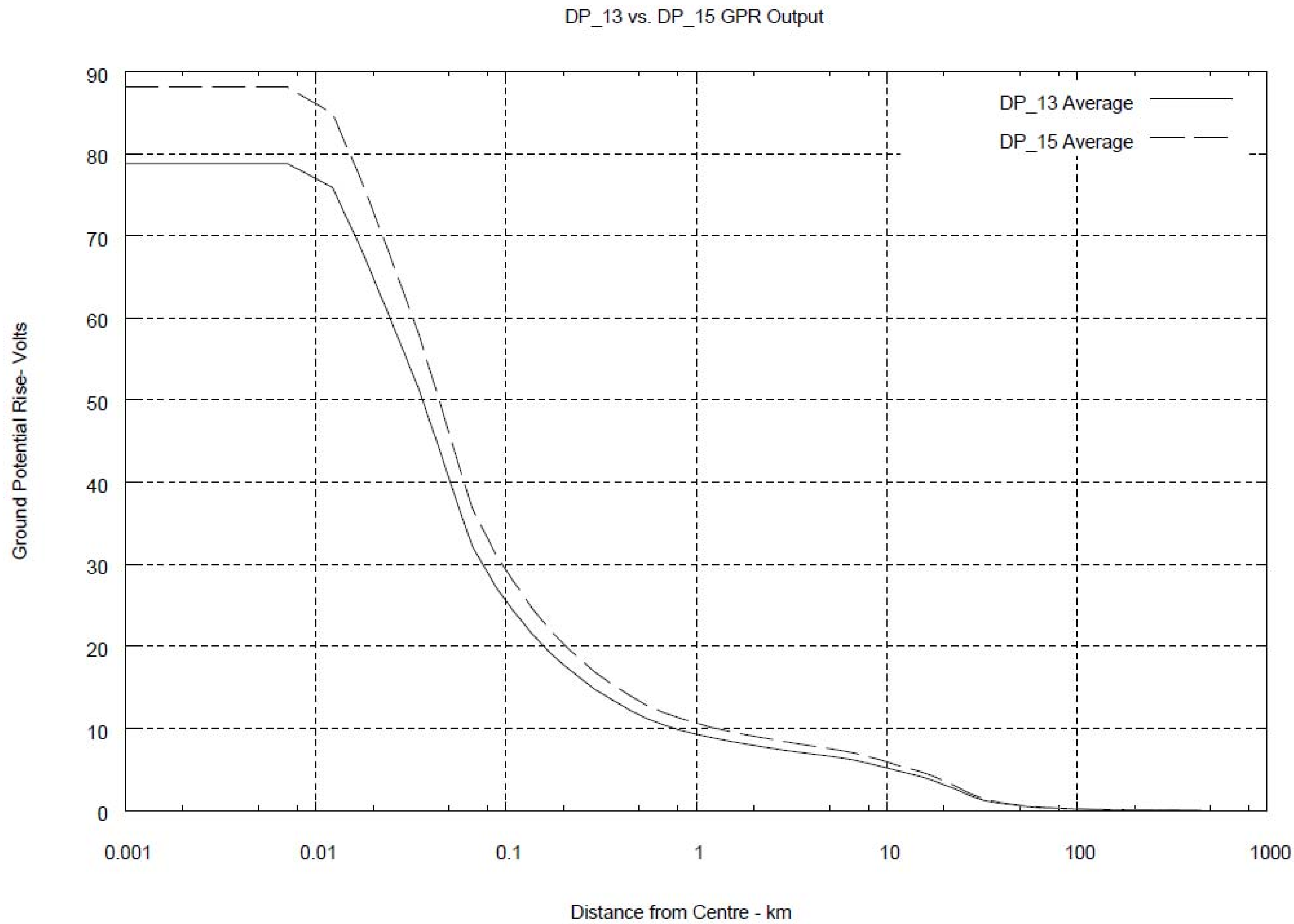


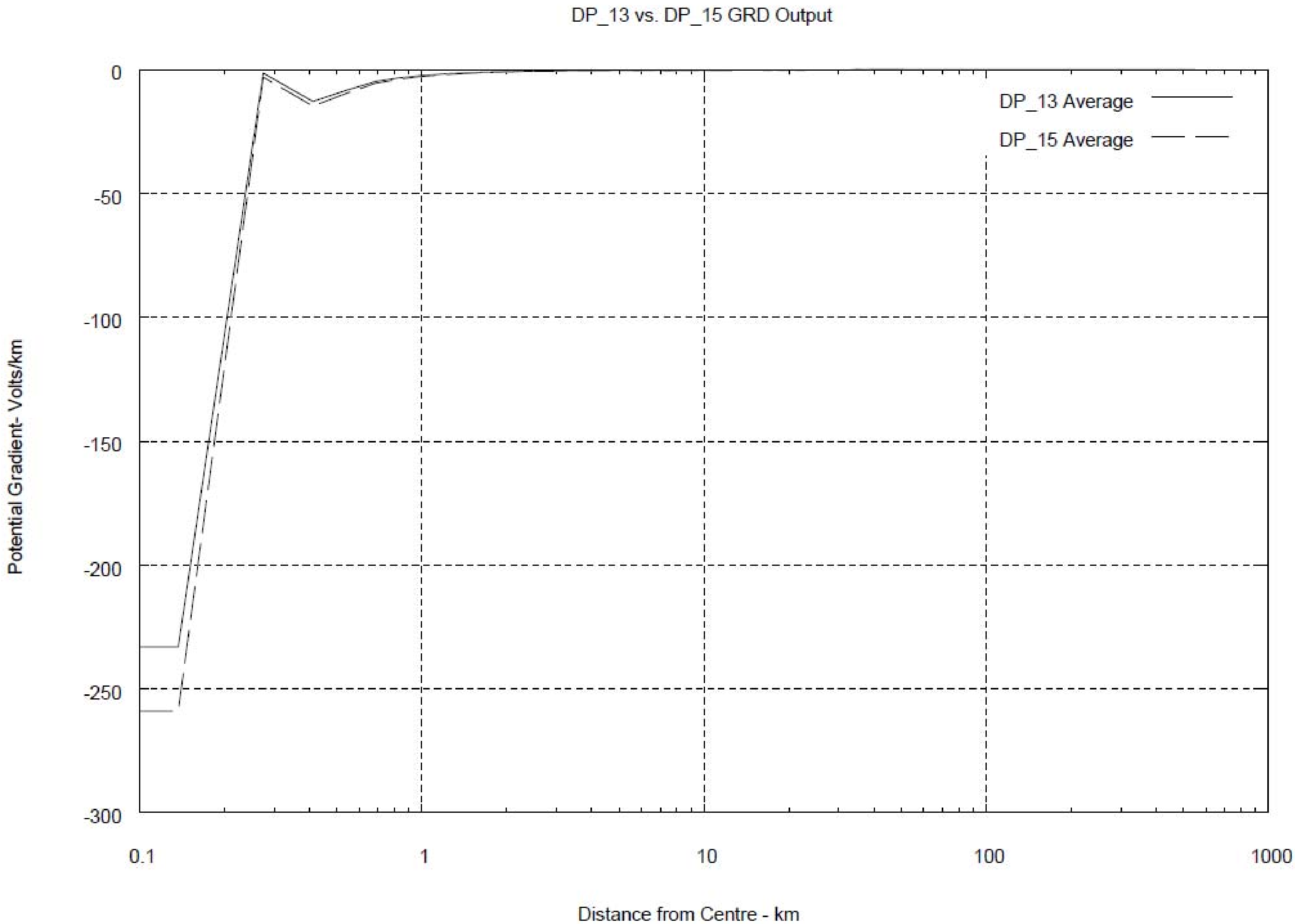
0 150km

Ground Potential Rise (V)

10	8	6	4	2	1	0.9	0.8	0.7
0.6	0.5	0.4	0.3	0.2	0.1			

DP_13 vs. DP_15 Average Comparisons


DP_13 vs. DP_15 GPR Output
Ground Potential Rise- Volts
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
1000
Distance from Centre - km
DP_13 Average
DP_15 Average


DP_13 vs. DP_15 GRD Output
DP_13 Average
DP_15 Average
Potential Gradient- Volts/km
0
-50
-100
-150
-200
-250
-300
0.1
1
10
100
1000
Distance from Centre - km

Appendix K

Chlorine Production Analysis

(AMEC)

Chlorine Production Summary for Nalcor

15Nov2010

I. Introduction

The objective of this summary is to evaluate the chlorine production at high silicon electrode elements operating as anode.

Tykeson et al. 1996 noted that high silicon iron alloys in high salinity environment are prone to high pitting rates. They state that electrodes with high silicon iron alloys should be used in waters of less than 20 PSU. The proposed water bodies are ~32 PSU.

The electrode elements proposed, however, are chill cast high silicon chromium type in accordance with ASTM A158 Grade 3 specifications. The chill cast process reduces the voids and improves structural bonding and are resistant to pitting corrosion in saline water of higher chlorine concentration (Anotec 2008). These elements were tested in the waters with a salinity of 34 PSU at current density 120 A/m^2 and found that the performance was acceptable (ABB 1999).

This summary is broken down into the following sections:

- Reactions at the anode and cathode
- Estimates of products from primary reactions
- Estimates of concentrations and speciations for secondary reactions
- Estimates of concentrations and speciation for tertiary reactions
- Toxicities of potential products

II. Reactions at the anode and cathode

The reactions involved that produce the chemicals of concern are listed below with the primary products being Chlorine gas (Cl_2) and Hydrogen gas (H_2) as described in Tykeson et al. (1996):

Anode Reaction

$2H_2O \rightarrow 4H^+ + O_2(g) + 4e^-$ **(1)**

$2Cl^- \rightarrow Cl_2(g) + 2e^-$ **(2)**

Cathode Reaction

$2H_2O + 2e^- \rightarrow 2OH^- + H_2(g)$ **(3)**

Secondary Reactions (Hypochlorite):
The products from reactions (2) can proceed to produce hypochlorite as shown below

$Cl_2(g) + H_2O \rightarrow HCl + HOCl$ (4)

$HOCl \rightarrow H^+ + OCl-$ (5)

Tertiary Reactions (Other pathways):

The hypochlorite solution can then follow a myriad of pathways similar to those for sodium hypochlorite as shown in **Figure 1**.

