REVIEW OF EXISTING METEOROLOGICAL STUDIES CONDUCTED ON THE LABRADOR – ISLAND TRANSMISSION LINK

NALCOR ENERGY – LOWER CHURCHILL PROJECT

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Contents

1. Introduction

In Canada, accumulated ice or combined ice and wind loadings govern the design of overhead transmission infrastructure. Several studies of probabilistic ice loadings along the proposed transmission route for the Labrador Island Transmission Link have been conducted from 1973 to 2010. In addition, Newfoundland and Labrador Hydro (NLH) conducted a climatological monitoring program to measure actual ice accumulations in the vicinity of the proposed transmission route from 1977 to 1987.

Nalcor Energy (Nalcor) has quantified the expected accumulations for various return periods, starting with the 50-year return period specified by the Canadian Standards Association (CSA) C22.3 and taking into account numerical modelling, full scale test structures and operational experience. Significant studies, NLH's ten-year monitoring program, and the current estimates are outlined below.

2. Review of Previous Studies

2.1. Meteorology Study of the Gull Island-Stephenville-Holyrood Transmission Line Routes, 1973 (Ref. 1)

The first study of ice loading of a proposed HVdc transmission line from Labrador to Newfoundland was conducted by M.C. Richmond and M.J. Fegley of Meteorological Research Incorporated (MRI) in 1973. The study considered a route from the Gull Island generation site to Holyrood and Stephenville. At the time, detailed meteorological records were available from the Atmospheric Environment Service for twelve stations in Newfoundland and Labrador and north-eastern Quebec. The earliest data recorded by these stations dated to 1953, with data availability ranging from six years for some stations to nineteen for those in continuous operation from 1953 until MRI collected the data required for their study in 1972.

MRI used a proprietary icing model to determine maximum ice accumulations for the worst storm each year for the seven weather stations nearest to the proposed HVdc transmission route. The yearly maxima for each station were then plotted on an extreme probability graph, which was used to determine the maximum glaze ice accumulation for any return period.

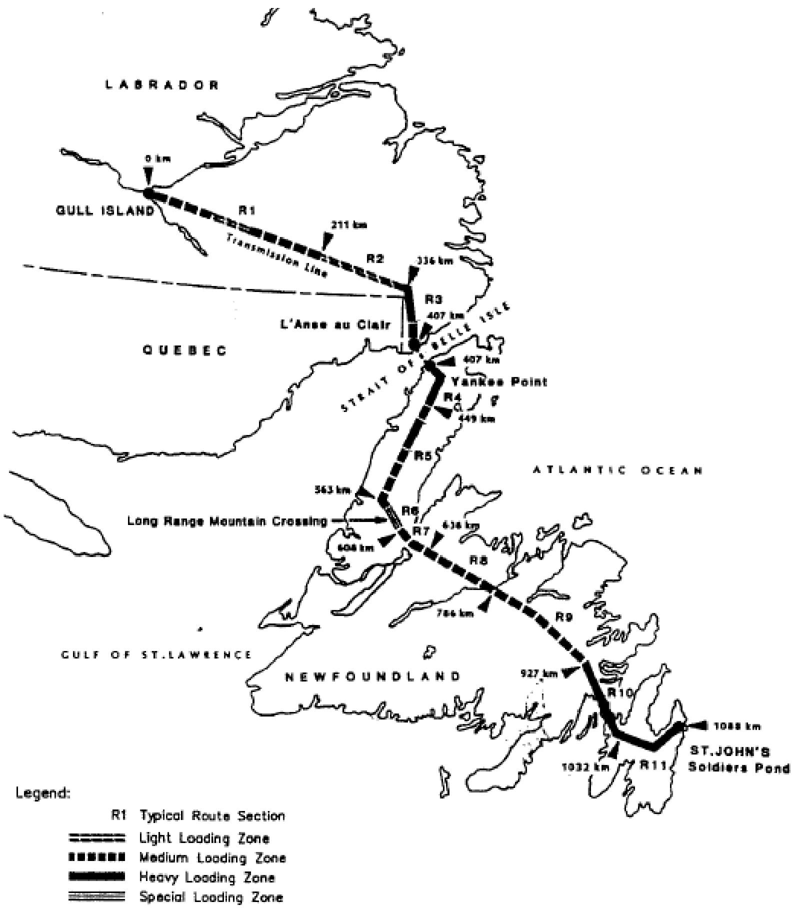

Figure 1: Climate regions based on MRI results (Teshmont 1998)

2.2. NLH Climatological Monitoring Program, 1977-1987, (Ref. 2 – Ref .11)

Beginning in 1977, Newfoundland and Labrador Hydro conducted a climatological monitoring program to measure actual icing in the area of the proposed HVdc line from Gull Island. The main test program ended in 1987 and relied primarily on passive ice meters (PIM) in inhabited areas and test tower sites along the proposed transmission route.

