Reference 19

HYDRO
THE POWER OF COMMITMENT

THE Lower Churchill PROJECT

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DC1070 - Preliminary Meteorological Load Review

prepared by

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in association with

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Executive Summary

In this study, meteorological loads are developed for the HVdc transmission line from Gull Island to Soldiers Pond and to Cape Ray. These loads pertain to wind and two types of atmospheric icing (glaze and rime), and are expressed as extreme values, both as individual and combined loads. The extreme values were developed from previous studies in the area, measurements of icing by Hydro, meteorological loading criteria used by Hydro in previous designs, and data from Environment Canada. A Reliability Design Based (RDB) approach, as described in Canadian Standards Association (CSA) and International Electrotechnical Commission (IEC) guidelines, was used in the development of these extreme values. The reference extreme value for transmission line design is normally based on a 50-year return period. These reference values were developed from the available data sources for six climatological regions (Figure 1) which cover the entire transmission line route, as determined in WTO DC1050 and WTO DC1060. Depending on the topographic diversity and complexity of these six regions, the resulting extreme value loads were further divided over shorter sections of the line route within each region to allow for various topographic effects on wind and icing accumulation. Thus, for a single region, a number of extreme value loadings can apply.

In the report, the extreme values are presented for 50, 150, and 500-year return periods, as recommended in the CSA and IEC guidelines. The 150 and 500-year values are determined from the (reference) 50-year value by using accepted extrapolation factors. The icing values so determined are then modified to allow for the effects of changes in topography on the ice accumulation. This amplification analysis, which is a methodology developed from icing studies in Québec, entailed a detailed assessment of the topography within each of the six regions by a meteorologist to determine suitable amplification factors. The extreme value loads are presented separately for (i) glaze icing, (ii) rime icing, (iii) wind, (iv) glaze and wind combined, and (v) rime and wind combined. The combined 50-year return period ice and wind value is determined from the 5-year icing value with 70 percent of the maximum hourly wind speed, as recommended in the guidelines. In the tables included in this summary and in the main text of the report, the unamplified values are representative of each of the six regions. The amplified values are shown as a range over each region. The complete details are included in Appendix D.

A brief review of the literature on ice accretion modeling was also carried out. This review served to point out some of the vagaries and shortcomings of these models as tools for developing design loads but also to indicate reasonable agreement in the case of some of the models with observed ice accumulations. Previous studies of a HVdc line from the Lower Churchill development used one of the more accurate models to estimate meteorological loads, and the current study used that earlier work to develop the reference loads over some of the line.

The following observations and conclusions may be drawn from the study:

1. The proposed transmission line will traverse a wide range of meteorological conditions, and different design meteorological loads will be necessary for different sections of the line.
2. Parts of the line may experience icing that is unprecedented for major transmission lines worldwide; it will be necessary to carefully route the line to minimize such loads. Additionally, de-icing methods may have to be employed.

3. The design loading in parts of the route through the Long Range Mountains will be due to a combination of rime and wind; the maximum combined load for the reference 50-year return period is 200 mm of ice and 105 km/h of wind.
4. The choice of return period (and associated extreme values) for design purposes depends on the reliability required of the transmission line. While the guidelines provide recommendations based on the voltage and strategic nature of the line, ultimately the owner will decide an appropriate design philosophy based on a risk assessment.
5. Prior to final design, wind measurements should be acquired to improve the understanding of topographic effects in the more critical, localized areas and thereby improve the confidence in the values chosen for design purposes.

Table 1
Glaze Loads (PIL) in mm radial by Region (Density = 0.9 g/cc)

Climatic Regions							
Return Period (Years)	**C1**	**C2**	**C3**	**C4**	**C4A**	**C5**	**C6**
50	35	75	75	75	60	75	75
150	42	90	90	90	72	90	90
500	49	105	105	105	84	105	105
Amplification range due to topography for 50-year reference	38-70	83-131	83-206	83-131	69-105	83-113	83-94

Table 2
Rime Loads (ICIL) in mm radial by Region (Density = 0.5 g/cc)

Climatic Regions							
Return Period (Years)	**C1**	**C2**	**C3**	**C4**	**C4A**	**C5**	**C6**
50	70	100	100	70	70	100	120
150	84	120	120	84	84	120	144
500	98	140	140	98	98	140	168
Amplification range due to topography for 50-year reference	88-123	100-175	100-200	70-123	70-123	100-125	120-150

Table 3
Maximum Hourly Winds in km/hr by Region

Climatic Regions							
Return Period (Years)	C1	C2	C3	C4	C4A	C5	C6
50	100	155	150	130	145	140	150
150	110	171	165	143	160	154	165
500	120	186	180	156	174	168	180

Table 4
Combined Glaze and Wind Loads by Region

Climatic Regions							
Return Period (Years)	C1	C2	C3	C4	C4A	C5	C6
50	18/70	38/109	38/105	38/91	30/102	38/98	38/105
150	21/77	45/120	45/116	45/100	36/112	45/108	45/116
500	24/84	52/130	52/126	52/109	42/122	52/118	52/126

Table 5
Combined Rime and Wind Loads by Region

Climatic Regions							
Return Period (Years)	C1 mm/km/h	C2 mm/km/h	C3 mm/km/h	C4 mm/km/h	C4A mm/km/h	C5 mm/km/h	C6 mm/km/h
50	39/70	55/109	55/105	39/91	39/102	55/98	66/105
150	46/77	66/120	66/116	46/100	46/112	66/108	79/116
500	54/84	77/130	77/126	54/109	54/122	77/118	92/126