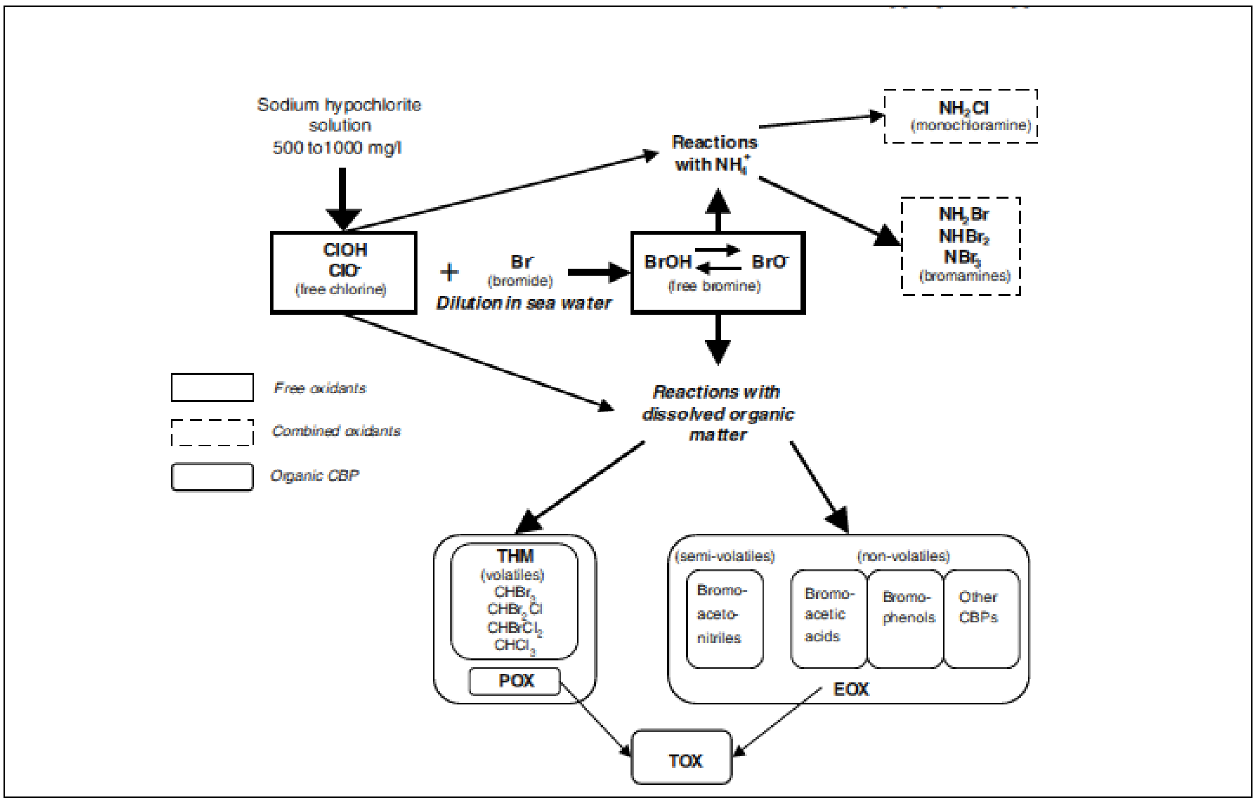


Figure 1. Potential hypochlorite pathways (Taylor 2006)

III. Estimates of products from primary reactions

The concentrations of products from reactions (2) and (3) have been estimated based on Faraday's Law and a maximum Cl_2 yield of 30% (Reaction 2) and maximum H_2 yield of 100% (Reaction 3) as used in Tykeson et al. (1996).

It is important to note that these are conservative estimates do not take into consideration the tidal flushing between the pond water and the ocean (twice per day) and chlorine evaporating from the pond into the atmosphere. In addition, the shoreline pond volumes in **Table 1** are based on the minimum dimensions established in the breakwater sizing and safety limit calculations. The actual shoreline pond volumes considered in the design of the Gull Island and Soldiers Pond electrodes are larger than those stated in **Table 1.** These three factors will further reduce the concentrations of chlorine and hydrogen in the pond as compared to the conservative values presented in **Table 1**.

Faraday's Law:

$$n = \frac{(T * I)}{(z * F)}$$

T = Operating time (s)
I = Total current (A)
z = Stoichiometric # of electrons transferred from anodic or cathodic reaction (2)
F = Faraday constant (96485 C/mol)
n = Products evolved (mol/s)

Figure 2. Faraday's Law

Table 1. Calculations of Cl_2 and H_2 yield based on Faraday's Law

Variable	Unit	Gull Island (Anode)	Gull Island (Cathode)	Soldiers Pond (Anode)	Soldiers Pond (Cathode)
T	**seconds**	1	1	1	1
I	**Amps**	2320	2320	1340	1340
z	**#**	2	0.50	2	0.50
F	**C/mol**	96485	96485	96485	96485
n	**mol/s**	1.20E-02	4.81E-02	6.94E-03	2.78E-02
n	**mol/year**	3.79E+05	1.52E+06	2.19E+05	8.76E+05
Cl_2 (30%)	**kg/s**	2.56E-04	-	1.48E-04	-
Cl_2 (30%)	**kg/year**	8.07E+03	-	4.66E+03	-
H_2 (100%)	**kg/s**	-	9.62E-05	-	5.56E-05
H_2 (100%)	**kg/year**	-	3.03E+03	-	1.75E+03
Pond length	**m**	100	100	60	60
Pond width	**m**	15	15	15	15
Pond depth	**m**	4	4	4	4
Pond volume	**L**	6.00E+06	6.00E+06	3.60E+06	3.60E+06
[Cl_2] one day	**g/L**	3.68E-03	-	3.55E-03	-
[H_2] one day	**g/L**	-	1.39E-03	-	1.33E-03

IV. Estimates of concentration and speciation from secondary reactions

Reaction (4) in seawater (average pH ≈ 8) will tend to move to the right (Tykeson et al. 1996) yielding a minimum amount of Cl_2 at equilibrium and a large amount of product (HCl and HOCl).

Reaction (5) will have a similar result. Using the Keq (5) = 3.5×10^{-8}, then the equilibrium equation is as follows and the ratio of the concentration of [HOCl] to [OCl-] can be calculated:

Keq = [Products]/[Reactants]

$$K_{eq} = \frac{[H^+] * [OCl^-]}{[HOCl]}$$

$$\frac{K_{eq}}{[H^+]} = \frac{[HOCl]}{[OCl^-]}$$

$$\frac{[HOCl]}{[OCl^-]} = 3.5$$

Keq = 3.5×10^{-8}
[H+] = 10^{-8} (at a pH of 8.0, ambient seawater)

Figure 3. Equilibrium for Hypochlorite production

V. Estimates of concentrations from tertiary reactions

As can be seen from **Figure 1**, the tertiary reactions can follow a number of different pathways that are not easy to predict. These reactions are dependent upon numerous variables and characteristics of the water including but not limited to:

- water temperature
- pH
- salinity
- light penetration
- current density
- dissolved organic matter concentrations
- coordination complexes (ligands and chelates)

To obtain the best estimate of speciation and chemical equilibrium without a field study, a software program such as MINEQL should be used.

VI. Toxicities of potential products

Most of the work analyzing the toxicity of hypochlorites in seawater involves the sodium hypochlorite, a product used in defouling of power plant cooling water intakes in marine environments (Lopez-Galindo et al. 2010, Taylor 2006). The toxicity of chlorinated byproducts (CBPs) in relation to sodium hypochlorite has been examined in literature reviews and **Table 2** presents some of those findings.

Coastal water quality standards and proposed 'reference levels' for presumed CBPs

Substance by QSAR classification	Water quality standard	Proposed 'reference level'
Class I (inert chemicals)		
Chloroform	12 µg/l[AA]	–
Bromoform[a]	–	5 µg/l[MAC E]
Dibromochloromethane[a]	–	5 µg/l[MAC P]
Dichlorobromomethane[a]	–	5 µg/l[MAC P]
Class II (less inert chemicals)		
2,4-Dibromoaniline	–	IDA
2,4-Dibromophenol[a]	–	IDA
2,4,6-Tribromophenol[a]	–	12 µg/l[MAC E/P]
2,4,6-Trichlorophenol	–	12 µg/l[MAC E]
Class III (reactive chemicals)		
Dibromoacetonitrile	–	IDA
Unclassifiable—potential Class IV (specifically acting chemicals)		
1,2-Dibromophenol[a]	–	20 µg/l (total DBPs)[P]
1,2,3,4-Tetrachlorobenzene	–	5 µg/l[MAC E]

Toxicity classifications after Verhaar and Hermens (1991) and results after Johnson et al. (1994).
IDA: Insufficient data available to complete QSAR analysis.
[AA] Annual average concentration.
[E] Proposed reference level derived from experimental data.
[MAC] Maximum allowable concentration.
[P] Proposed reference level derived from QSAR predictions.
[a] Subsequently found as a CBP.

Table 2. Toxicity of some of the potential chlorinated byproducts (from Taylor 2006). QSAR (Quantitative structure-activity relationship) is a process whereby chemical structure is correlated with biological activity.

VII. References

ABB Corporate Research. 1999. Publication SECRC/D/LR-99/108. 8pp.

Anotec , 2008. HIGH SILICON CAST IRON for ELECTRODES, Anotec Pubication. Rev. 02, January 17, 2008. 3pp.

Lopez-Galindo, C., M. C. Garrido, J. F. Casanueva, and E. Nebot, 2010, Degradation models and ecotoxicity in marine waters of two antifouling compounds: Sodium hypochlorite and an alkylamine surfactant.: *Scie. Tot. Environ*., v. 408, p. 1779-1785.

Taylor, C. J. L., 2006, The effects of biological fouling control at coastal and estuarine power stations. *Mar. Poll. Bull*., v. 53, p. 30-48.

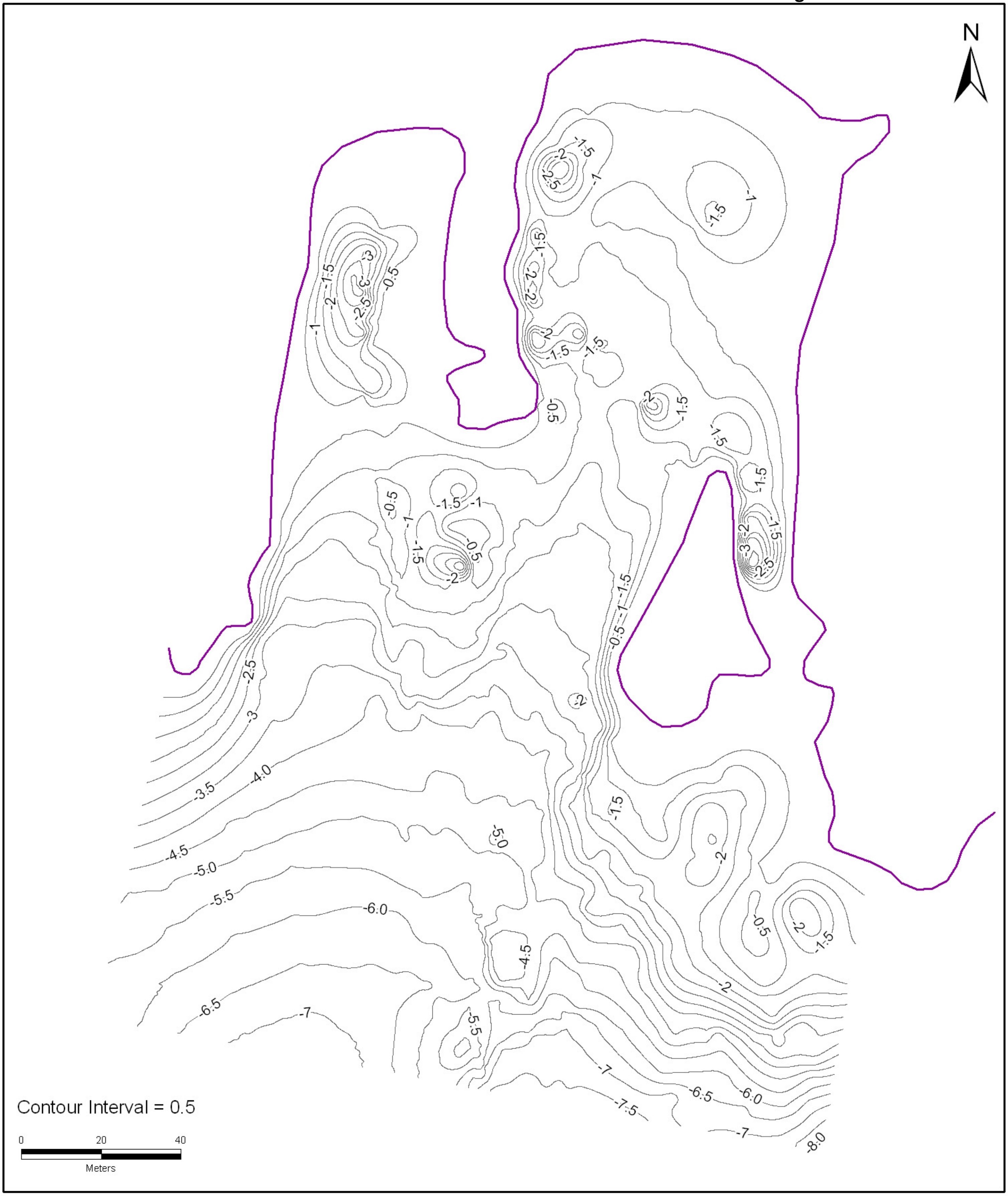
Tykeson, K., A. Nyman, and H. Carlsson, 1996, Environmental and geographical aspects in HVdc electrode design. *IEEE Transactions on Power Delivery*, v. 11, p. 1948-1954.