Figure 2: NLH passive ice meter

The test tower structures operated by Newfoundland and Labrador Hydro were generally un-instrumented and varied somewhat in geometry, but were guyed, steel lattice towers. In addition to single towers, a small number of single test spans were erected, including the one shown in the figure below. Both the towers and test spans were erected in the area of the proposed HVdc transmission route. The sites were visited monthly throughout the winter during the programs life to record the conditions and measurements of the icing accumulation. Test tower sites in the Long Range Mountains generally experienced greater accumulations of rime ice than glaze ice due to their high elevations (see Section 2.6).

Figure 3: NLH Test Span in the Long Range Mountains, as photographed in 2010

2.3. Newfoundland and Labrador Hydro Failure Review, (Ref. 12)

In 1995, NLH conducted an investigation of failures of existing power lines in eastern Newfoundland during the previous 30-year period. Using these observed ice accumulations, Newfoundland and Labrador Hydro revised its standard design load for transmission lines on the Avalon Peninsula. The finalized report assesses the capacity of the lines, estimates ice loads based on historical data, assesses reliability, and provides a cost benefit for several upgrade options. The report also provides a review of several line failures focusing on the cause of the failures.

2.4. Preliminary Meteorological Load review, (Ref.19)

In its 2008 *Preliminary Meteorological Load Review*, Hatch divided the proposed transmission route into six numbered climactic zones, as shown in the figure below. Zone C4A, was excluded from the analysis. Hatch then estimated base ice accumulations for each climactic zone based on a 50-year return period before adjusting for topography. The minimum design criteria specified by CSA C22.3., and the maximum accumulation calculated by Hatch from Newfoundland and Labrador Hydro's passive ice meter data based on a 50-year return period is summarized as follows:

• In region C1, the loads are based on previous studies for the 735 kV transmission lines to Québec and information from Hydro-Québec's passive ice meter network.

• In region C2, the loads are based on ice measurements made at Blanc-Sablon on the Québec coast near the cable crossing, results from the Newfoundland and Labrador Hydro passive ice meter network program and on field observations during the field visit in October 2007.

• In regions C3 and C4, the loads are based on the regional geography, MRI study values and on extrapolation of data gathered in the area since 1975.

• In regions C5 and C6, the loads are based on current Newfoundland and Labrador Hydro design criteria.

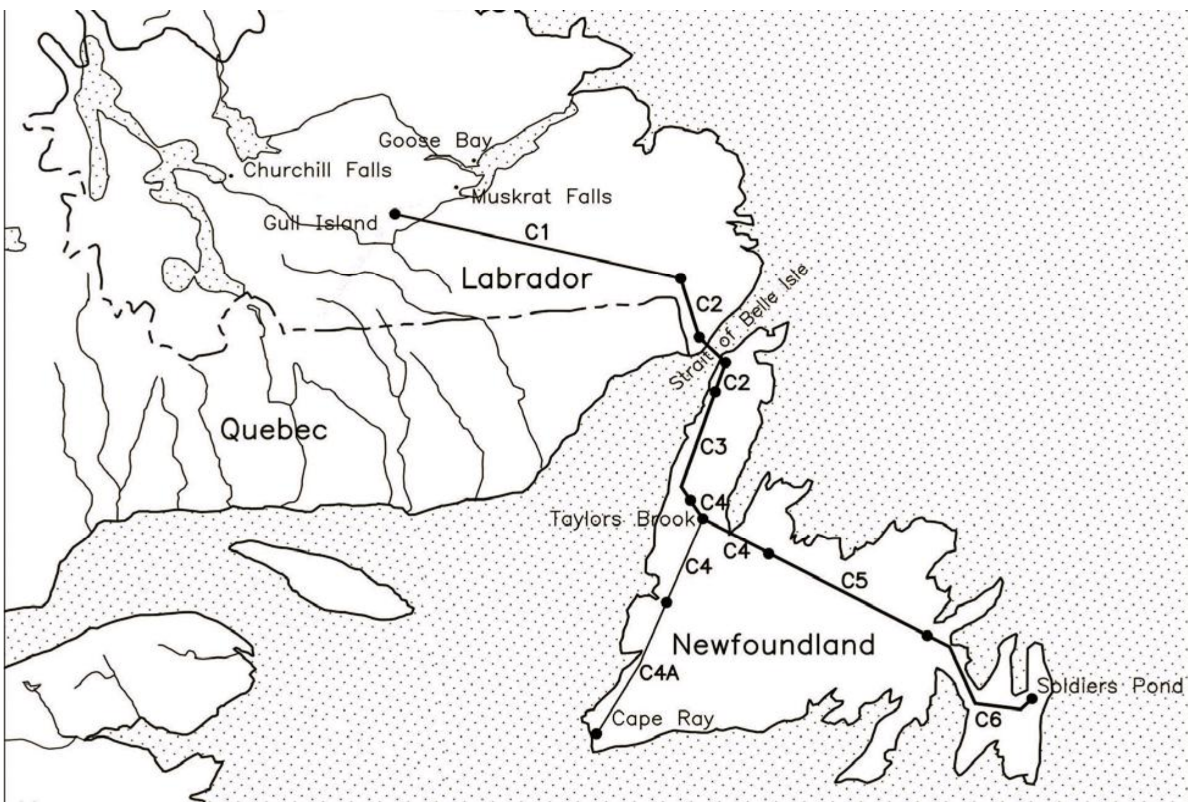

Figure 4: Climactic zones used in Preliminary Meteorological Load Review (Ref. 19)

Since icing is known to increase with elevation in Newfoundland and Labrador, and to vary greatly with exposure, Hatch adjusted their base accumulations using their own methods for each section of the proposed HVdc transmission line for local topography.