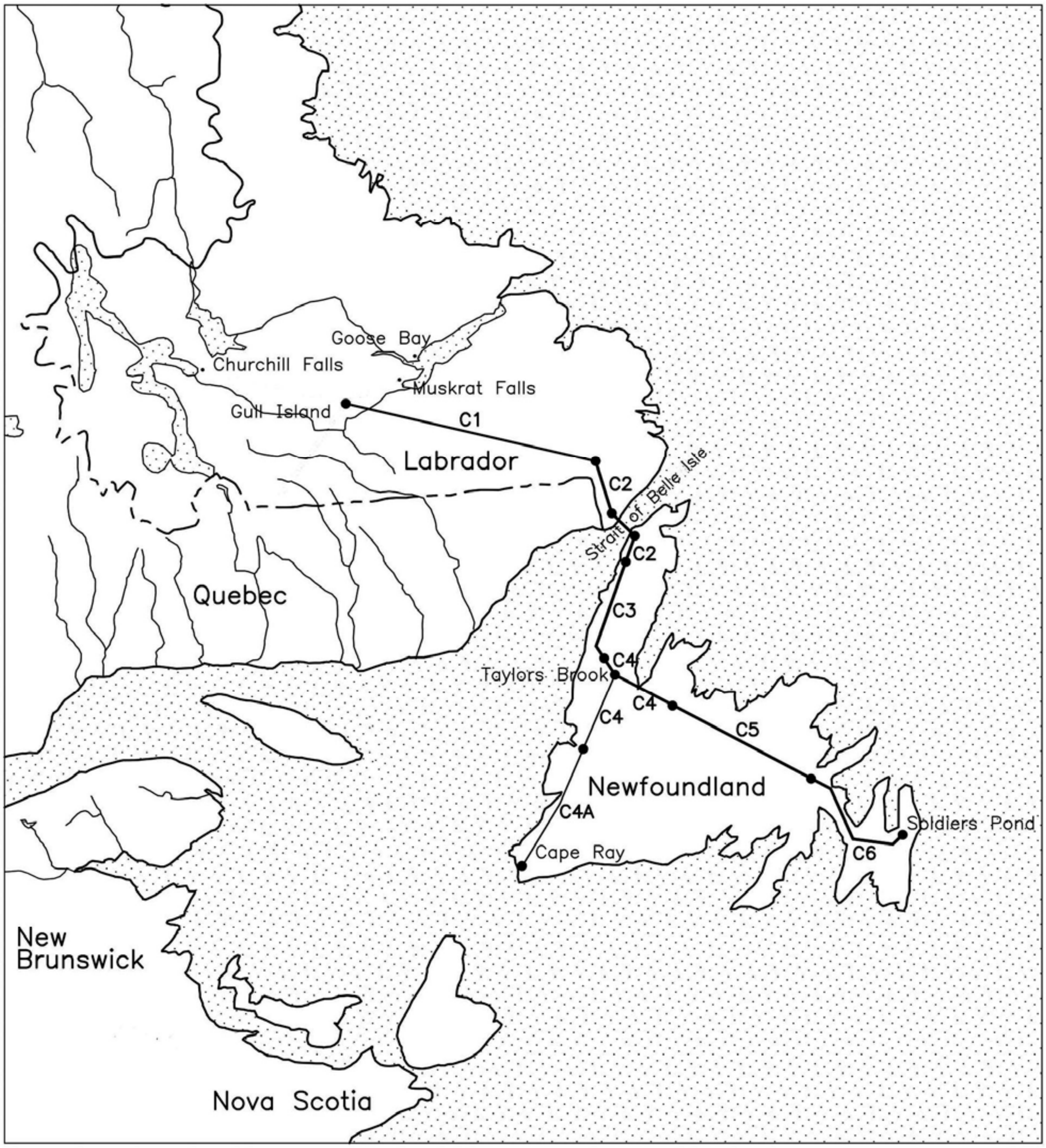

Figure 1
Climatic Regions C-1 to C-6

1. Introduction

1.1 Background and Purpose

Newfoundland and Labrador Hydro (Hydro) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. These sites are located downstream 225 km and 285 km respectively from the Upper Churchill hydroelectric facility that was developed in the early 1970's. The total potential capacity at the two sites is approximately 2,800 megawatts (MW), the Gull Island site being the larger at 2,000 MW.

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

In April 2007, NLH contracted Hatch Ltd. of St. John's to undertake a program of studies to address aspects of this development, relating primarily but not exclusively, to hydrology/hydraulics and transmission components. Approximately thirty such studies have been carried out by Hatch and its associated sub-consultants, RSW of Montreal, Statnett of Oslo, and TransGrid Solutions of Winnipeg. The program has been managed from Hatch's office in St. John's using the company's project management tools and a project services team that has liaised throughout with a similar group in Hydro.

The Lower Churchill Project (LCP) transmission system is proposed to comprise of a double circuit 230 kVac line, single circuit 735 kV lines, and bipolar HVdc lines (Figure 1-1). The HVdc lines will connect the Gull Island Converter Station to those at Soldiers Pond and other markets.

The purpose of this WTO was to review the HVdc line routing from a meteorological perspective and to recommend appropriate icing and wind loadings to be used in the design of the line, as addressed in WTO DC1080.

1.2 Interrelation with other WTO's

This WTO was carried out in conjunction with the following studies also being performed for the LCP.

- Corridor Selection and Construction Infrastructure – Gull Island to Québec Border (WTO AC1130).
- Corridor Selection and Construction Infrastructure – Gull Island to Soldiers Pond (WTO DC1050).
- Corridor Selection and Construction Infrastructure – Taylors Brook to Cape Ray (WTO DC1060).
- Tower Type Selection (WTO DC1080).

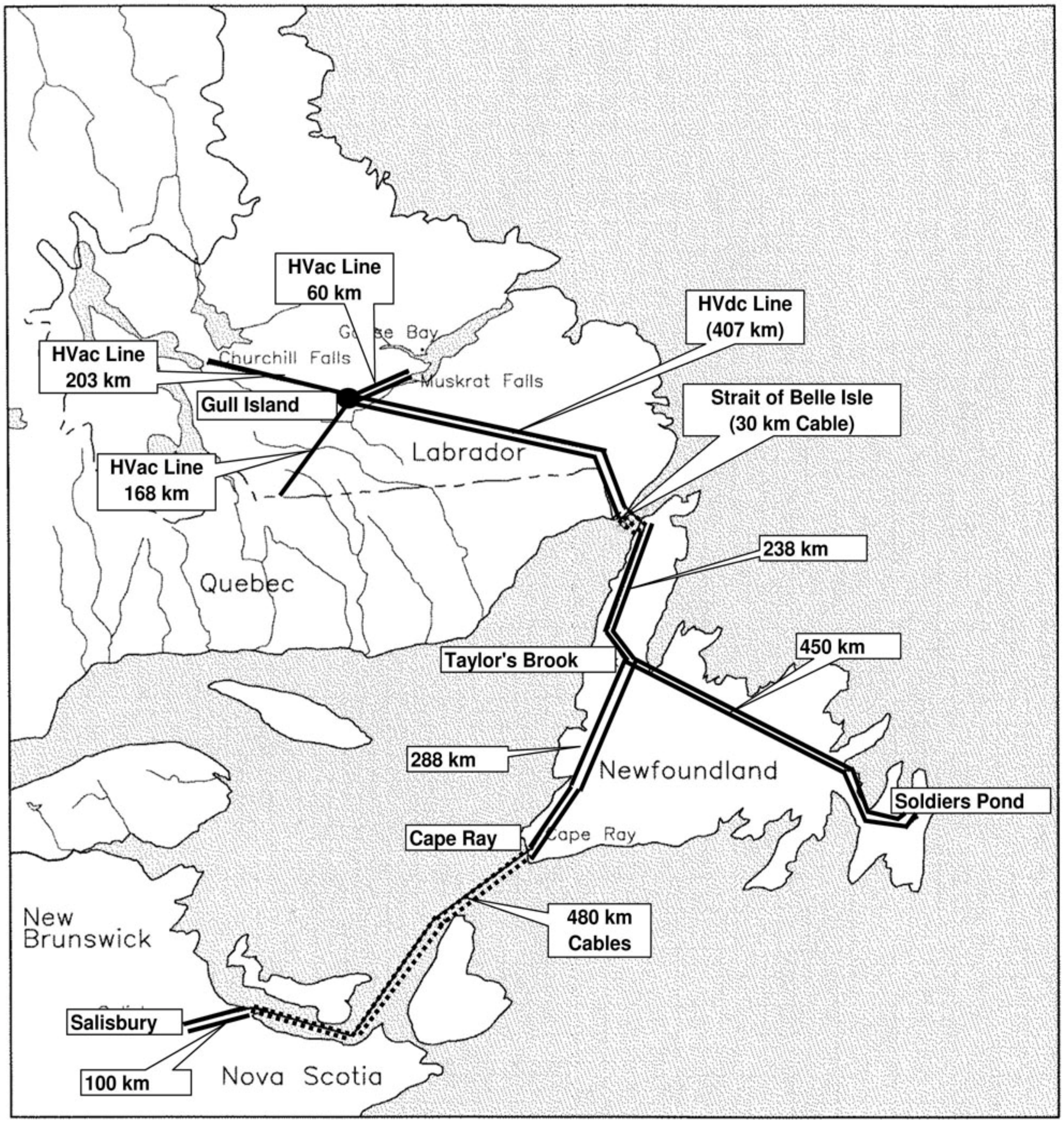

Figure 1.1 - Key Plan
(New Brunswick option shown)

1.3 Approach to the Work

In general, the approach to the work was to:

- review previous meteorological loading studies for the area;
- update these studies from a review of more recent data and analytical methods;
- review and incorporate Hydro's experience with icing measurements and design approaches;
- include observations from a field reconnaissance during this study, and;
- derive meteorological loading criteria using these sources and appropriate return period values for the different line sections.