Appendix L

Bathymetric Survey

L'Anse-au-Diable North

(Nalcor Energy)



nalcor energy

FIGURE xxx

L'Anse au Diable Contour Map

Appendix M

Bathymetric Survey

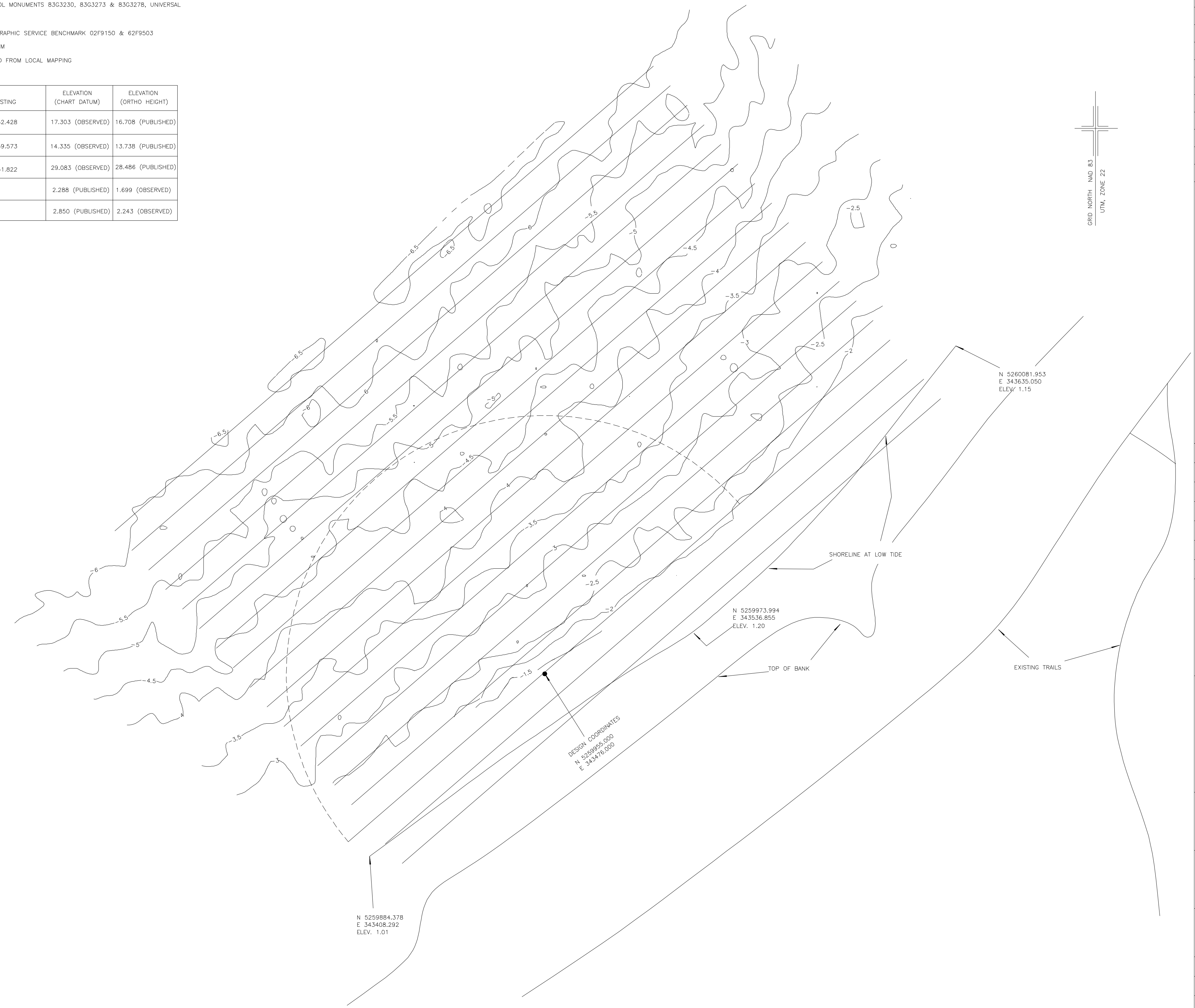
Dowden's Point

(Edwards and Associates)

NOTES:

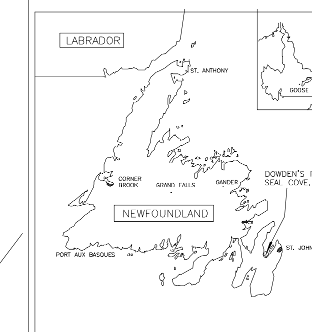
- GRID COORDINATES REFERENCED TO PROVINCIAL CROWN CONTROL MONUMENTS 83G3230, 83G3273 & 83G3278, UNIVERSAL TRANSVERSE MERCATOR PROJECTION SYSTEM
- CHART DATUM ELEVATION REFERENCED FROM CANADIAN HYDROGRAPHIC SERVICE BENCHMARK 02F9150 & 62F9503
- NEGATIVE ELEVATIONS REPRESENT DISTANCE BELOW CHART DATUM
- LOCATION OF THE TOP OF BANK AND EXISTINGS TRAILS DERIVED FROM LOCAL MAPPING

CONTROL MONUMENT	NORTHING	EASTING	ELEVATION (CHART DATUM)	ELEVATION (ORTHO HEIGHT)
83G3230	5259322.540	342962.428	17.303 (OBSERVED)	16.708 (PUBLISHED)
83G3273	5259082.374	342839.573	14.335 (OBSERVED)	13.738 (PUBLISHED)
83G3278	5258265.489	343751.822	29.083 (OBSERVED)	28.486 (PUBLISHED)
02F9150			2.288 (PUBLISHED)	1.699 (OBSERVED)
62F9503			2.850 (PUBLISHED)	2.243 (OBSERVED)



LEGEND

— — — — —	RADIAL LIMIT (100 METERS)
—— N ——	CONTOUR
————	SHORELINE
————	GRID LINE DESIGN
————	TOP OF BANK
————	TRAILS



No.	DESCRIPTION	DATE
	REVISIONS	

EDWARDS AND ASSOCIATES LTD.
P.O. BOX 158, MARYSTOWN, NFLD
TELEPHONE (709) 279-1990
FAX (709) 279-2185

Z:\Shared\IAN\Edwards Logo\edwards-logo-small.jpeg

REGISTERED PROFESSIONAL ENGINEER
I. G. EDWARDS
SIGNATURE
PROVINCE OF NEWFOUNDLAND

PROVINCE OF NEWFOUNDLAND
PERMIT HOLDER
CLASS A
THIS PERMIT ALLOWS
EDWARDS AND
ASSOCIATES LTD.
TO PRACTICE PROFESSIONAL
ENGINEERING IN THIS
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D0122 PERMIT NO. 2010 YEAR

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P.O. BOX 13216 ST. JOHN'S, NL, A1B 4A5

PROJECT: 2010 BATHYMETRIC SURVEY
DOWDEN'S POINT
SEAL COVE, NL

TITLE: CONTOUR MAP

SCALE: 1:750	DATE: AUGUST, 2010	DRAWN BY: S.S.
DESIGNED BY: I.E.		APPROVED BY: I.E.
PROJECT NO. 5323		DWG NO. 1 OF 1

Appendix N

Site Photographs

L'Anse-au-Diable North

Figure N-1: View of L'Anse-au-Diable North (looking southwest)

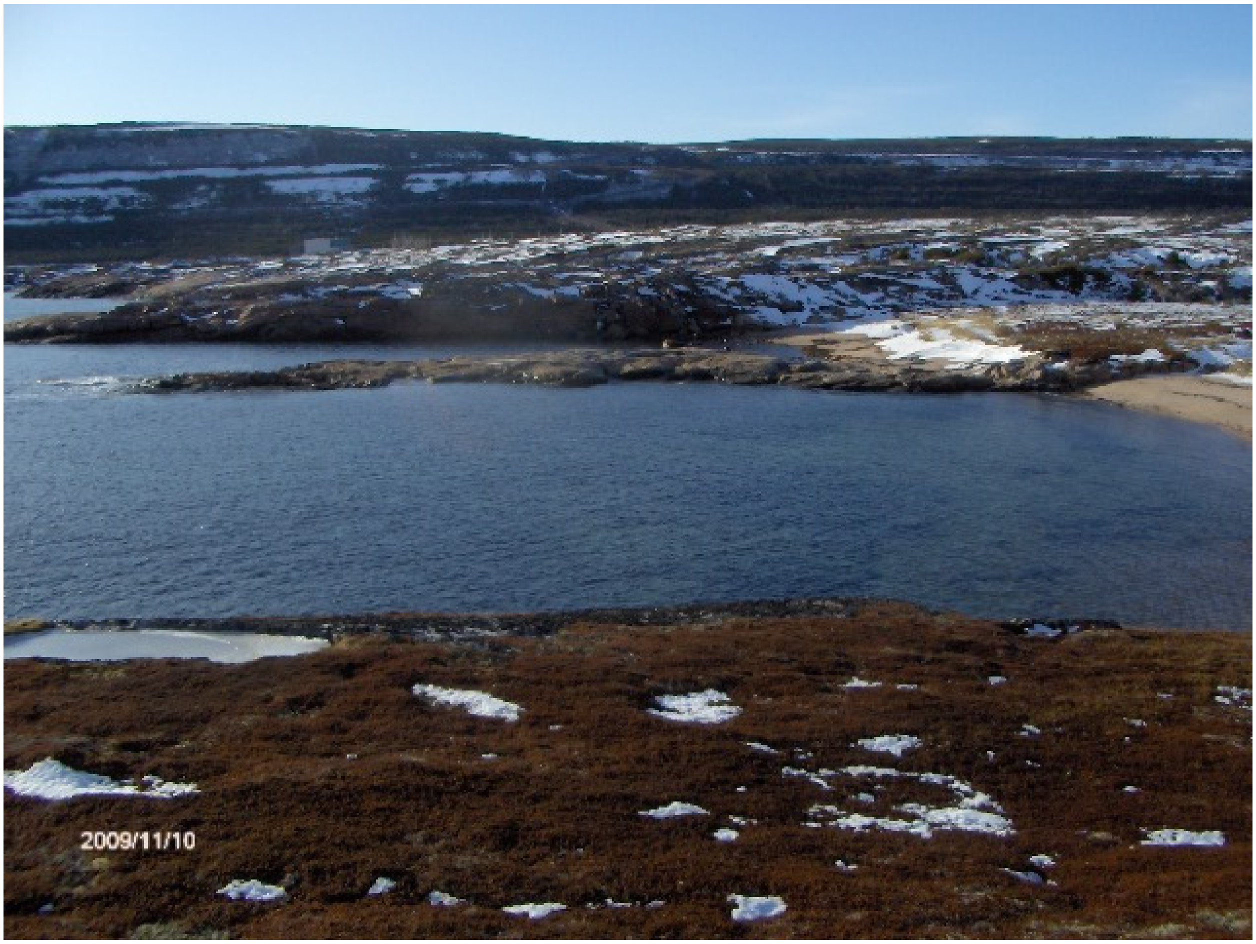


Figure N-2: View of L'Anse-au-Diable North (looking west)

Appendix O

Site Photographs

Dowden's Point

Figure O-1: View of Dowden's Point (looking southwest)

Figure O-2: View of Dowden's Point (looking northwest)