2.5. Evaluate Extreme Ice Loads from Freezing Rain (Ref. 22)

In 2010, Kathleen Jones of the Cold Regions Research and Engineering Laboratory (CRREL) provided new accumulation estimates for glaze ice along the proposed HVdc transmission line based on a methodology recently used to map maximum radial ice accumulations for the United States. Jones relied on Environment Canada weather records from twenty-six stations in her study area, compared to twelve for the 1973 MRI study. Jones also benefited from a longer period of record than Richmond and Fegley, with data from the twenty-six station available for anywhere from 12.5 years to 55.5 years for those stations in continuous operation since 1953.

Jones used two models developed at CRREL to estimate ice accumulations based on available meteorological data. The CRREL model includes a heat-balance calculation to determine what proportion of freezing precipitation accretes to a standard wire size. The Simple model is more conservative in that it assumes all freezing precipitation will accrete to the wire; consequently, it is independent of temperature. Both models give similar results in cold windy conditions, but the CRREL model will give lower radial ice accumulations in low winds if the temperature is near freezing.

Jones attempted to confirm both her model results and assumptions by searching for media reports for potentially damaging storms, defined as storms where either the CRREL or Simple model returned a radial ice thickness. Based on the available media reports, as well as data from Newfoundland and Labrador Hydro's passive ice meter network, Jones chose the results of the more conservative Simple model as the basis for her extreme value analysis, believing them to correspond better to reported glaze ice accumulations.

2.6. In-Cloud Icing review (Ref. 19, Ref. 20, Ref 21)

The extreme loading zones throughout the Labrador – Island Transmission Link proposed corridor have been intensely studied since the first studies in the 1970's. The project reports mentioned above have included In-cloud icing and severe wind estimation on several portions of the route and NLH's extensive monitoring field program had in-cloud icing regions as a major focus. In general, the Alpine regions of the transmission line corridor include the southeastern portion of Labrador, two areas on the Long Range Mountains and a small section in central

Newfoundland. See Appendix A for the region map. Ongoing work on meteorological testing in critical areas involves the following:

- Evaluation of icing measurement on three newly constructed test spans on the Long Range Mountains since 2009.
- Modelling historical icing events in the most severe location using nearby weather observation.
- Modelling and simulating icing for selected weather conditions using state-of-the-art meso-scale numerical weather prediction system. (WRF model)
- Modelling and simulating selected weather conditions using historical numerical models.

The first report containing these new studies and models is included in Ref. 21(2) "Evaluation of in-cloud icing in the Long Range Mountain Ridge". The follow on report will analyse another year of data and will make a recommendation on design loads for alpine regions based on a vast amount of statistical, numerical and historical analysis.

3. Nalcor Meteorological Estimation

Since the completion of the CRREL report, Nalcor has conducted significant review and comparison analysis of reasonable design loads for ice accumulation along the proposed HVdc transmission route.

The analysis considered all previous studies and in particular, Ref. 19, Ref. 22, and design loads and operating experiences of existing transmission lines operated by Newfoundland and Labrador Hydro in the vicinity in the proposed route (see attached list). In general the estimated accumulations are greater than the accumulations used for the design of existing transmission lines and those forecasted by Kathy Jones, but are less than those recommended by Hatch in their 2008 *Preliminary Meteorological Load Review*, which were based largely on the MRI 1973 report.

The following is a short summary of the results:

Appendix A, "Ice Load Region Maps" outlines 11 different line sections based on meteorological loading. The regions have been categorized as follows:

1) Average Sections (6 sections in central and northern Newfoundland as well as Labrador). Historically, due to NLH's smaller size of conductors and larger expected ice loads, a combined condition of 50 % maximum ice and 50 % maximum wind load pressure on a transmission line has been the governing design case. As per CSA 22.3 No 1-10 Clause 7.2, engineering studies were carried out to analyze the effect of increasing glaze ice design loads on the HVdc transmission tower weight. It was determined that due to the large size of the HVdc conductor; NLH's maximum 110 mph gust wind speed proves to be the governing design load case. This was true when comparing this maximum wind load case to combined values up to 25 mm radial ice and 55 mph wind. Due to the combined load being 50 % of the maximum load as per NLH standards, the value of 50 mm radial ice was selected as the Maximum design ice load for the average region of the HVdc line. Using a design maximum ice load of 50 mm does not significantly increase the cost of the Average section.