The work was led by RSW, who were supported by meteorological sub-consultants experienced in the study of the behavior of icing and wind on high voltage transmission line systems. Additionally, Environment Canada services were engaged to do an updated extreme value analysis of wind, precipitation and air temperature data over periods ranging from 17 to 53 years, from weather monitoring stations across Newfoundland and Labrador. A review was also carried out of ice modeling approaches and the influence of topography and existing line design standards, including CSA and IEC most recent editions.

1.4 Terminology

The IEC uses the term "atmospheric icing" for a number of processes in which water in various forms in the atmosphere freezes and adheres to objects exposed to the air. There are in general two types:

- precipitation icing; and
- in-cloud icing.

The former may occur in the form of freezing rain or wet snow accretion.

Freezing rain occurs when raindrops or drizzle fall from a warm upper layer of air through a colder layer at a lower elevation. The supercooled drops freeze on contacting an object at air temperature, and the resulting accretion is a clear solid ice called glaze.

Wet snow accretion, which is of lesser concern and not normally a design consideration in Newfoundland, may occur if the air temperature is low enough to cause freezing of the accumulated wet mass of snow.

In-cloud icing or rime is that resulting from the freezing of supercooled water droplets in fog or a cloud, normally a feature at high elevation. The formation may be hard or soft rime depending on the characteristics of the droplets and the prevailing meteorological conditions. The density of hard rime may be two to three times as much as that of soft rime.

2. Review of Previous Work

Since the early 1970's, Hydro companies (NLH, CF(L)Co, Lower Churchill Development Corporation) have conducted studies relating to the development of the Lower Churchill River hydroelectric potential and the construction of a HVdc transmission line to the island of Newfoundland. Other relevant studies have also been carried out in relation to the existing transmission lines from the Upper Churchill. This section of the report reviews this body of work and summarizes the findings in terms of meteorological phenomena and loadings.

2.1 MRI Studies

Meteorological Research Inc. (MRI) of California carried out the earliest, and perhaps still the most definitive, study of meteorological loadings on a proposed HVdc transmission line system from Labrador to the island of Newfoundland. (MRI,1973). The study, which addressed a route from Gull Island to Holyrood (Soldiers Pond) and Stephenville, consisted of a field survey, climatological study, and analysis of data and application of the results to the proposed route. MRI used the precipitation, wind and temperature data available at that time from a number of weather stations and an in-house simulation model to derive maximum radial ice thicknesses for 10, 25, 50 and 75-year return periods. The transmission line route was divided into loading regions or segments, and some of these were further subdivided. The values resulting from the extreme value analysis were then adjusted for route segments based on exposure and known incidents of icing. The simulated ice loading table developed by MRI is presented in Table A.1 in Appendix A for the 11 route segments (Figure A.1) from Gull Island to Holyrood for the 50-year return period.

The principal conclusions arising from the study were:

- The heaviest accumulations of glaze icing will occur in eastern Newfoundland (near the Isthmus of the Avalon), along the high terrain of the Great Northern Peninsula (Long Range Mountains), and near the Strait of Belle Isle. The calculated 50-year return period radial glaze ice thickness for each of these areas was 110 mm, 110 mm, and 100 mm, respectively.
- These areas are also vulnerable to heavy accumulations of rime icing with the Long Range Mountains area being the most susceptible. The calculated 50-year return period value for rime icing in this area at elevations greater than 365 m was 240 mm. In the area of the Isthmus, the value was 157 mm; and for the coast of the Strait of Belle Isle, including 50 km inland on the Labrador side, the value was 170 mm at elevations greater than 150 m.
- When icing and wind were combined, glaze ice loadings were higher in all cases except for those locations with elevations greater than 365 m, because of the higher density of glaze ice.
- For the three areas noted above, the 50-year wind and ice combined values were:
    - Isthmus of Avalon: 128 km/h hourly wind speed and 86 mm of glaze
    - Long Range Mountains (365 m to 550 m): 128 km/h and 173 mm of rime
    - Strait of Belle Isle (<150 m): 122 km/h and 71 mm of glaze
      (>150 m and <457 m): 122 km/h and 112 mm of rime

- Both glaze and rime icing may stay on conductors for several days.
- While wet snow accumulations can be heavy, notably in the Strait of Belle Isle area, loadings would not be large enough to be the limiting design value.
- High wind speeds will occur both during and following icing events.
- The extent of line affected in any one icing event will depend on the location and orientation of the storm system. Heavy loadings may occur over extensive areas; however, extreme value loadings will be localized and limited to a few kilometers of line and usually to a few spans.
- A program of remote instrumentation for measurement of wind and icing in the most critical areas of the route was recommended.
- A study of sea salt contamination of power lines was recommended.

MRI considered ground elevation as a factor in their modeling of precipitation icing and rime icing. Besides looking at ground elevation as a key factor for in-cloud icing, MRI took into account local geographical and topographical effects. MRI had operated four instrumented sites in 1975 and had been involved in line routing analysis up to the end of 1979 (ref. 31).

Elevation was also a factor for extrapolating wind speed from the airport measurements to the line route. Topography is now known to be a significant factor in icing, as explained in reference 1- section 5.2 "Variation of ice thickness with topography". Freezing precipitation is affected by topography which can lead to a lifting of moist air, which as it moves faster and cools down, leads to an increase in the liquid water content (LWC) and in the droplet size. In-cloud or rime icing may also be affected by topography as changes may lead to greater wind speeds which would tend to accelerate rime formation.

MRI also carried out a separate study in 1973 following an icing storm that caused a failure of a Hydro Québec transmission line west of Sept-Isles. This study also covered the 735-kV line from Churchill Falls. Data from Schefferville were used for the northern section of the line and from Wabush for the southern section. The extreme ice loadings were calculated to be 48 mm for the northern section and 53 mm for the southern section for a 50-year return period. The maximum wind for both sections was 115 km/h. No values were provided for the combined effect of ice and wind.

2.2 RSW Studies

As a part of a review of the ac transmission lines in western Labrador for Hydro and CF(L)Co., RSW developed icing loads in three separate studies (RSW, 1995, 1999a, 1999b). The 1995 study, which was concerned with establishing a maximum foreseeable loss for the 735-kV line from Churchill Falls, used predicted ice and wind loads from Environment Canada and actual ice measurements from Hydro-Québec's passive ice meter observation program. The values proposed by Environment Canada for the entire line were separate ratings of 18 mm of ice and 90 km/h of wind for a 50-year return period and 22 mm of ice and 96 km/h of wind for a 150-year return period.