Appendix P

Infrastructure Information

L'Anse-au-Diable North

HATCH™

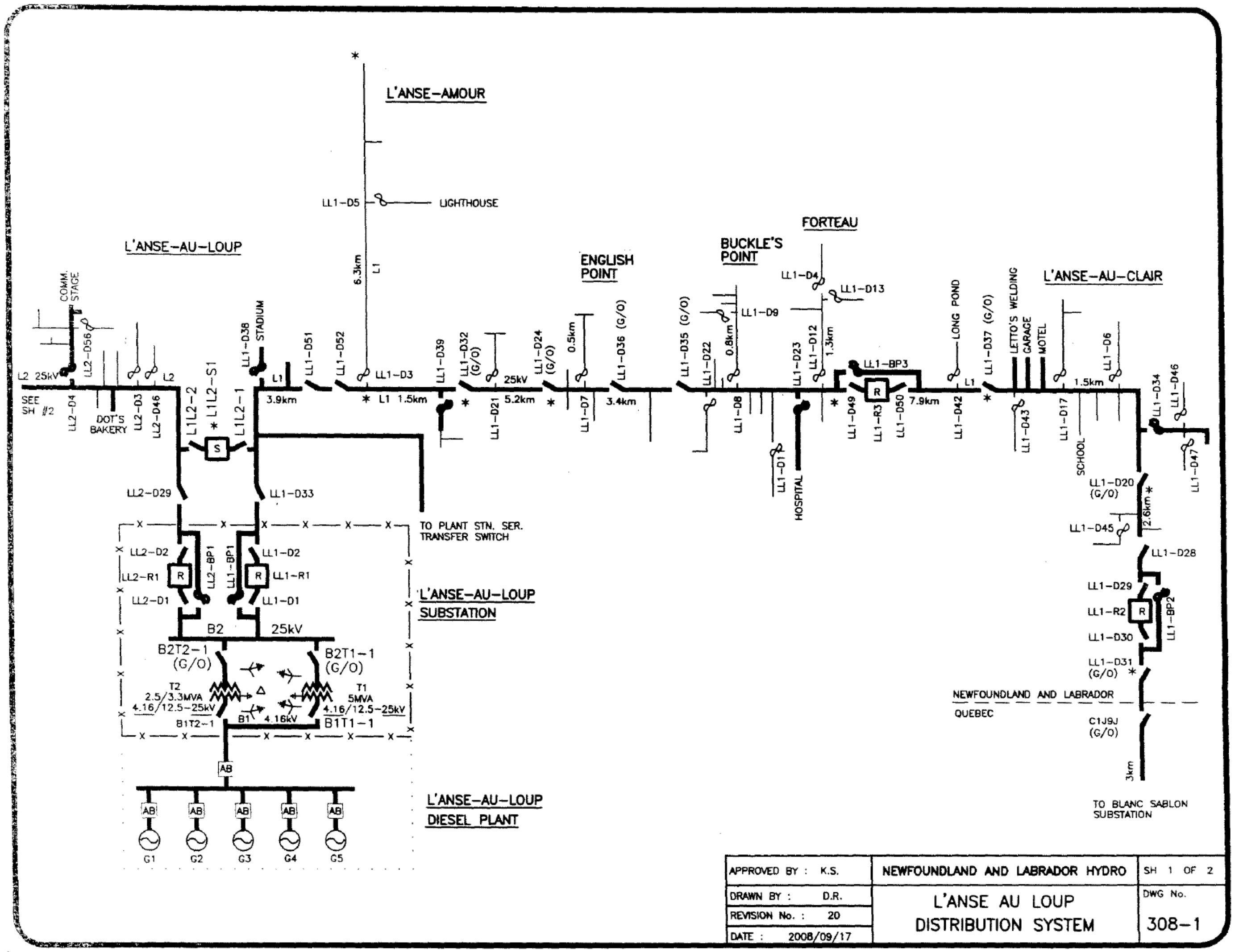


Figure P-1: L'Anse au Loup Distribution System SLD (DWG No. 308-1)

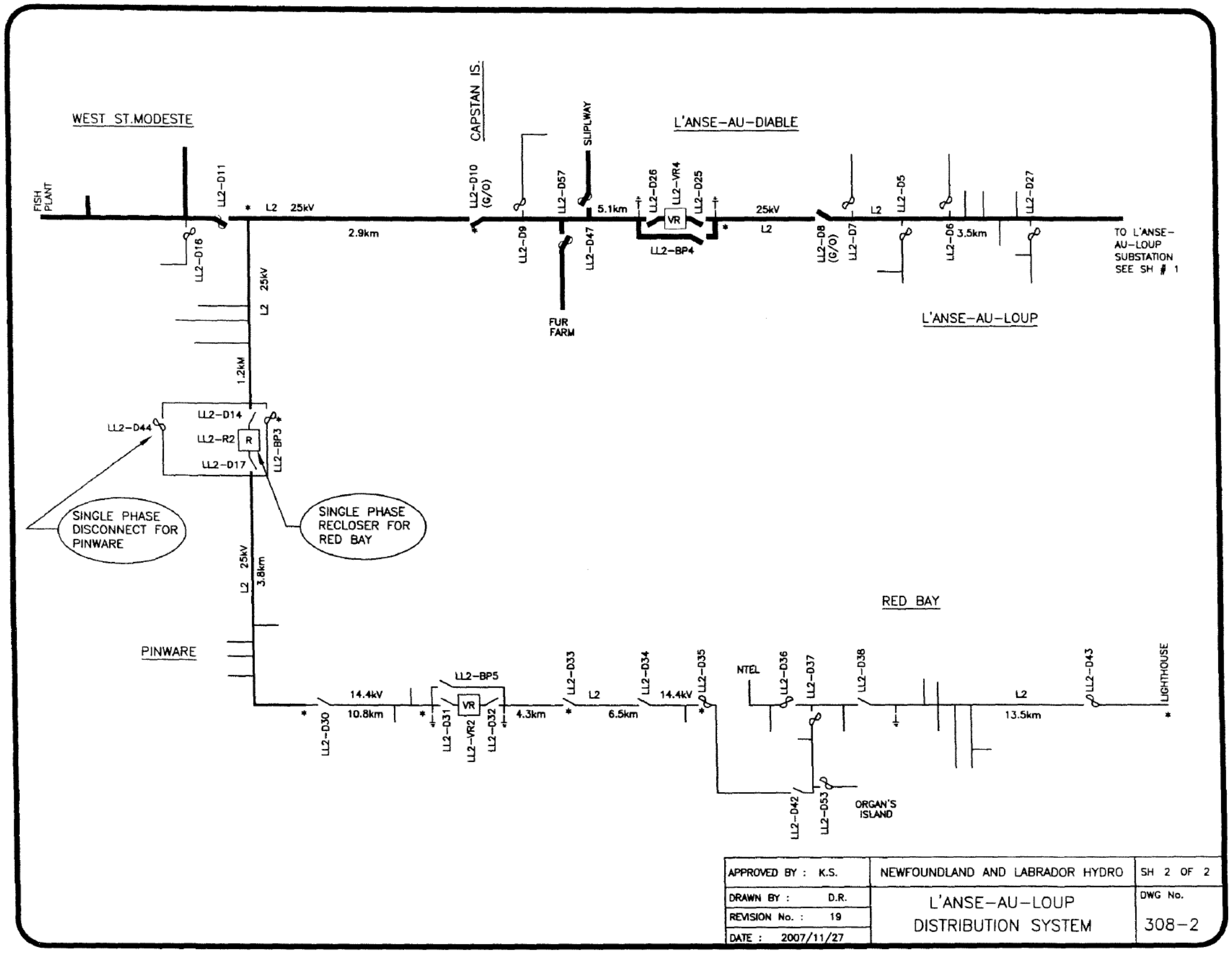


Figure P-2: L'Anse au Loup Distribution System SLD (DWG No. 308-2)

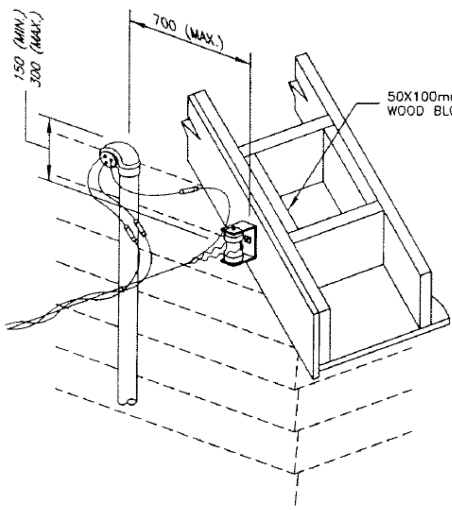


FIGURE 1
HOUSE CONNECTION IN EAVE

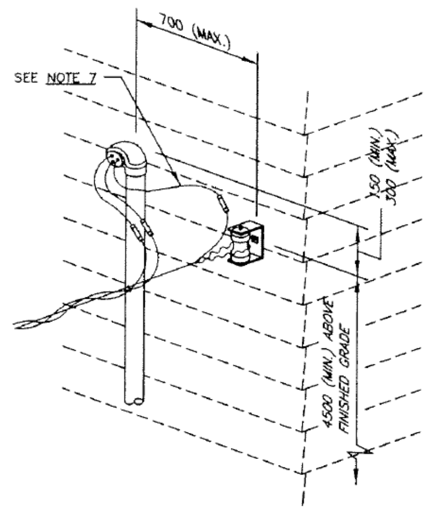


FIGURE 2
HOUSE CONNECTION IN SIDING

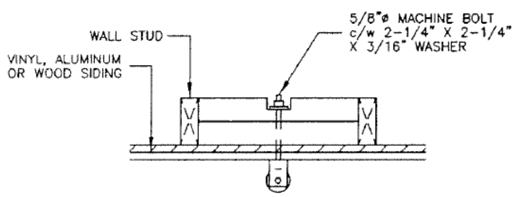


FIGURE 3 – PLAN
WOOD FRAME CONSTRUCTION

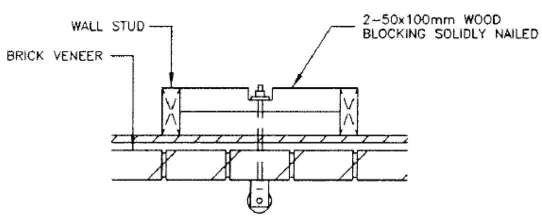


FIGURE 4 – PLAN
BRICK VENEER CONSTRUCTION

NOTES:

1. ALL HARDWARE TO BE HOT-DIPPED GALVANIZED STEEL.
2. THE LOCATION OF THE SERVICE SHALL BE TO THE SATISFACTION OF NEWFOUNDLAND & LABRADOR HYDRO AND THE ELECTRICAL INSPECTION AUTHORITY.
3. HORIZONTAL DISTANCE FROM SERVICE ENTRANCE HEAD TO THE CENTRE OF SERVICE ATTACHMENT SPOOL SHALL NOT EXCEED 700mm.
4. SERVICE ATTACHMENT SPOOL SHALL BE LOCATED NOT LESS THAN 4.5m ABOVE FIN. GRADE AND SUBJECT TO THE CANADIAN ELECTRICAL CODES (6-110 & 6-114).
5. WHERE VINYL, ALUMINUM, etc. SIDING IS USED, THE CUSTOMER MUST ENSURE THAT SOLID BLOCKING IS INSTALLED TO SECURE THE SERVICE ATTACHMENT. THE BLOCKING SHALL BE A MINIMUM OF 100mm SQUARE (REFER TO SHT. 2 OF 2 & FIGURE 3).
6. REFER TO DI-10-22 (SHT 2 OF 2) FOR SERVICE ATTACHMENT CONNECTION DETAILS.
7. NEUTRAL IS TO FORM THE LONGEST LOOP, SO IT IS THE LAST TO PULL APART.