2) Eastern Section (1 section in eastern Newfoundland). The design load of 75 mm glaze ice used for the Avalon Peninsula by Newfoundland and Labrador Hydro since 1996 has been chosen for the easternmost sections of the line, based on NLH's 1995 review.

3) Alpine Sections (4 sections in central and northern Newfoundland). These sections are subject to rime icing due to their elevation and topographical features. Further study is ongoing in these areas using numerical weather models and data from test spans located in the Long Range Mountains in western Newfoundland.

Table 1: Existing NLH Lines in Proximity to HVdc Corridor

Line	Location	Loading Zone	Proximity to HVdc	Voltage (kV)	Year Constructed.	Construction	Loading: Max Ice (inch)	Loading: Max Wind (mph)	Loading: Combined Ice (inch)	Loading: Combined Wind (mph)
TL 205	Stony Brook to Bay D'Espoir	Average	Central Newfoundland Region	230	1967	Steel	1	110	0.5	73
TL 207*	Sunnyside to Come By Chance	Eastern	Avalon Peninsula	230	1968	Steel	3	110	1.5	55
TL 210	Grand Falls to Gander	Average	Central Newfoundland Region	138	1969	Wood & Steel	1	110	0.5	73
TL 217*	Western Avalon to Holyrood	Eastern	Avalon Peninsula	230	1970	Steel	2.6***	110	2	62
TL 237*	Come by Chance to Western Avalon	Eastern	Avalon Peninsula	230	1968	Steel	2.6***	110	1	55
TL 240	Churchill Falls to HVGB	Average	Labrador	138	1976	Wood	1	72	0.5	55
TL 241	Plum Point to Peter's Barren	Average	Northern Peninsula	138	1983	Wood	0.5 - 2	110	1	55
TL 244	Plum Point to Bear Cove	Average	Northern Peninsula	138	1983	Wood	1.5	95	0.5	55
TL 247**	Deer Lake To Cat Arm	Average	Northern Peninsula	230	1984	Steel	1.75	110	1	55

*Line was part of Avalon Upgrade.

**Line has eight separate loading zones with the section of the line closest to the HVdc corridor having 1.75 inches

***25-year return value

4. References

1. Meteorological Study of the Gull Island- Stephenville-Holyrood Transmission Line Routes. M.C. Richmond, M.J. Fegley (Meteorology Research Inc.) 30 November 1973.
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21. Report #1 and Evaluation of in-cloud icing in the Long Range Mountain Ridge. Landsvirkjun Power. December 2010.

22. Evaluate extreme ice loads from freezing rain. Cold Regions Research and Engineering Laboratory (Jones, K). January 2010.

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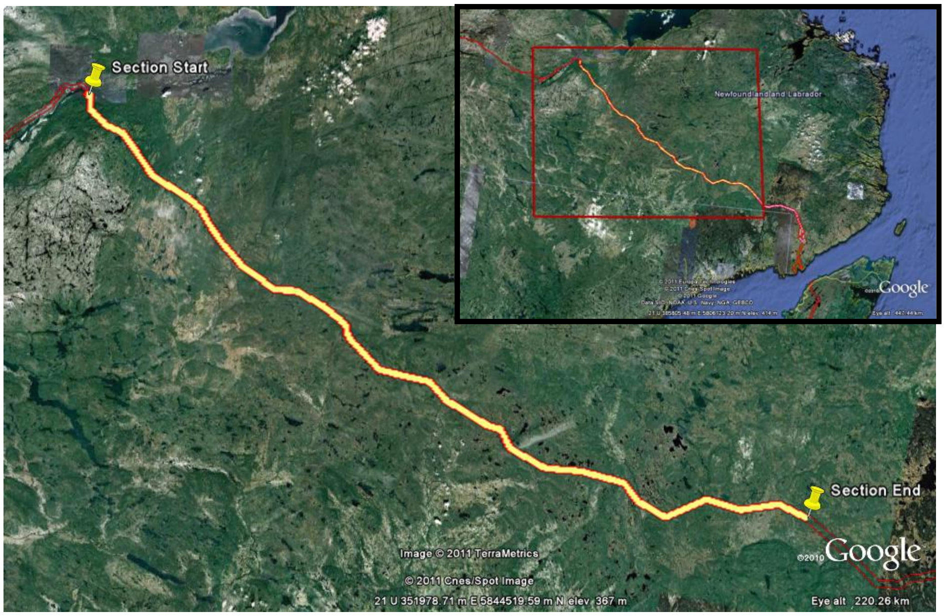
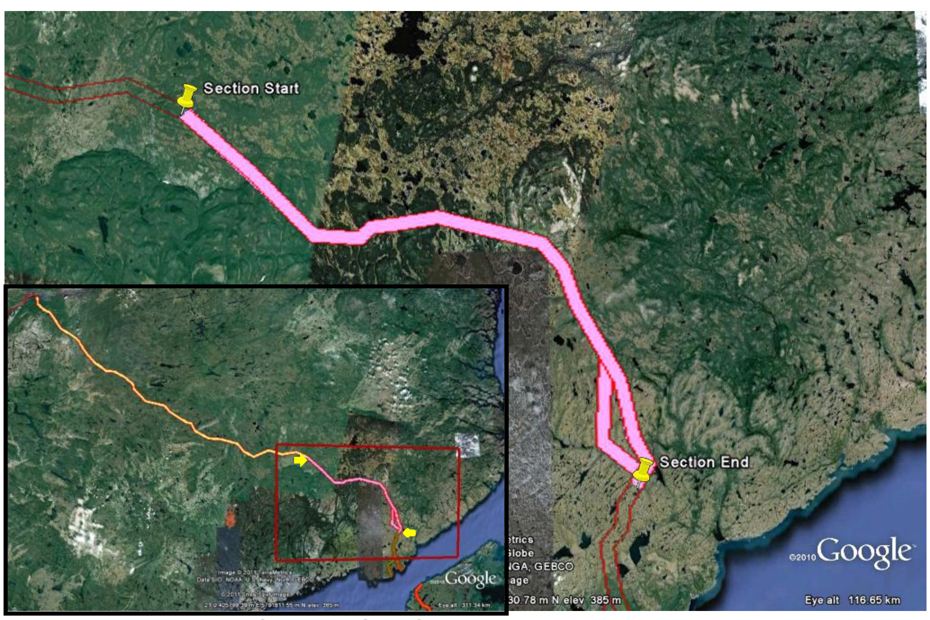
APPENDIX A – Ice Loading Region Maps