(Note : Environment Canada values taken from the ice map included in the CSA document are point loads and must be multiplied by 1.5).

Based on Hydro-Québec data, RSW recommended separate ice thicknesses and wind speeds of 35 mm and 90 km/h for a 50-year return period and 40 mm and 110 km/h for a 150-year return period. The recommended combined loading values were 18 mm of ice with 67 km/h of wind for 50 years and 40 mm of ice with 82 km/h of wind for 150 years. Note that in the case of the uncombined loads, the Environment Canada values are significantly lower than those determined from the Hydro-Québec data as well as the predicted values from the MRI study of the same line in 1973. The modeling approach used by Environment Canada is believed to be based on Chaine and Skeates (1974).

In RSW 1999a, there is an extensive discussion of transmission line icing with application to the development of additional Extra High Voltage (EHV) ac transmission capability in Labrador. Aspects of both glaze and rime icing are addressed, and design ice and wind loading values are determined from an analysis of Hydro Québec ice meter data and modeling based on Environment Canada data for selected weather stations. The results are also compared with MRI's work of 1973. The latter was found to overestimate ice accumulation alone, when compared with both the Environment Canada and Hydro-Québec values. The loadings recommended by RSW for combined ice and wind ranged from 11 mm and 68 km/h for a 50-year return period to 17 mm and 84 km/h for a 500-year return period. Of the three operating lines from the Churchill Falls plant, the 230-kV and 735-kV lines (in operation for more than 35 years) were designed to an equivalent of 30 mm of radial ice (without wind), and the 138-kV line (in operation for more than 25 years) to 38 mm of ice.

RSW 1999b is a study of an upgrade to the 735-kV structures to accommodate icing of the overhead ground wire (OHGW) based on two icing events in late 1995 and 1997. In the December 1995 event, a combination of glaze ice followed by wet snow and rime resulted in an accumulation of between 5.5 kg/m and 6.5 kg/m on a ground wire and the detachment of a wire due to broken U-bolts at the tower connection. In the December 1997 event, an initial accumulation of glaze ice was followed by accumulations of rime over a three-week period during which time very little ice was shed from the lines. Observations by work crews suggested that a 75 mm of radial in-cloud icing may have accumulated on the ground wires.

2.3 Monitoring Programs 1977-2002

During the ten years from the fall of 1977 to the summer of 1987, Hydro operated a meteorological network to obtain climatic information and data related to the HVdc line project from Gull Island. This data gathering network was equipped with Passive Ice Meters (PIM), Rosemont Ice Detectors (RID), Anemometers and a Test Tower Site (TTS) for measuring glaze and rime icing events. There were 22 PIM stations in operation during the program as detailed in Table 2.1 (No information was available for the first year of operation.) These monitors were installed on the island of Newfoundland and in southern Labrador. Also, from the fall of 1999 to the summer of 2002, a monitoring program was in place at Gull Island. These programs and Hydro's experience with icing over a 20-year period are addressed in Haldar (2007).

Table 2.1
Instruments for the Climatological Monitoring Program (1977 to1987)

Seasons	PIM	RID	TTS	Anemometer*
1978-1979	28	3	14	4
1979-1980	30	3	19	4
1980-1981	29	2	18	5
1981-1982	29	1	18	4
1982-1983	22	0	18	3
1983-1984	22	0	25	2
1984-1985	22	0	17	0
1985-1986	22	0	23	1
1986-1987	22	0	22	1

** The anemometer data was of poor quality and has not been used in this evaluation.*

Passive Ice Meter Network (PIM)

For the PIM network, four stations were located in Labrador and the others were located in Newfoundland, mainly in inhabited areas, and were monitored by trained observers. All analyzed PIM data were taken from annual reports, from the fall of 1978 to summer 1987 (9 seasons). The 1977/1978 report was not available. The basic premises for the program are defined in the first report, but it is assumed that Hydro used the same passive ice meter as Hydro-Québec, and all measurements are assumed to be taken in the same way as for the Hydro-Québec PIM network. All ice measurements are assumed to be ice diameter, observed on a 25 mm diameter cylinder. Using corrections factors (F_c) of 0.7 for glaze without icicles, and 1.1 for glaze with icicles (developed by Hydro-Québec over the last 30 years), the maximum radial ice was estimated at each station for each season. (See Figure 2.1).

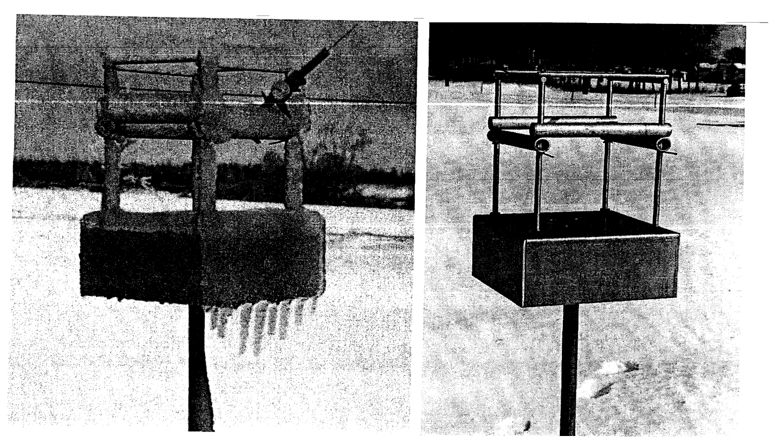

Figure 2.1
Passive Ice Meter used by Hydro-Québec

The radial ice thickness (t in mm) on the conductor is determined by the following formula:

$$t = F_c \ (D_i - D_t)$$

D_i = total ice diameter measured on the passive ice meter

D_t = tube diameter = 25 mm

F_c correction factor

Table B-1 in Appendix B provides the measured maximum glaze, and Table B-2 gives the calculated maximum radial ice in mm using the corrections factors. Of the 29 PIM stations, 15 have nine seasons of observations. Eight stations measured more than 25 mm of radial ice between the fall of 1978 and the summer of 1987; namely, Hampden (53 to 58 mm), Point Amour (45 mm), Yankee Point (45 mm), Goose Bay (14 to 35 mm), Springdale (7 to 35 mm), Buchans (32 mm), Gander (28 mm), Plum Point (28 mm) and Harbour Deep (27 mm).

Although the data set is small, it was plotted using the Gumbel extreme value curve making a grouping of two sets with three stations (Plum Point – Hawkes Bay – Harbour Deep) and (Hampden – Buchans – Springdale)[1]. The result is illustrated in Fig. B-1. The distribution established for Plum Point – Hawkes Bay and Harbour Deep gives 50 mm for a 50-year return period, 63 mm for a 150-year return period and 77 mm for a 500-year return period. The distribution for Hampden – Buchans – Springdale gives 77 mm, 95 mm and 114 mm for the same return periods.