R4	MINOR REVISIONS TO NEUTRAL WIRE & NO. 7 NOTE ADDED (SHT. 1 OF 2) & NO. 5 NOTE ADDED (SHT. 2 OF 2)	SEPT./05

HYDRO

DISTRIBUTION
ENGINEERING STANDARDS

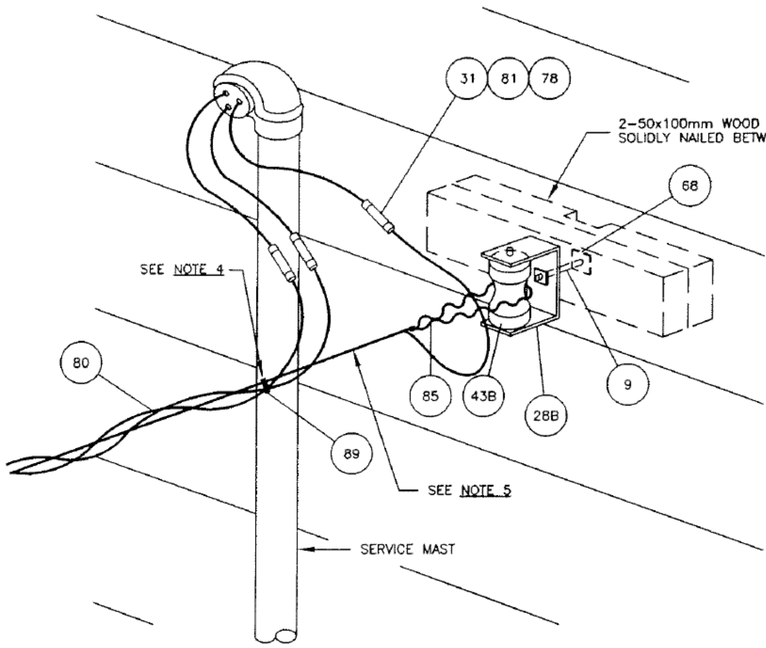
SERVICE CONNECTION & INSTALLATION DETAILS (NEW CONSTRUCTION) (1 OF 2)

APP'D.	D. PIKE
ISSUED	2006-06-01
DRAWN	D. MONTAGUE
CHECKED	D. PIKE
DWG. No.	DI-10-22-R4

PLOT SCALE 1:1

Figure P-3: Service Connection & Installation Details (DWG No. DI-10-22-R4, pg. 1)

HATCH™



ITEM No.	QTY.	DESCRIPTION
9	1	BOLT, MACHINE 5/8" X LENGTH REQ'D C/W NUT
28B	1	CLEVIS, SECONDARY SPOOL 2" X 2-1/4"
31	3	SLEEVE, SERVICE ENTRANCE (CHART 10-1)
43B	1	INSULATOR, SPOOL TYPE 2-1/2" X 2-1/4"
68	1	WASHER, SQUARE 2-1/4" X 2-1/4" X 3/16" WITH 11/16" H.
78	A.R.	COMPOUND, SEALING AND DIELECTRIC
80	A.R.	TRIPLEX
81	A.R.	TAPE, VINYL ELECTRIC (SEE NOTE 3)
85	1	GRIP, PREFORMED DEADEND (CHART 10-2)
89	1	TIE, SERVICE CABLE (SEE NOTE 4)

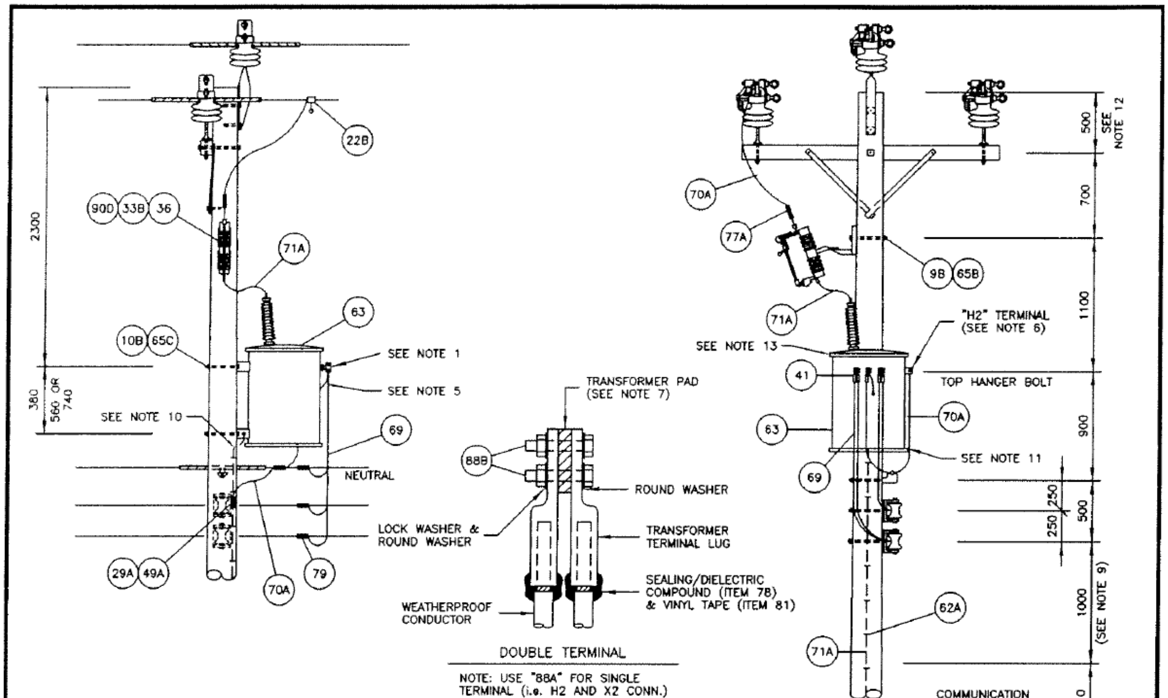
NOTES:

1. REFER TO DI-10-22 (1 OF 2) FOR INSTALLATION DETAILS.
2. NEWFOUNDLAND & LABRADOR HYDRO WILL SUPPLY EACH NEW CUSTOMER WITH ITEMS 9, 28B, 43B & 68.
3. SEALING COMPOUND AND VINYL TAPE TO BE USED AT BOTH ENDS OF EACH SERVICE ENTRANCE SLEEVE TO PREVENT WATER INGRESS.
4. THE SERVICE CABLE TIE CAN BE SECURED TO EITHER SIDE OF THE LOOP SECTION OF THE PREFORMED DEADEND GRIP IF CABLE SLIPPAGE IS A PROBLEM.
5. NEUTRAL IS TO FORM THE LONGEST LOOP. SO IT IS THE LAST TO PULL APART.

R4	MINOR REVISIONS TO NEUTRAL WIRE & NO. 7 NOTE ADDED (SHT. 1 OF 2) & NO. 5 NOTE ADDED (SHT. 2 OF 2)	SEPT./05	APP'D.	D. PIKE
HYDRO	DISTRIBUTION ENGINEERING STANDARDS		ISSUED	2006-06-01
This Drawing contains intellectual property of Newfoundland and Labrador Hydro (HYDRO) and shall not be copied, used or distributed in whole or in part without prior written consent from HYDRO. Use of the drawing shall be restricted to purposes of prosecution of a contract with HYDRO.	SERVICE CONNECTION & INSTALLATION DETAILS (NEW CONSTRUCTION) (2 OF 2)		DRAWN	D. MONTAGUE
			CHECKED	D. PIKE
			DWG. No.	DI-10-22-R4

PLOT SCALE 1:1

Figure P-4: Service Connection & Installation Details (DWG No. DI-10-22-R4, pg. 2)



NOTES :

1. REFER TO CHART 14-1 FOR SIZE AND QUANTITY OF LEADS, TYPE OF LUG AND QUANTITY OF HEX. BOLTS.
2. SEE "STANDARD GROUND COIL INSTALLATION DETAILS" REFER TO DWG. DI-15-04 (LATEST REV.).
3. GROUND ROD TO BE USED WHERE IT IS IMPRACTICAL TO INSTALL GROUND COIL.
4. REFER TO DI-14-12 (LATEST REV.) FOR "TFR. TERMINAL & SECONDARY DROP LEAD DETAILS"
5. TANK STRAP OR EQUIVALENT JUMPER MUST BE SECURED, CONNECTING TANK TO TRANSFORMER SECONDARY NEUTRAL TERMINAL.
6. FOR SINGLE PRIMARY BUSHING TFRS., PRIMARY WINDING NEUTRAL (H2) IS ELECTRICALLY CONNECTED TO TFR. TANK INTERNALLY. THEREFORE, THE TFR. TANK GROUND AND THE PRIMARY NEUTRAL TERM. (H2) MUST BE SEPARATELY CONNECTED TO SYSTEM NEUTRAL. REFER TO DWG. DI-14-18 (LATEST REV.). TRANSFORMERS BUILT TO CEA SPECIFICATION HAVE H2 TERMINAL ON OPPOSITE SIDE OF TFR. TANK.
7. "PENETROX" TO BE APPLIED TO CONTACT SURFACES AND SCRATCH INTO SURFACES USING WIRE BRUSH BEFORE MAKING CONNECTION.
8. ITEM "22B" TO BE CHANGED TO "22A" IF COPPER LEADS REQUIRED.
9. ON LATERAL COMMUNICATION DROP WIRE, THIS SEPARATION CAN BE REDUCED TO 600mm.
10. FOR TRANSFORMER GROUNDING DETAILS, REFER TO DWG. DI-14-17 (LATEST REV.). (3 SHEETS).
11. ANY LOWER RIM PROTECTIVE LINER IS TO BE REMOVED FROM THE TRANSFORMER AFTER INSTALLATION IN THE POLE.
12. FOR SINGLE PHASE CONSTRUCTION 500mm AT TOP OF POLE CAN BE OMITTED.
13. REFER TO STANDARD DI-14-13 (LATEST REV.) FOR LIGHTNING ARRESTER INSTALLATION DETAILS.
14. BACK TO BACK SECONDARY DEADENDS CANNOT HAVE TWO SEPARATE VOLTAGE SOURCES IN A TRANSFORMER STRUCTURE. NEUTRAL DROP LEADS SHOULD BE ONE SIZE SMALLER THAN INDICATED IN CHART 14-1A.

R15	NOTE 10 REMOVED AND ITEM NO. 33 CHANGED TO 33B	AUG./08

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APP'D.	T. GARDINER
ISSUED	2008-08-05
DRAWN	D. MONTAGUE
CHECKED	B. NOBLE
DWG. No.	DI-14-05-R15

25kV SINGLE PHASE TRANSFORMER MOUNTING

(1 OF 2)

CAD

Figure P-5: 25 kV Single Phase Transformer Mounting (DWG No. DI-14-05-R15, pg. 1)

ITEM NO.	QTY.	DESCRIPTION
9B	1	BOLT , MACHINE 5/8" X 10"
10B	2	BOLT , MACHINE 3/4" X 12"
22B	1	CLAMP , HOT LINE (SEE NOTE 8)
29A	1	CONNECTOR , COMPRESSION TAP #4 TO #4
33B	1	CUTOUT , FUSE 27kV , 100A
36	1	FUSELINK
41	AS REQ'D	CONNECTOR , TRANSFORMER TERMINAL LUG
47	1	MOULDING , GROUND WIRE
49A	1	PIN , TERMINAL No. 2
62A	AS REQ'D	STAPLES , GROUND WIRE , 3/8" X 1 1/4"
62B	AS REQ'D	STAPLES , GROUND WIRE GUARD , 2" X 11/16"
63	1	TRANSFORMER
65B	1	WASHER , CURVED 2 1/4" X 2 1/4" X 3/16" WITH 11/16 H.
65C	2	WASHER , CURVED 3 1/8" X 3 1/4" X 1/4" WITH 13/16 H.
69	AS REQ'D	WIRE , ARVIDAL-PEWP (SEE NOTE 1)
70A	AS REQ'D	WIRE , #2 ARVIDAL
71A	10.5m	WIRE , #4 SOLID SD COPPER
77A	1	SLEEVE , PIGTAIL #2 ALUMINUM
78	AS REQ'D	SEALING / DIELECTRIC COMPOUND
79	7	CONNECTOR , PRESS-ON COMPRESSION
81	AS REQ'D	VINYL TAPE
88A	NOTE 1	BOLT , HEX HEAD 1/2" X 1 1/2" c/w WASHERS AND HEX NUT
88B	NOTE 1	BOLT , HEX HEAD 1/2" X 2" c/w WASHERS AND HEX NUT
90D	1	BRACKET, CROSSARM MOUNT

R15	NOTE 10 REMOVED AND ITEM NO. 33 CHANGED TO 33B	AUG./08

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25kV SINGLE PHASE
TRANSFORMER MOUNTING
(2 OF 2)

APP'D.	T. GARDINER
ISSUED	2008-08-05
DRAWN	D. MONTAGUE
CHECKED	B. NOBLE
DWG. No.	DI-14-05-R15

CAD

Figure P-6: 25 kV Single Phase Transformer Mounting (DWG No. DI-14-05-R15, pg. 2)

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Figure P-7: Map of Infrastructure near LAD North
(Note: red circle - 5 km radius; blue circle - 10 km radius)

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Table P-1: Transmission Line Data

Note: There are no existing transmission lines within this 10 km zone.