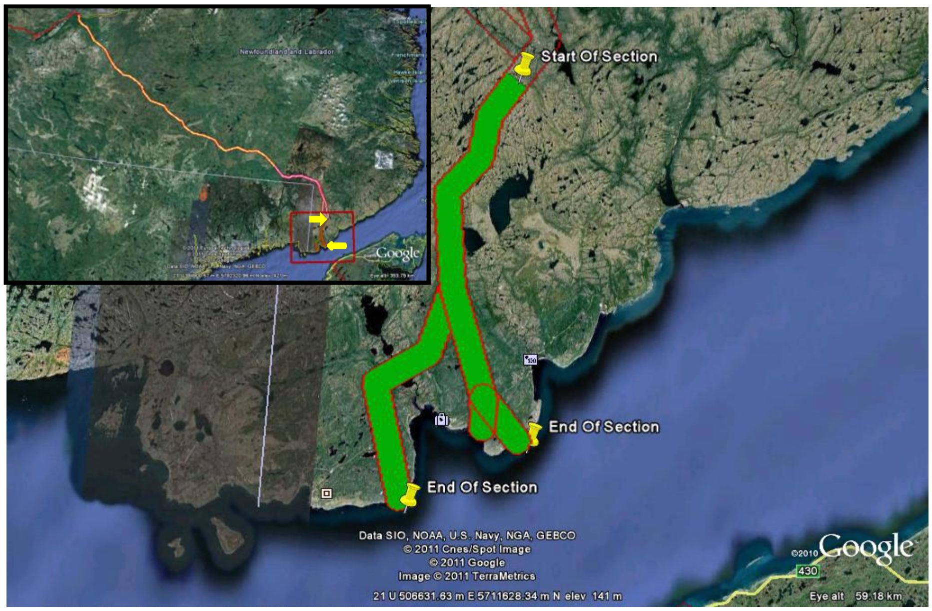
Zone 1 – Inner Labrador

Average Climate Region
50mm max ice load



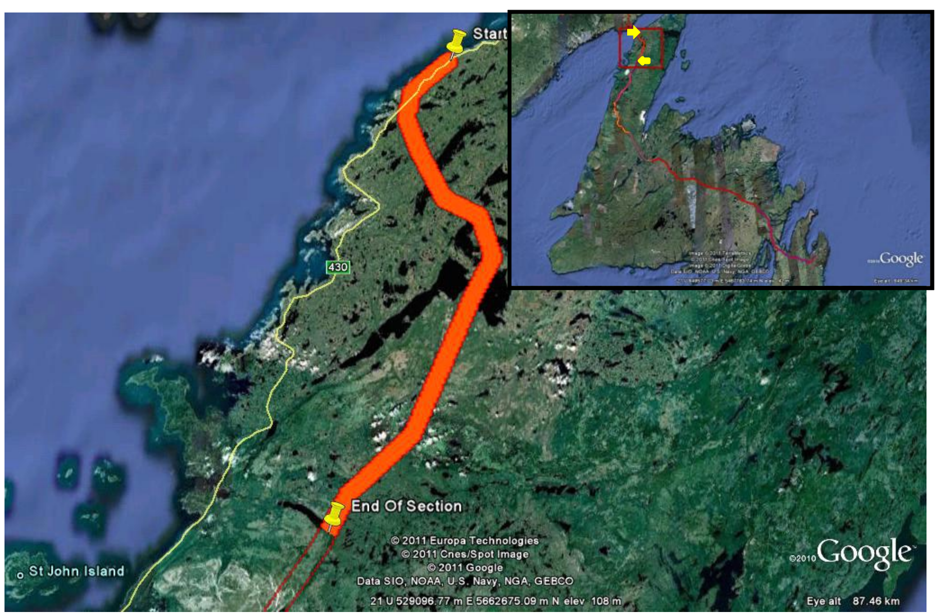
Zone 2 – Alpine Labrador

Alpine Region
Ice Load Yet To Be Determined



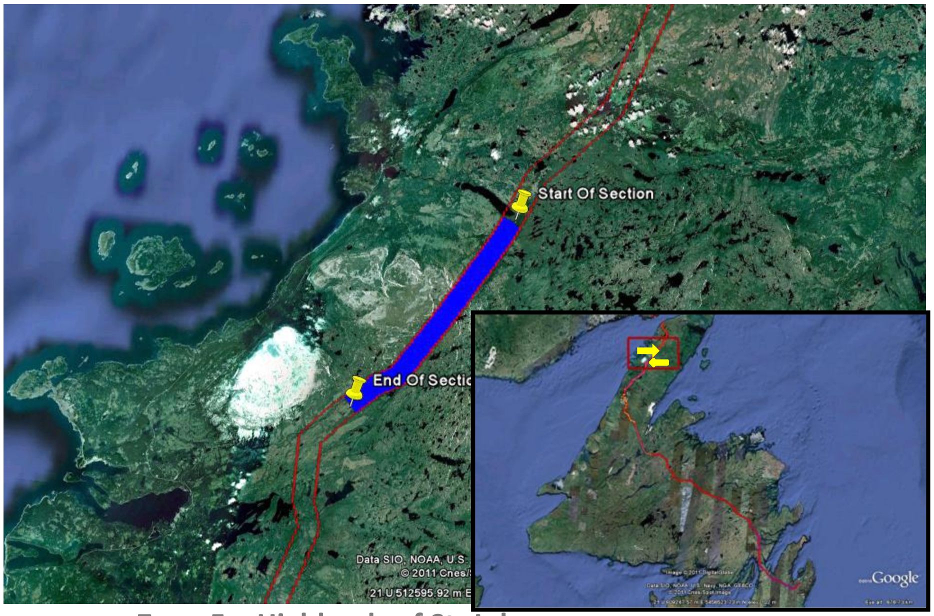
Zone 3– Labrador Coast