Hydro closed their PIM network in 1987, after ten years of operation, so the data collected is statistically of low value. However, the ice thickness distributions as plotted are acceptable as initial estimates of the 50-year return period icing loads, especially in the Long Range Mountains and in the area of White Bay, where the Taylors Brook substation will be located. Although PIM data was not checked for quality over the program, it is used as a source of information for the present study. Unexplained geographical variations in ice loads in areas well known for heavy loads illustrates the high degree of spatial and temporal randomness of precipitation icing.

Rosemont Ice Detectors (RID)

Rosemont Ice Detectors were installed at three stations and they operated for four seasons. The maximum ice accumulation measured from these detectors is presented in Table B.3. For the RIDs at Yankee Point (located close to Strait of Belle Isle) and for the RID at Sunnyside (located at the beginning of the Avalon Isthmus), there was very little measured ice accumulation during the program.

[1] This type of exercise was done by Hydro-Québec to produce The Québec Glaze Atlas. With 133 PIM stations, they did 236 triads. The period of data was 25 years from 1975 to 2000. They did so because the power line ran across the province through different climates.

At Four Mile Pond station, located on the Avalon Peninsula near the Holyrood substation, the last three years of measurements give inconsistent data, especially for the season 1980/1981. In the 1979/1980 report, it is mentioned that problems were encountered with the recorder during the season, and it is most probable that there were problems with this instrument during the last two years also.

Because of the very short period of observation, only four seasons, and because of the doubt that surrounds this data, the RID data was not used in this study.

Test Tower Site Network (TTS)

The TTS network included 14 sites at the beginning of the program increasing to 25 during the season of 1983/1984 (Appendix B – Table B-4), and these sites were visited on a monthly basis. Two stations were located in Labrador (L'Anse au Loup 4 and L'Anse au Loup 4a), one at Sheffield Lake in Newfoundland, and six were located in the Long Range Mountains area. Table B-4 presents data for glaze and rime ice from test tower sites close to the line routes (locations are given in maps in Appendix B). The site registering the most hard rime is Portland Creek 2, on February 6, 1982, with 915 mm (total thickness) reported on the tower.

The Portland Creek sites were located at over 500 m above sea level and, for the most part, at the top of mountains, where they were exposed to in-cloud icing. There were six different sites, 2, 2a, 2b, 2c, 2d and 2e, and four (2, 2a, 2b and 2d) registered extensive hard rime ice. During virtually every season of the program, at least one site registered between 200 and 300 mm of hard rime.

Although the Portland Creek sites were more affected by hard rime ice, some glaze was also registered. In February 21, 1979, the Portland Creek site 2a registered 65 mm of glaze ice on the tower. In March 16, 1981, the Portland Creek site 2d registered between 75 and 175 mm of glaze on the ground, but there was no data indicating glaze on the tower or on the guys. Also, on December 14, 1984, the Portland Creek site 2 registered 450 mm of pendant glaze. On February 13, 1985 the Portland 2b registered 760 mm of rime on the tower.

At the Sheffield Lake site, located 410 m above sea level, on February 16, 1979, between 50 and 65 mm of ice was registered on tower legs while the tower top was encased in 150 to 200 mm of ice. This Test Tower Site is located 25 km southeast of the Hampden PIM station, where between 53 and 58 mm of radial ice was registered. This is assumed to be glaze ice.

The sites in Labrador, L'Anse au Loup 4 and 4a, located between 475 and 520 m above sea level, registered glaze and hard rime ice, with between 50 and 65 mm of glaze three times during the program. They also registered 300 mm of hard rime on April 13, 1981, and 450 mm of rime on March 8, 1984.

The TTS network program, even with a short period of observation and incomplete coverage, has provided an excellent indication of variations of glaze and rime ice in mountainous areas through which the HVdc line will pass. Butt (1986) used the available data to develop an extreme values analysis which, although not statistically valid, gives valuable information about the effect of elevation, geography and topography on both precipitation and in-cloud icing (see Table B-4a and Figure B-2). The TTS program shows that the icing climate of the region may be unique in the sense that both precipitation and in-cloud icing may occur within the same period of time. It is thus necessary to combine these two types of ice loads. Deposits of high density have been observed at monthly site visits, and the icing events are frequent and intense with some events occurring at many sites on a given month, indicating extensive atmospheric systems. This information is critical for evaluating localized ice loads and for analyzing failure risk of different proposed line routes.

Monitoring at Gull Island

The program at Gull Island included a meteorological station and two ice monitoring stations installed by Hydro-Québec and Hydro from 1999 to 2001. The meteorological station included active and passive ice sensors. A second passive ice sensor was also installed at Peak's Hill located approximately 10 km northwest of the Gull Island site. C–CORE was engaged to run the program and prepare reports for each year. Two of the three reports were available for review in this study. Over two seasons, eight icing events were recorded, the worst of these being in early May 2000 during which 10 mm of ice was observed over a 21 hour period. In the remaining seven events, the thickness ranged from less than 1 mm to 4 mm.

2.4 Comparison of Icing Values

Table 2.2 shows a rough comparison of the measured icing data from these programs with the projected values (mm) from the MRI study for three approximately similar regions. Note also that the extreme value analysis mentioned above for the Buchans-Springdale-Hampden (BSH) section suggested a 50-y return period value of 77 mm for glaze icing based on the nine years (maximum) of data. While drawing definitive conclusions from a short data set is not recommended, it does appear that the MRI extreme values, while being more conservative than the projection from the PIM data, are reasonable for glaze icing. However, the values for rime are significantly below the measured values in the TTS program. A design approach to accommodating such large values for rime icing is addressed in Section 5.

Table 2.2
Comparison of PIM & TTS data with MRI 50-yr Extreme Values

Climatological Region	PIM max		TTS max		MRI 50-yr value	
	mm	yrs	mm	yrs	Glaze	Rime
C2 Strait Of Belle Isle	45	8	450 (rime)	5	97	145
C3 Long Range Mountains	21	9	760 (rime)	8	112	240
C4 Buchans-Springdale-Hampden	58	9	200	1	91	40

(C2, C3, C4 refer to climatological regions as described in Section 5.4)

3. Ice Accretion Modeling

When there is insufficient icing data from actual freezing precipitation events to develop extreme values for design purposes, one may use numerical models that predict ice thicknesses based on a variety of meteorological variables that exist during the icing event; i.e. the model hindcasts the ice accretion from the meteorological data. A description of twenty such models is given by Henry (1987).

For the most part, only limited testing of these models has been done by comparing them with actual ice accretion events. Tests reported in the literature often show conflicting results in terms of the accuracy with which the models predict actual icing thicknesses. For example, of nine models tested by Yip and Mitten (1991), the Chaine and Skeates (C&S) model was found to be the best at determining glaze ice accretion. However, work reported by Haldar et al (1996) showed that this model vastly over-predicted the actual ice accretion in a CEA (Canadian Electrical Association) study of three ice test sites in Canada, while models by MRI (1977) and Makkonen (1984) provided closer and reasonable agreement. And in work by RSW (1999), it was found that the C&S model under-predicted ice accretion when compared with experience on Hydro-Québec lines, and the design load was increased accordingly. Thus for this one model, three sets of tests show reasonable agreement in one case but significant under-prediction and over-prediction of actual ice accretion in the others. The model, which was developed in the early 1970's (Chaine and Skeates, 1974), is probably the most familiar model in Canada as it has been used for many years by the Atmospheric Environment Service of Environment Canada.