General:	
Transmission Line Name:	
Voltage Rating:	
Terminal Stations:	
Remote end Terminal Station	
Tower/Span:	
Type of Tower:	
Type of Foundation:	
Conduction Configuration (phase/skywire):	
Approximate Span:	
Transmission line plan drawing(s)	
Length of Transmission Line	
Conductors	
Phase conductor number/size/type:	
Skywire number/size/type:	
Grounding/Continuity	
Skywire is continuous (yes/no):	
All Towers Grounded (yes/no):	
Tower Grounding Impedance:	
Counterpoise Connections between Towers	

Table P-2: Distribution System Data

General:	
Distribution Line Name:	**L'anse Au Loup Distribution System**
Voltage Rating:	**25kV**
Terminal distribution Station:	**25kV**
Pole/Span:	
Type of pole:	**Wood Pole**
Type of Foundation:	**Direct Buried**
Conduction Configuration:	**Wye**
Approximate Span:	**85m**
Distribution system area map	**See Single Line Diagram**
Conductors/Distribution Transformer	
Phase conductor size/type:	**1/0**
Neutral Size:	**1/0**
Distribution transformer (single phase or three phase Y grounded)	**Single Phase or Three Phase Bank**
Typical distribution transformer sizes	**25kVA, 50kVA, 75kVA, 100kVA**
Grounding/Continuity	
Neutral is continuous (yes/no):	**yes**
Grounding per CSA standards, four grounds per 1000 m run and at transformers (yes/no)	**Higher than CSA Standards. Ground every pole.**
Pole Grounding Impedance (Pole ground rod in parallel with residential ground rod(s))	**N/A**
Residential Connections	
Provide description and sketch of single phase distribution transformers and house connections	**See Drawing "DI-14-05-R15"** **See Drawing "DI-10-22-R4"**
Confirm hose ground type (ground rods, ground plates, or cold water system)	**Usually Ground Rods**
Provide estimate of typical ground resistance	**< 6 Ohms**

Table P-3: Distribution Station Data

General:	
Voltage Rating	**25kV**
Single line diagram showing transformers, lines and feeders	**See Single Line Diagram**
Grounding and Conductive Connections	
Station ground electrode Impedance:	**See Single Line Diagram**
Transformer winding connections	**See Single Line Diagram**
T/L Skywires	**N/A**
Remote end station transformer windings connections	**See Single Line Diagram**
Grounding connections to generating station	**See Single Line Diagram**

Table P-4: Miscellaneous Structures/Installations (Bridges, industrial plants, harbour)

- The blue line includes a # of small communities (Pinware,West Saint Modest, L'Anse au loup and Captsan Island) most of these Communities have harbours and community wharfs.
- There is also a Marina marked on the attached map called Riteway Construction Limited.

Note: These are not a Nalcor Energy assets, therefore limited information exists

Structure Name:	
Description of Structure/facility:	**Harbours, Wharfs, Marina**
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	
Approximate size of structure (length m x width m or diameter m)	
Information on cathodic protection system if applicable for the structure.	

Appendix Q

Infrastructure Information

Dowden's Point

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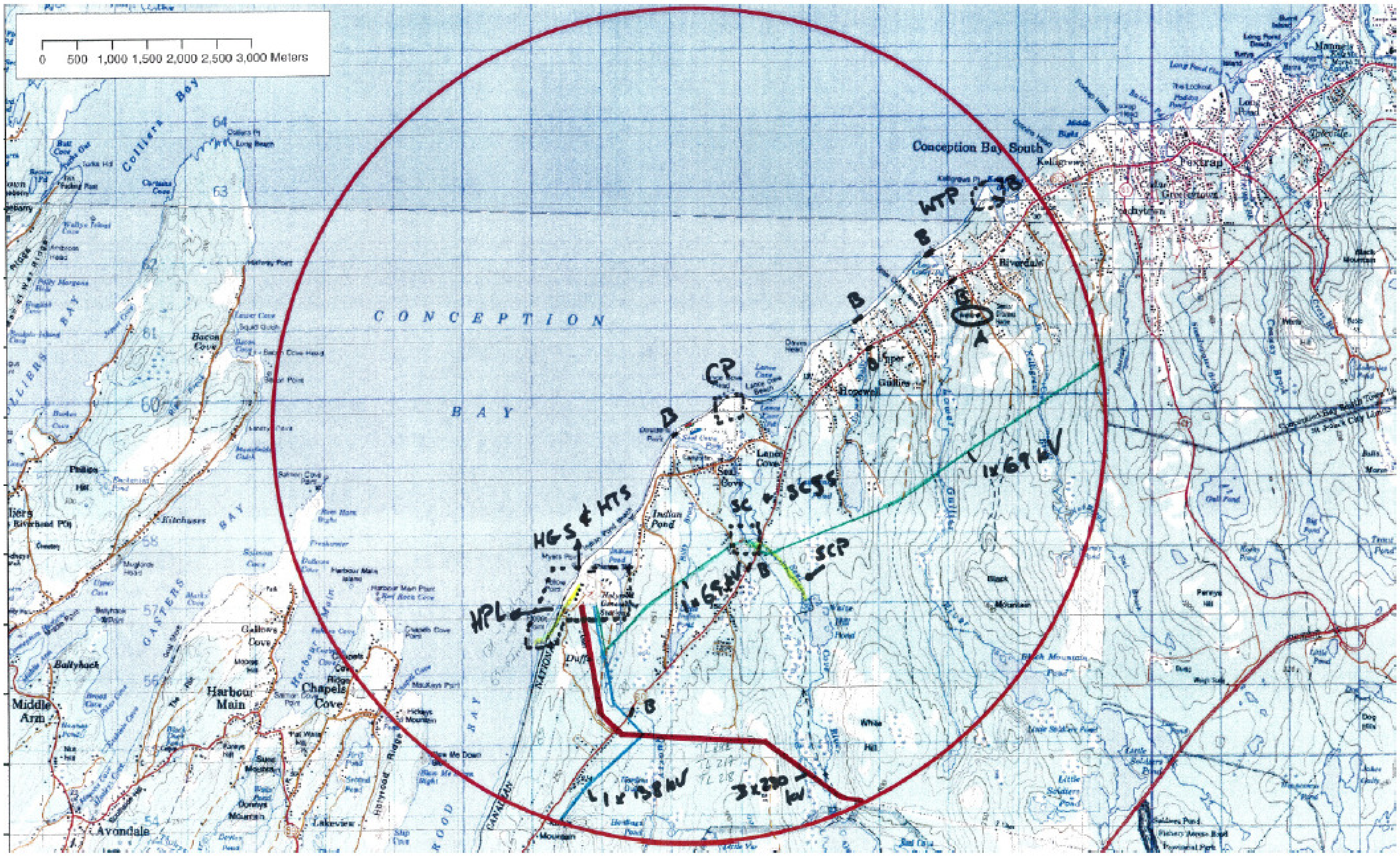
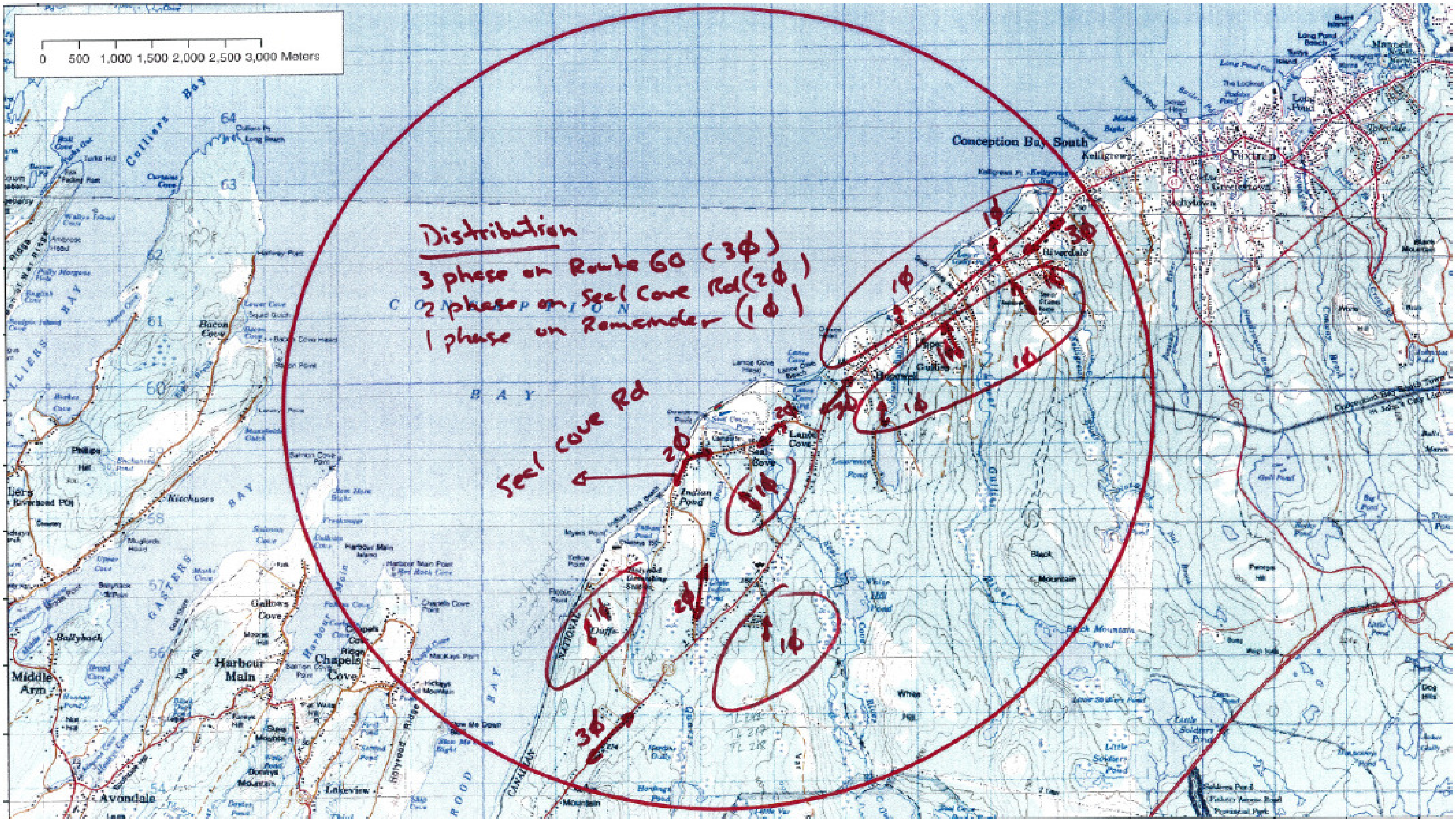