Average Region
50mm Ice Load



Zone 4 – Northern Peninsula Coast

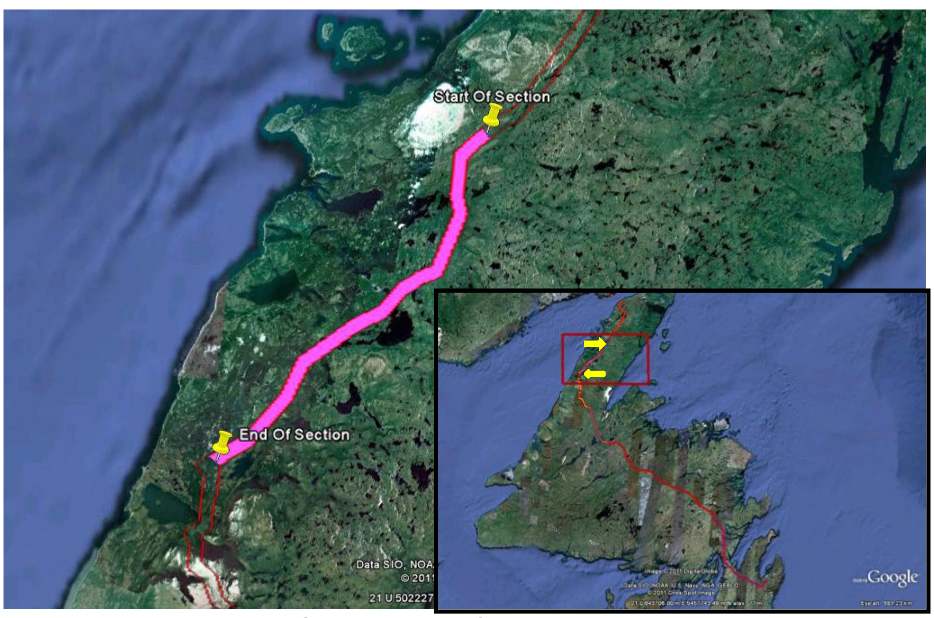
Average Region
Max ice load 50mm



Zone 5 – Highlands of St. John

Alpine Region

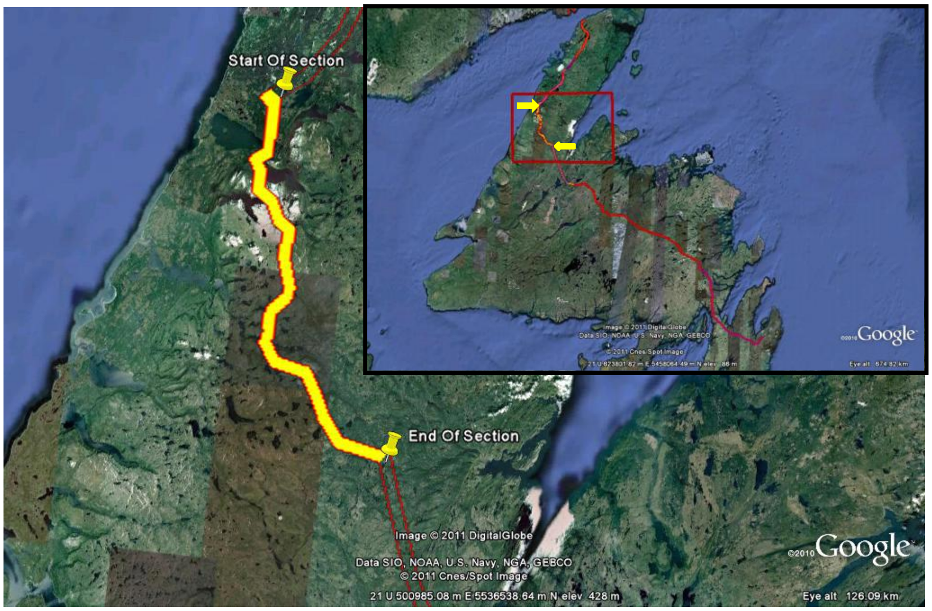
Ice Loading Yet To Be Determined