Makkonen (1996) reviewed the conceptual development of ten models and suggested that, while three of the ten were expected to be "good" in their prediction of ice accretion under moderate conditions, all would be only "fair" to "poor" in predicting ice accretion under extreme conditions. He then proposed a more comprehensive model based on his prior model as referenced above.

Jones (1996) used icing data from 169 freezing rain storms over a period of 44 years (at Springfield, Illinois) to compare the CRREL (Cold Regions Research and Engineering Laboratory), Makkonen, C&S, and MRI models with a so-called Simple Model developed by the author. The paper provides useful information on how the models treat the various meteorological and process parameters to explain the differences in their handling of the icing process for accretion on a cylinder. All of the models use at least three weather parameters: precipitation rate, wind speed, and present weather code which indicates whether the precipitation is freezing rain. The four detailed models also require air temperature data whereas Jones' Simple Model does not. All models are also based on the development of a uniform radial ice thickness on a cylinder. The MRI model uses the fall speed of rain drops, and the CRREL model uses the hourly dew point temperatures, atmospheric pressures and solar radiation fluxes. While all four models also require the user to specify the diameter of the cylinder on which the ice accretes, Jones found that only the C&S model showed a significant dependence of ice accretion on the cylinder diameter (larger thicknesses on smaller cylinders); the other three showed almost no relationship between the ice thickness and the diameter. Jones' model is also independent of cylinder diameter. (This dependence of the ice thickness on cylinder diameter in the C&S model may help explain what appear to be contradictory results in the work mentioned above, if the ice were accreting on objects with different diameters.)

In her comparative tests, Jones found that the CRREL and MRI models predicted somewhat less ice than her Simple Model because the latter assumes that all of the precipitation impinging on the cylinder will freeze whereas the others allow water that does not freeze immediately to drip off. And the MRI model typically would predict less ice than the CRREL model because the latter allows some of the excess water to freeze as icicles. The differences would thus be greater at higher precipitation rates. The Makkonen model agreed more closely with Jones' model because the algorithm for the former also assumes that most of the impinging rain is frozen directly or is incorporated within the ice mass. Additionally, Jones notes that the heat transfer coefficient in the Makkonen model is high for typical freezing rain conditions and is more appropriate for rime icing. The C&S model was found to predict significantly larger ice thicknesses than the other models, and the author questions some of the model assumptions.

An additional comparison test reported by Jones relates to hindcasting of a single 10-h freezing rain event on a 2.65 cm diameter cylinder at CRREL's facility in February 1995. The equivalent radial ice thickness corresponding to the measured ice mass was 0.20 cm. Jones' simple model and the CRREL, Makkonen, and MRI models all hindcast a uniform radial ice thickness of 0.19 cm while the C&S model ice thickness was 0.40 cm, or twice as much as the actual thickness.

Thus to summarize:

- There are a large number of mathematical ice accretion models, and their predictions of accretion may vary significantly. A limited amount of comparison in actual icing events also demonstrates differences in model prediction and observed ice accumulation from one model to another.
- The C&S model, which has been used most frequently in Canada, also provides conflicting results in predicting ice thickness within the one model; this may be due in part to the different diameters of cylinders (or conductors) existing in the various cases since this model shows a strong relationship of ice accumulation to the cylinder diameter.
- Of the models described here, Jones' so-called Simple Model and the Makkonen model may over-predict ice thickness because all of the impinging rain is assumed to freeze (in both) and the heat transfer coefficient may be high (in the latter).
- The CRREL and MRI model show the closest agreement, although the former may predict somewhat greater ice accumulation since some excess water is allowed to freeze as icicles.
- All of the models are based on the development of a uniform radial ice thickness on a cylinder. The CRREL model with its icicle algorithm allows for a variation on this uniform treatment.

Based on this comparison, the most realistic models appear to be those by CRREL and MRI with Jones' and Makkonen's models providing somewhat more conservative results. The advantage of Jones' model is in its ease of use and dependence on only a few meteorological parameters while being able to provide reasonable results. In the context of the present study, the results of this brief review of icing models lends support to the use of the prior work by MRI in the study area and, in particular, the use of the MRI modeling results in helping to determine appropriate ice loadings for this new work.

4. Overview of the Climate in the Study Area

4.1 General

In Environment Canada's publication titled "The Climate of Canada", Newfoundland is shown to be the home of a fascinating array of climates and weather, with many of the features of the province's climate explained by its unique geography. There are few physical barriers to protect Newfoundland from weather systems that sweep across it, and its situation on the eastern side of North America favours strong seasonal contrasts in the air masses. Climatically, Newfoundland is the most maritime of the Atlantic Provinces, and this maritime climate results, generally, in more changeable weather with ample amounts of low cloud, heavy precipitation, and strong winds.

Newfoundland is one of the stormiest parts of the continent with some of the most variable weather, and the strongest winds of any province in Canada, with average annual wind speeds greater than 20 km/h. Generally, coastal stations have stronger winds than inland stations, valleys have lighter winds than elevated terrain, and winter is decidedly windier than summer. Winds are predominantly from the west year-round, but variations are common both from location to location and from month to month. Prevailing wind directions are west in winter and west-southwest in summer. Calm or light wind occurs about 2 to 3% of the time along the coast but more than 10% of the time inland.

Freezing rainstorms also tend to be more frequent in Newfoundland. The area between St. John's and Gander is especially prone to prolonged periods of freezing precipitation that may last for several hours or intermittently for two days or more. Freezing rain or freezing drizzle occurs an average of 150 hours each winter, with March being the most severe.

Labrador's climate is more continental than maritime, because it is on the eastern side of the continent, so it experiences strong seasonal contrasts in the characteristics and movement of air masses. The predominant flow is off the land. The rugged Torngat Mountains in the north, with peaks above 1500 m, and the Mealy Mountains in the south, with peaks about 1200 m, confine the moderating influence of the Atlantic Ocean largely to the coastal regions. Compared with the maritime climate of the east coast of Labrador and the Québec north shore of the Gulf of St. Lawrence, the continental climate of the interior is characterized by much colder winters and warmer summers.

4.2 Meteorological Data

The primary period of interest throughout the study area is November through April since this is the period during which icing may occur. In Labrador, this period could extend by a month on each end. The brochure "Climate Normals, 1971 – 2000" published by Environment Canada was analyzed for temperature, precipitation, and wind data to update the data base used in the MRI study of 1973.

4.2.1 Temperature and Precipitation

The mean temperature in Newfoundland does not go below -10 °C from November to April except on the Northern Peninsula. In the eastern part of the island, especially on the Avalon Peninsula, the mean temperature is -5°C (Table C-1). The mean temperature in Labrador is much lower, with Wabush, in central Labrador, having a mean temperature below -18°C from December to February. The mean temperature is -22.7°C in January and between -5.0° and -13°C for November, March and April. At Goose Bay, the weather is somewhat affected by the climate off the coast and the mean temperature is higher than in central Labrador. In January, the coldest month, the mean temperature is -18.1°C. Along the coast of Labrador (Cartwright) and the Québec north shore (Blanc-Sablon), the mean temperature never drops below -15°C from November to April.

In Newfoundland, rainfall is present during each month from November to April, with over 50 mm of rain each month in the southern and the eastern part of the island, and between 30 and 50 mm for the rest of the island, except on the Northern Peninsula (St. Anthony and Daniel's Harbour) which receives less rainfall (10 to 35 mm). (Table C-1 – Appendix C).