MAP – 1

Figure Q-1: HV Transmission/Generation Infrastructure



MAP – 2

Figure Q-2: 12.47 kV Distribution Infrastructure

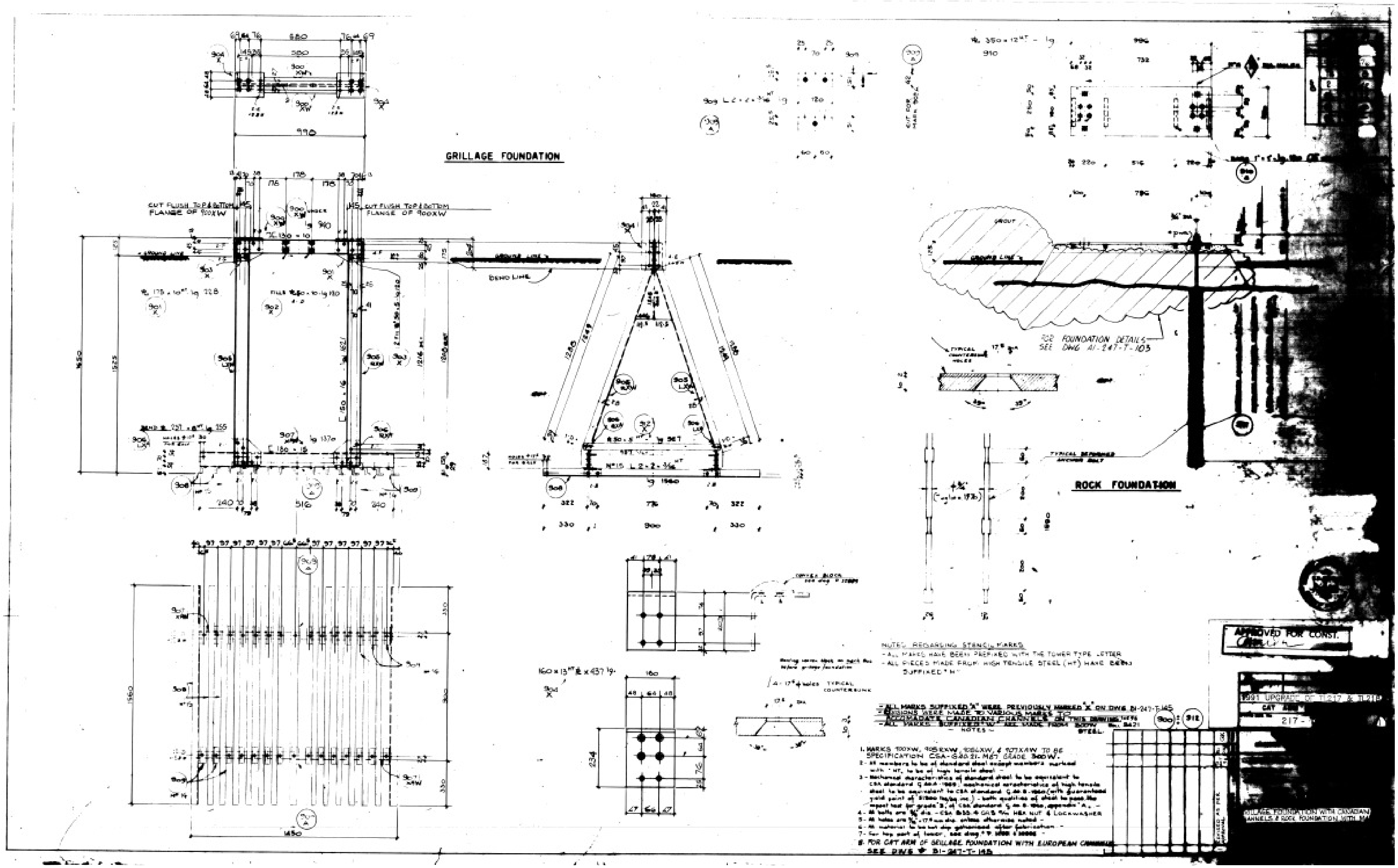


Figure Q-1: HV Transmission Line Pole Foundation

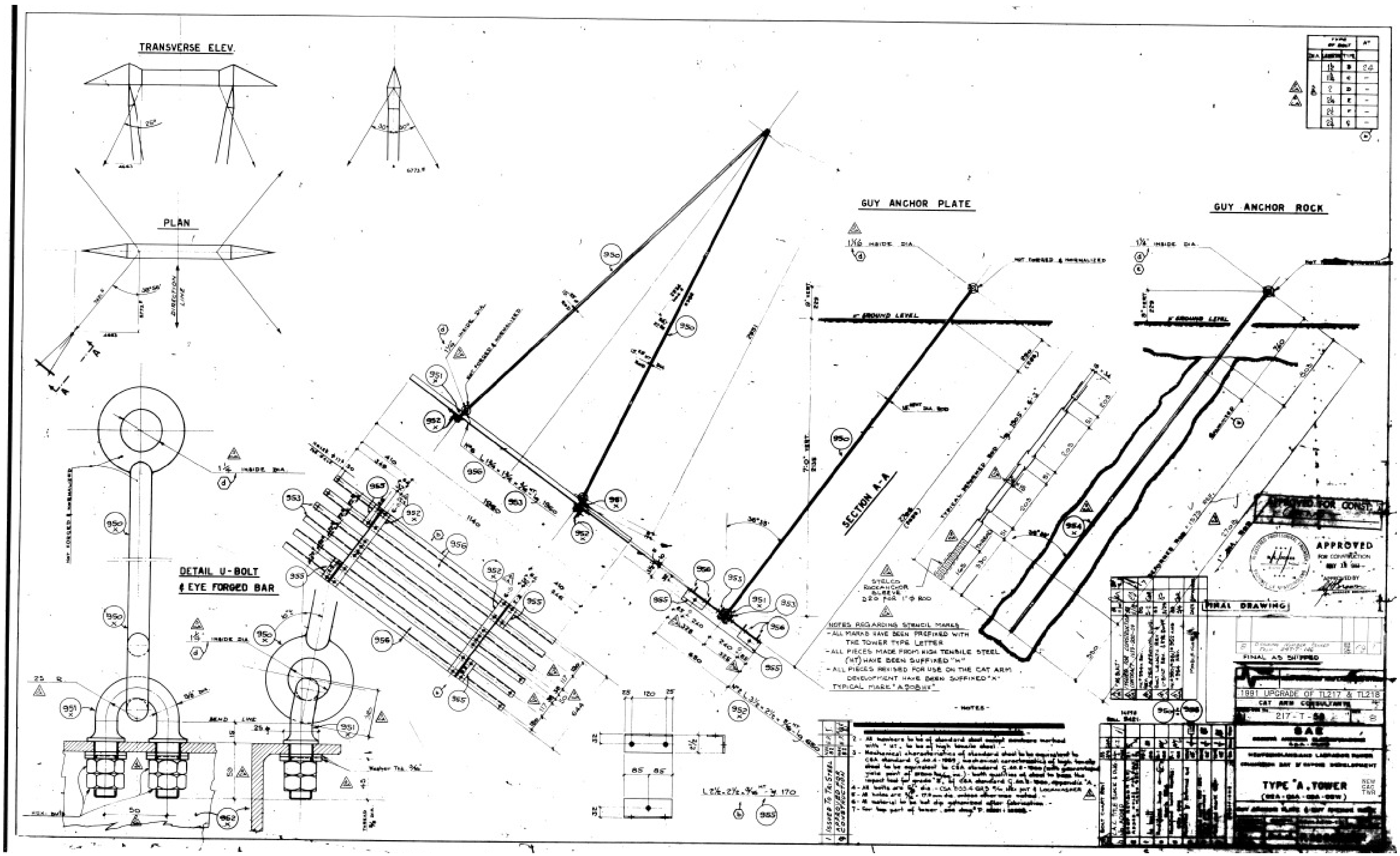


Figure Q-2: 230kV Line Guywire Anchor

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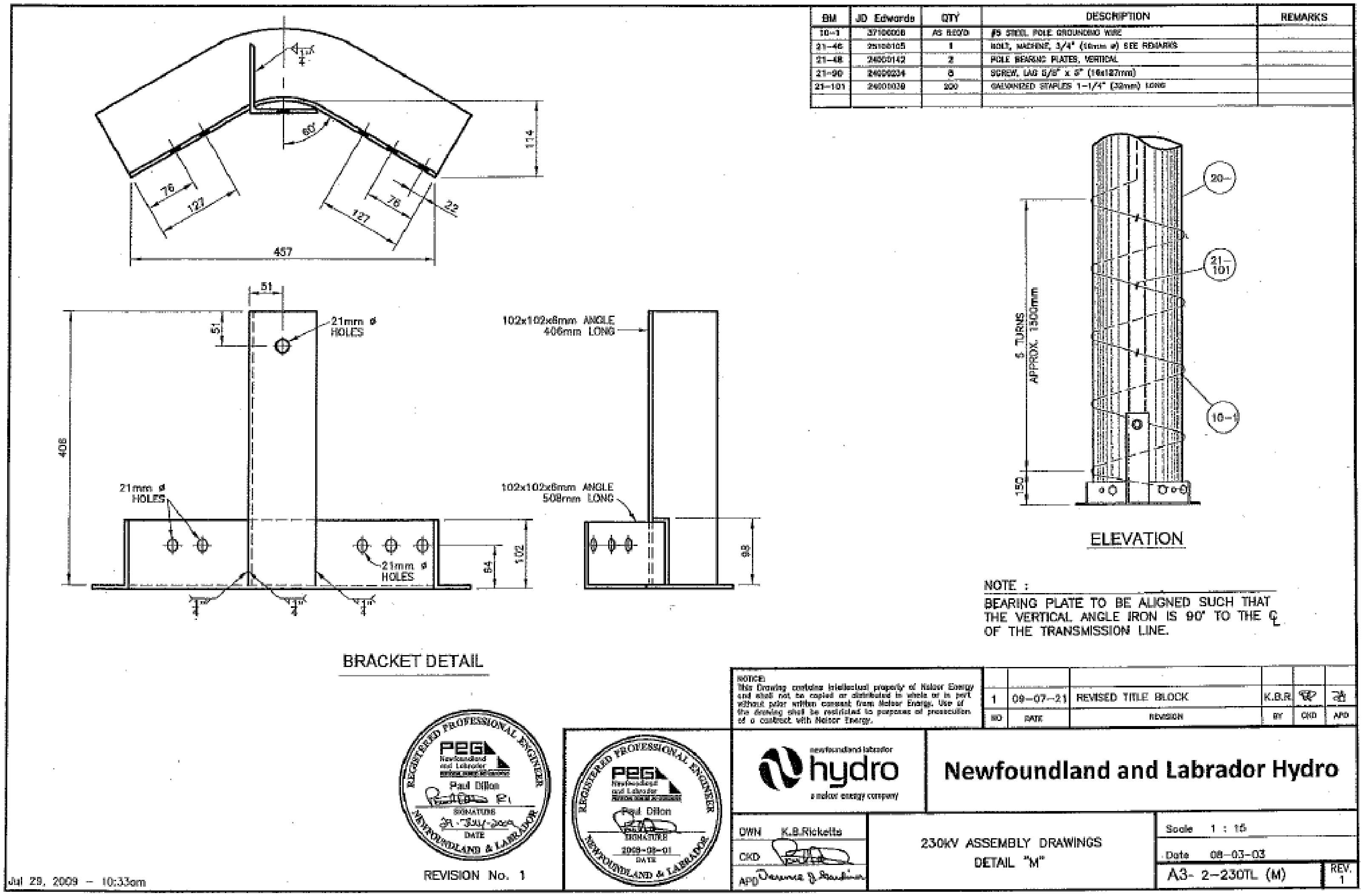
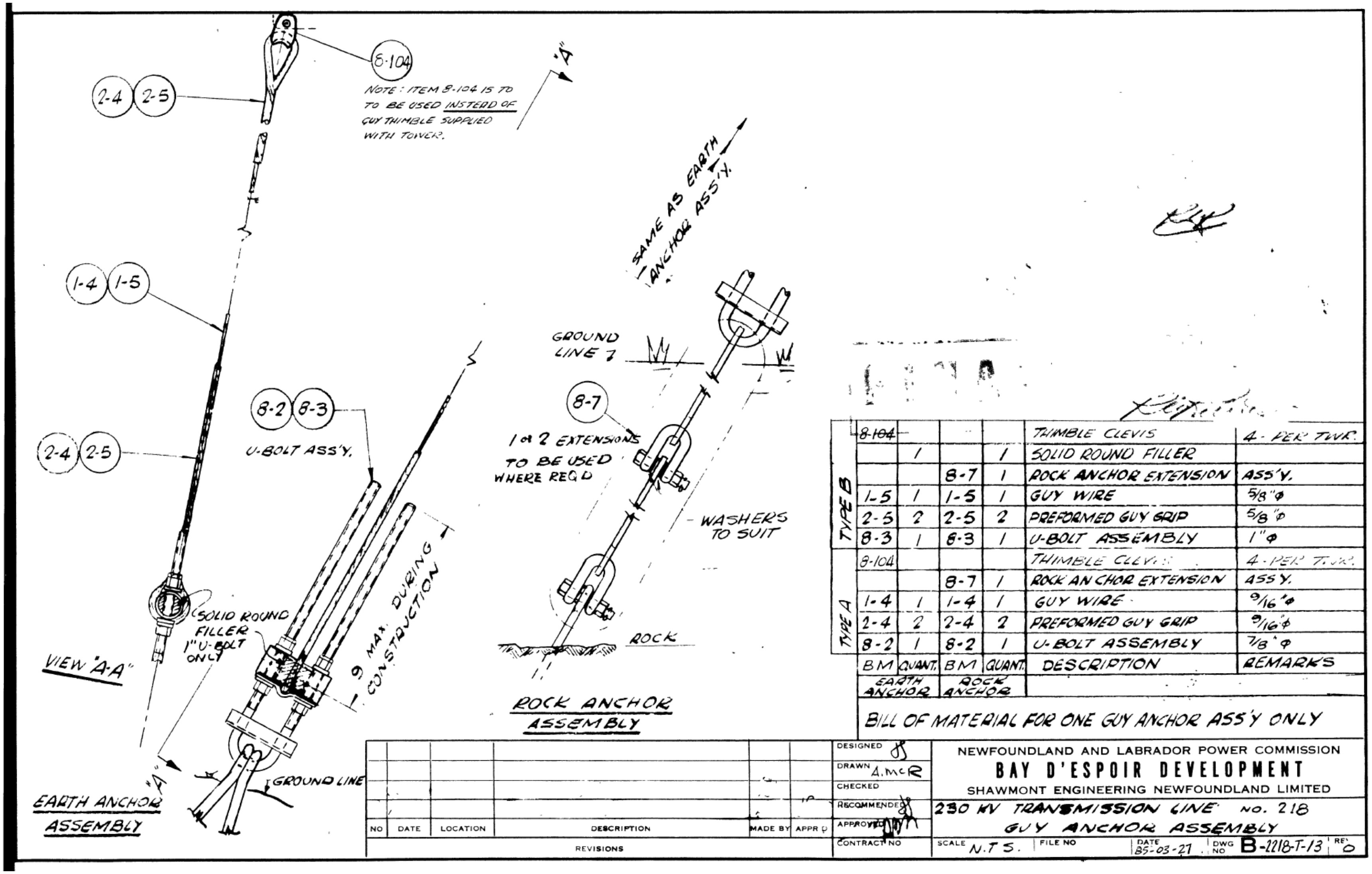