Zone 6 – Northern Peninsula

Average Region

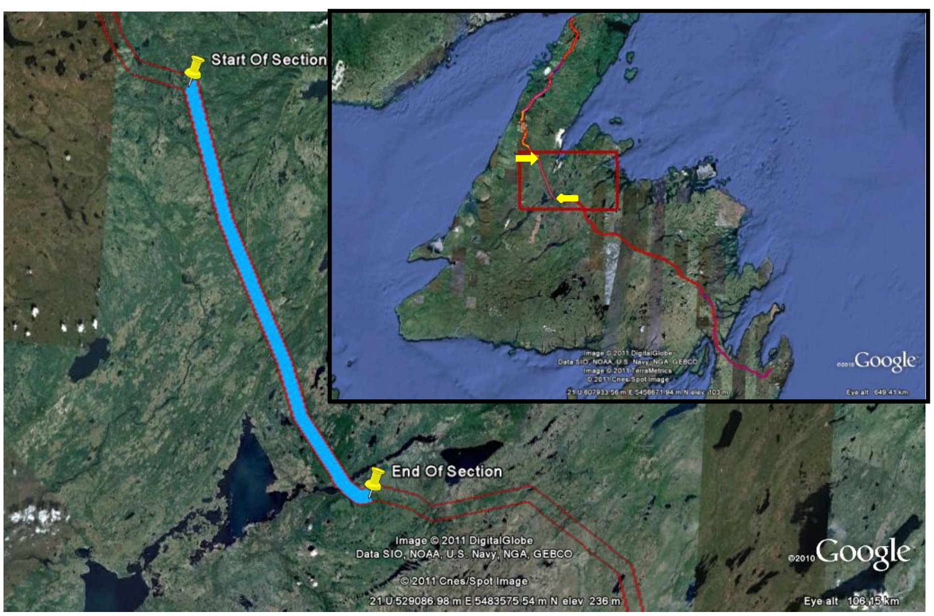
Max ice load 50mm



Zone 7 – LRM

Alpine Region

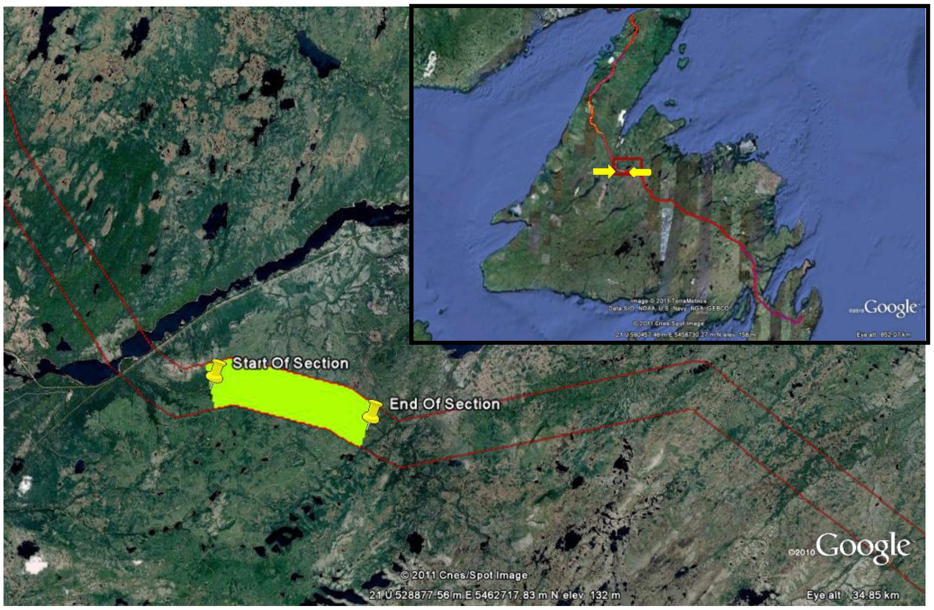
Ice Loading Yet To Be Determined



Zone 8 – Central West NFLD

Average Region

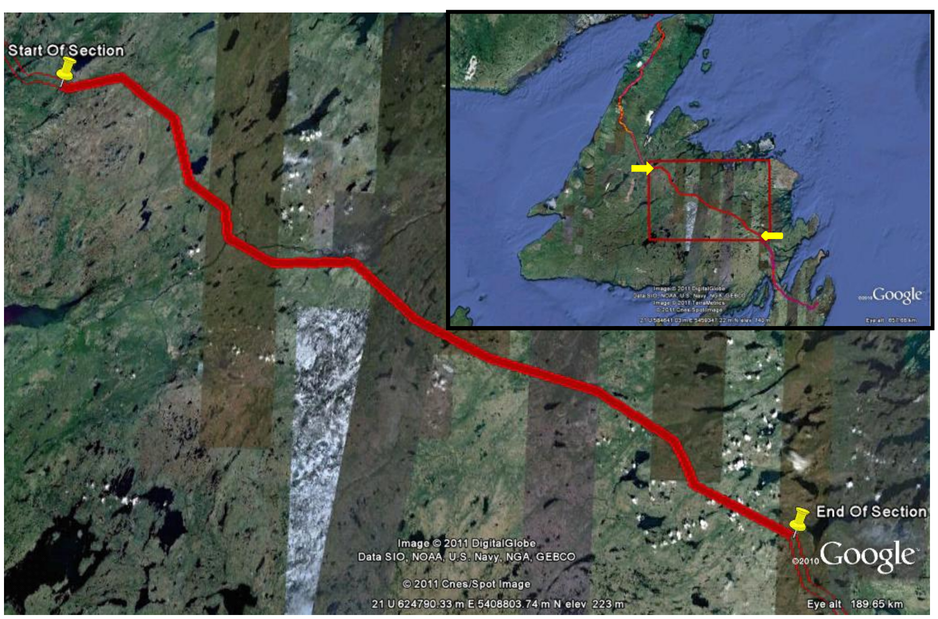