The eastern and the southern parts of the island have between 5 and 15 days of rain each month, with between 3 and 10 days for the rest of the island, except for St. John's and Gander which have almost 10 days of rain each month. In Labrador, rainfall is almost absent between December and March, with less than 10 mm of rain, and between 2 and 4 days of rain per month.

For the whole island, there are at least two days of freezing rain each month from December to March, except for St. John's and Gander which have between 4 and 9 days per month of freezing rain, almost 50% of the days when rainfall occurs. In Labrador, there are between 1 and 3 days of freezing rain.

4.2.2 Mean Annual Wind Speed

In Newfoundland, most stations record average annual wind speeds greater than 20 km/h (Table C-2).The mean wind speed from November to April is higher along the coast, especially in the southern part of the Island (25 to 30 km/h). Bonavista, on the east coast, is the windiest location with winds of between 30 and 40 km/h, and inland (Deer Lake and Gander) the winds are between 15 and 25 km/h. The prevailing direction for the whole island is mainly west from November to April.

In Labrador, the wind is essentially from the west from November to April and the average speed is around 15 km/h. Along the coast of Labrador (Cartwright) and the Québec north shore (Blanc-Sablon), the average wind speed is between 20 and 25 km/h; the prevailing direction is from the south at Cartwright and from the west at Blanc-Sablon.

4.2.3 Maximum Hourly Wind Speed

The maximum hourly wind speed is commonly used in transmission line design for determining wind loads in combination with ice loads, and is defined as the maximum speed of the wind measured during the last two minutes before the hour. Data was obtained from Environment Canada for each station and projected for 50, 150 and 500-year return periods. Data for 20 stations are presented in Table C-3 (Appendix C), with the choice of station determined by project geography. Five stations are located in Labrador (Wabush Lake A, Churchill Falls A, Goose A, Cartwright, Mary's Harbour A), one in the Province of Québec (Blanc Sablon A), one in the Strait of Belle Isle (Belle Isle) and the other thirteen stations are in Newfoundland. Seventeen of the twenty 20 stations have more than 30 years of data.

In central Labrador (Wabush Lake A, Churchill Falls A and Goose A), the maximum hourly wind speed for a 50-year return period is between 60 and 80 km/h. Along the east coast of Labrador and Québec north shore, wind speeds are higher, with 93 km/h at Mary's Harbour A station, 100 km/h at Cartwright, and 120 km/h at Blanc Sablon A. Belle Isle station is the windiest location, with a 50-year return period maximum hourly wind speed of 172 km/h recorded in January , reflecting the funnelling effect of the Strait. For all sites, January is the month with the highest wind speed.

In Newfoundland, Badger and Deer Lake A, which are located inland, have maximum hourly wind speeds of less than 100 km/h from November to April, with 75 km/h at Badger and 85 km/h at Deer Lake A. For the other eleven stations, the maximum hourly wind speed have more than 100 km/h from November to April, except for some months in St Anthony A, Gander A, Stephenville A and Argentia, which are less exposed even though they are along the coast. Along the west coast of the Northern Peninsula, at Daniel's Harbour, the maximum hourly wind speed is 125 km/h and there are many bays along the coast of this peninsula that can funnel the wind and increase this speed.

At Stephenville, the 50-year return period maximum hourly wind speed is 100 km/h. Along the south coast at Port aux Basques, Burgeo, and St Lawrence, the maximum hourly wind speed for a 50-year return period varies from 110 to 130 km/h. At Port aux Basques, located less than 20 km from Cape Ray, the maximum hourly wind speed is 126 km/h in February. The 50-year return period maximum hourly wind speeds on the Avalon Peninsula (Argentia, Cape Race and St. John's) vary between 110 and 125 km/h. At Bonavista, the maximum hourly wind speed, for a 50-year return period, is 130 km/h.

Almost all stations register the highest value in January, except for the stations on the Avalon Peninsula, where the highest value is in February.

4.2.4 Field Trip

A field trip was carried out by helicopter from October 26 to 31, 2007. The objective of this trip was to meet local people to gather information on any icing events they may have remembered, to visit existing meteorological stations, to locate and visit the old PIM and TTS sites and to look for evidence of broken tree tops as evidence to quantify the amount of ice that has affected the region. Most of these objectives were accomplished and a good impression of the terrain and conditions to be encountered was achieved. The detailed site visit report is included in Appendix E.

Although broken tree tops were observed in both climatic regions C2 and C3 (Section 5.4), the number was generally less than would have been expected considering the evidence of precipitation icing measured at the PIM stations during their operation.

Since the start of the James Bay transmission lines in the early1970's Hydro-Québec has used the observation of tree damage for the evaluation of risks due to tornados and to localized ice storms. Due to it eccentric load, glaze will break tree tops when the ice load is over 30 mm in equivalent ice thickness. The number of broken tree tops is proportional to the ice intensity. Recent observations of broken tree tops have been useful for analysing the intensity and the dimension of ice storms. Older broken tree tops have also been used for line routing particularly for avoiding areas where icing is amplified, called ZAG (Zones of potential Amplification of Icing or Givrage in French). Older broken tree tops are not easily visible from helicopter and long walks are often necessary to discover old major ice storms. It is not easy to estimate the storm intensity since the number of dominant trees at the time of the storm is not known, but it is possible to date past ice storms from tree growth ring analysis (Dendrochronology). Some spruces had shown a long memory along the Québec North Shore, over 120 years in one case. It is not infrequent to see more than one break per tree, near Pentecôte for example where the memory of three ice storms (1973, 1992 and 2005) is easily visible from ground. Hydro-Québec uses this approach in areas prone to heavy in-cloud icing, areas which are systematically avoided at the routing stage of a transmission line project. While studying in-cloud icing at Mont-Valin (1000 m) near Chicoutimi for example, it has been observed that tree tops frequently affected by in-cloud icing are actually enveloped and protected by light rime and by dry snow. From what has been observed in Newfoundland at the higher elevations of the Long Range Mountains, it seems that frequent rime could protect tree tops from damage due to glaze. Hard rime and glaze seem to occur together in this case.

5. Development of Design Meteorological Loads

5.1 Review of Hydro's Approach

The work by Haldar (1996) referred to previously notes that the early transmission line designs for icing loads were based on CSA guidelines. Since these early designs, a number of icing events over a 30-year period resulted in the use of more stringent criteria as new lines were built and older ones upgraded. In 1995, a detailed failure investigation of existing lines was completed and it was concluded that the observed line failure rate of the system, based on icing events over a 30-year operational life, could be modeled with an annual rate of 0.1 (10-year return period) for the entire Avalon Peninsula. In reviewing the observed ice load on conductors, it was noted that 38 mm to 50 mm of equivalent radial glaze ice was found to be on conductors and/or on guy wires in many instances. This information was used to revise the original design ice load criteria (1:25 year return period loading) to 63 mm radial glaze ice thickness when upgrading the existing lines, and to 75 mm for building new lines, for the equivalent of a 50-year return period loading. As illustrated in Table 5.1, ice load criteria have been increased through practical experience from 1965 to 1988.