Figure Q-2: TL218 Wood Pole Foundation and Grounding



	Earth Anchor BM	Earth Anchor QUANT.	Rock Anchor BM	Rock Anchor QUANT.	DESCRIPTION	REMARKS
TYPE B	8-104				THIMBLE CLEVIS	4 - PER TWR.
		1		1	SOLID ROUND FILLER	
			8-7	1	ROCK ANCHOR EXTENSION	ASS'Y.
	1-5	1	1-5	1	GUY WIRE	5/8"Φ
	2-5	2	2-5	2	PREFORMED GUY GRIP	5/8"Φ
	8-3	1	8-3	1	U-BOLT ASSEMBLY	1"Φ
TYPE A	8-104				THIMBLE CLEVIS	4 - PER TWR.
			8-7	1	ROCK ANCHOR EXTENSION	ASS'Y.
	1-4	1	1-4	1	GUY WIRE	9/16"Φ
	2-4	2	2-4	2	PREFORMED GUY GRIP	9/16"Φ
	8-2	1	8-2	1	U-BOLT ASSEMBLY	7/8"Φ

BILL OF MATERIAL FOR ONE GUY ANCHOR ASS'Y ONLY

Figure Q-3: Guy Anchor Assembly Drawing

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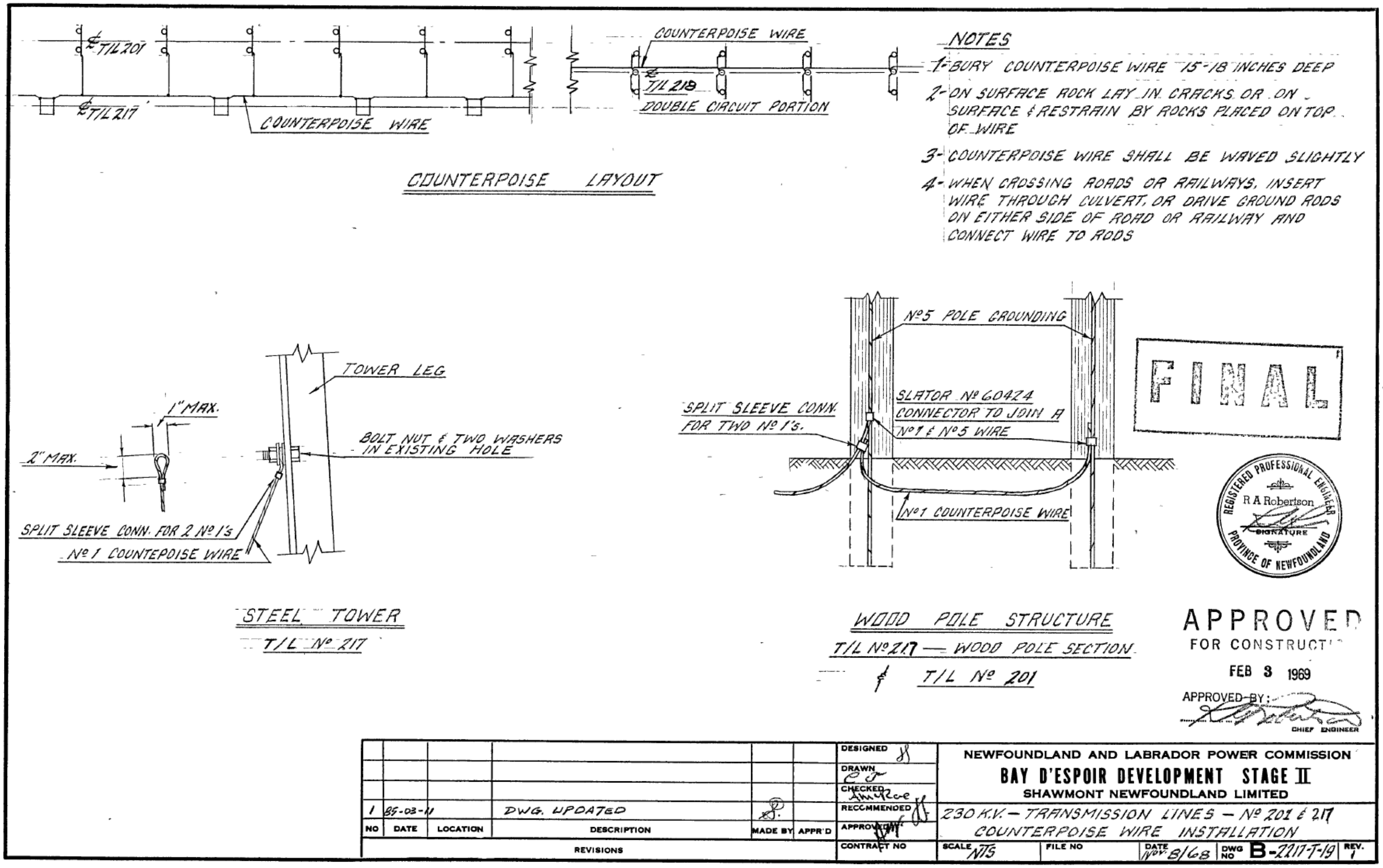

Figure Q-4: Counterpoise Installation Drawing

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Table Q-1:Soliders Pond Request for Infrastructure Information

Sr #	Item Description/ Information Required	NE-LCP Input	Remarks
A	**230 kV Tower Footing Impedance- A typical value of 15 Ohm-m was assumed in DC1250.**		The tower/pole footing impedance values are required to calculate dc stray currents. The grounding arrangement drawings are required to estimate the amount of copper/steel and to estimate the tower/pole impedance if values are not available.
1	TL217 steel tower footing impedance design value and grounding arrangement.	See Attached 2217-T-19	**Both towers are equipped with 230 kV lines. The attached drawing would be the best reference available. TL242 would have similar arrangements.**
2	TL242 steel tower footing impedance design value and grounding arrangement.	See Attached 2217-T-19	
B	**230 kV Tower Foundation and Guy Anchor Steel**		Information is required to estimate the tolerable loss of material.
1	TL217 steel tower steel grillage foundation drawing.	See Attached. 2217-T-057	
2	TL217 tower guywire anchor size and installation arrangement.	See Attached. 2217-T-058	
3	TL242 steel tower steel grillage foundation drawing.	See Attached. 2217-T-058	
4	TL242 tower guywire anchor size and installation arrangement.	See Attached. 2217-T-058	
5	TL218 tower guywire anchor size and installation arrangement.	See Attached 2218-T-013	
C	**Station Grounding Grid Impedances and Sizes**		Information is required for the dc stray current calculations and to estimate the tolerable loss of grounding grid.
1	Holyrood Transmission Station (HRD) grounding grid impedance.	Not Available	**This value has not yet been modeled and will not be available until a later date.**
2	Holyrood Transmission Station (HRD) grounding grid arrangement drawing.	See Attached A0-310-E-20, 310-E-119, 310-E-251	
3	Hardwood Station (HWD) grounding grid impedance.	Not Available	**This value has not yet been modeled and will not be available until a later date.**
4	Hardwood Station (HWD) grounding grid arrangement drawing.	See Attached A0-333-E-50	
5	Western Avalon Station (WAV) grounding grid impedance.	15.01 ohms	**This value is not worse case (no frost in ground). Worse case value will not be available until a later date.**
6	Western Avalon Station (WAV) grounding grid arrangement drawing.	See Attached A0-306-E-07	
7	Oxen Pond Station (OPD) grounding grid impedance.	9.4 ohms	**This value is not worse case (no frost in ground). Worse case value will not be available until a later date.**
8	Oxen Pond Station (OPD) grounding grid arrangement drawing.	See Attached B1-303-E-07	
9	Bay Roberts Terminal Station (BRB) grounding grid impedance.	Sent request to Newfoundland Power we should have this information sometime next week.	
10	Bay Roberts Terminal Station (BRB) grounding grid arrangement drawing.		
11	Seal Cove Terminal Station (SCV) grounding grid impedance.		
12	Seal Cove Terminal Station (SCV) grounding grid arrangement drawing.		
13	Kelligrews Terminal Station (KEL) grounding grid impedance.		
14	Kelligrews Terminal Station (KEL) grounding grid arrangement drawing.		
D	**Transformer Winding Resistances and Excitation Currents**		
1	Refer to Sheet "XMFR" in this workbook for the transfomer data required.	See Attached XFMR.	
E	**Distribution Network**		
1	Distribution pole footing grounding impedance.	See Attached. DI1504-R7	**These are the distribution engineering standards.**
2	Distribution circuit review to ascertain the plan, conductor sizes, neutral sizes, distribution transformer population.	Not Available	The information provided earlier (DC1250 stage) is a generic schematic.

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