Max ice load 50mm



Zone 9 – Central Alpine

Alpine Region

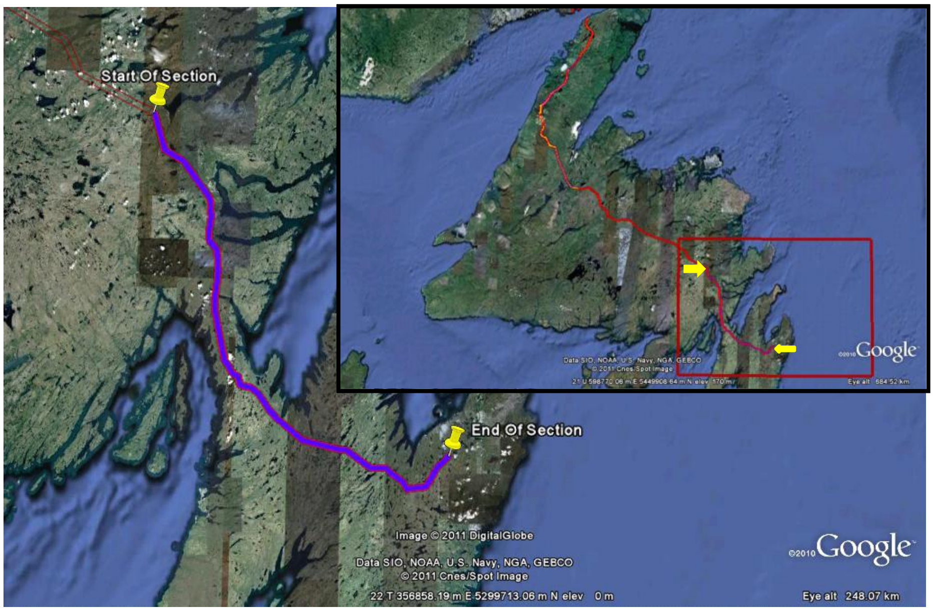
Ice Loading Yet To Be Determined



Zone 10 Central East NFLD

Average Region

Max ice load 50mm



Zone 11 – Eastern NFLD

Eastern Region
Max ice load 75mm