Table 5.1
Practical Equivalent Ice Limit Loads used by Hydro (after Haldar,1996)
(an overload factor of 1.33 is assumed on nominal loads)

Year	Nominal Ice Load (inches)	Nominal Ice Load (mm)	Limit Loads (mm)
1965-1975	1.0 – 1.5	25 – 38	33 - 51
1976-1988	1.75 – 2.25	44 – 57	59 – 76
	Extreme Ice Load (inches)		
1999-2001	2.25 – 3.0	-	66 - 76

Previously, the ice loads were calculated from a deterministic approach, based on practical experience and CSA criteria with a safety factor, but the new and increased load are based on a RBD approach, using ice load statistics. In the new approach the load is the extreme value having a very low probability of occurrence, and it corresponds to the ultimate strength of line components which is determined from individual strength dispersion.

Although no new lines have been built recently in Newfoundland and Labrador, several lines have been upgraded based on this reliability analysis approach. These are:

- TL 217 Western Avalon to Holyrood (1999 and 2000) with design loads of 66 mm and 75 mm radial ice;
- TL 207 Sunnyside to Come by Chance (2001) with a design load of 75 mm radial ice;
- TL 237 Come by Chance to West Avalon (2001) with a design load of 63 mm radial ice;
- TL 236 Hardwoods to Oxen Pond (2002) with a design load of 75 mm radial ice; and

- TL 242 Holyrood to Hardwoods (2002) with a design load of 63 mm radial ice.

From the analysis of failure rates, this study produced statistical extreme ice loads, and the line upgrading was based on a 50-year return period. These loading criteria are valid references for the design of the Gull Island to Soldiers Pond HVdc line in the areas of the Avalon and Connaigre Peninsulas, but they must be adjusted, both for the security level required by such a line and for the various climatic and topography conditions along its route, particularly in areas where no lines were built in the past and for which the only reliable information comes from the TTS.

Further analysis of operating data is required because current information is not necessarily consistent with specified criteria. For example, the line TL 240 from Churchill Falls to Goose Bay, built in 1976, was apparently upgraded in 1999 to loads of 44 and 57mm, and it is not clear if these ice loads are nominal loads with traditional safety factors or ultimate loads.

5.2 Reliability Based Approach

In 2003, IEC introduced its standard 60826 for the reliability-based design for the construction of overhead transmission lines, taking into account that the climatic loads and line component strengths are random variables. The reliability is characterized by the probability that the line will perform its task under the environmental and operating conditions during a specified time. Reliability is thus a measure of the success of the line to perform its task. The line is considered reliable when its strength is greater than the effect of applied loads. The complement to reliability is the probability of failure.

IEC 60826 is not a complete design manual but gives guidance for the preparation of national overhead lines standards. Before 1995, CSA-C22.3 used the deterministic design method by specifying climatic loads according to local operating experience and weather records. Component strengths were specified and safety factors were proposed to cover uncertainties in the climatic loads and material strength. In 1995, CSA-C22.3 introduced RBD. CSA-C22.3 has retained the deterministic method in its new edition, but recommends the use of RBD for new high voltage or other important lines.

By using the RBD method, it is recognized that absolute reliability cannot be achieved and that there is always a risk that the design loads can be exceeded or that the component strengths will be less than the design loads. Nevertheless, the RBD method is the most appropriate tool to target a level of risk or to implement a cost/risk analysis.

Three reliability levels (I, II, III) are provided in IEC 60826 and CSA–C22.3. These levels correspond to return periods of 50, 150 and 500 years.

- Level I (50-year return period) is considered the minimum for all permanents lines and is called the reference reliability level. It is regarded as providing an acceptable reliability level in respect of continuity of service and safety of the public and is commonly used for medium and high voltage lines.
- Level II (150-year return period) is commonly used for strategic and extra high voltage lines (315 kV and above).

- Level III (500-year return period) is used for very strategic extra high voltage lines that are a unique source of supply.

Other levels may be selected based on local conditions and on an economic optimization between the cost of increased reliability and the present worth of the cost of future failures. Ultimately, the reliability level selection will be an owner decision based on the risk that the utility is willing to take considering such factors as the degree of system redundancy, customer needs and societal expectations.

Where sufficient data exists, the yearly maximum climatic loads such as ice or wind can be fitted to a Gumbel extreme value distribution function which can be used to calculate extreme value loads for selected return periods. A reference value (in this case the 50-year value) may also be extrapolated to other periods by using appropriate factors as shown in Table 5.2.

Table 5.2
Extrapolation Factors for Extreme Climatic Loads (based on a 50-year return period value)

Return Period T (years)	Probability of Occurrence in 50 years	Wind Speed	Ice Variable	
			Ice Thickness	Ice Weight
50	64%	1	1	1
150	28%	1.10	1.15*	1.20
500	10%	1.20	1.30*	1.45

The above values are sufficiently accurate for a coefficient of variation (COV) of up to 0.16 for wind speed, 0.30 for ice thickness and 0.65 for unit ice weight as derived from the Gumbel distribution function.

IEC and CSA standards require that at least 20 years of climatic data and at least five years of ice observation on the transmission line sites be available to use the statistical approach and these adjustment factors. Considering that the climatic data available along the proposed HVdc line does not meet this requirement, the adjustment factors for precipitation icing identified by an asterisk in Table 5.2 were set at 1.20 and 1.40 instead of 1.15 and 1.30 in accordance with Hydro-Québec experience on the north shore of the St-Lawrence River.

CSA C22-3 provides one map (Figure 3) covering Canada and gives the values of the 50-year-return period radial ice thickness of glaze during an ice storm at given points. Since transmission lines cover large areas, those values have to be multiplied by a spatial factor of 1.5, as indicated in CSA-C22.3 Appendix D3.

Another CSA-C22-3 map (Figure 2) provides the values of the 50-year return period hourly wind speed at 10 m above ground for terrain roughness Category B. Terrain Category B is the reference terrain defined as "open country with very few obstacles". No spatial factor for wind was required in the first CSA-C23 editions covering the RBD method, but this is presently under review and future editions will include such a requirement with a value of 1.05 or 1.15. (Jones, 2005) CSA-C22.3 notes that extremes of rime ice greater than values indicated on the ice map can occur on hills, mountain, and ridge tops, especially in coastal areas. In such areas, the standard recommends that local experience and knowledge be used in determining design rime ice thickness.

For Newfoundland and Labrador, the two maps give the following values:

- Ice load: between 20 and 40 mm with a spatial coefficient of 1.5 which leads to between 30 and 60 mm of radial glaze ice.
- Wind load: between 120 and 140 km/h with a spatial coefficient of 1.15 leading to between 140 and 160 km/h.

CSA also notes that other special local conditions could prevail and line designers should investigate those special conditions and design according to those findings recognizing that the CSA requirements represent minimum values. Environment Canada is presently reviewing the Canadian load maps and the methodology which was applied for the previous maps. This work, which is supported by Canadian utilities, will be available in late 2008.

Additional insight into ice loadings at higher elevations may be gained from a review of the practice in Norway where Statnett reports that the guideline for in-cloud icing is between 210 mm and 280 mm radial thickness.

5.3 Application to the Proposed HVdc Line

5.3.1 General

MRI (1975) proposed the RBD approach for the Gull Island to Holyrood HVdc line, which was, at that time, based on meteorological data from only a few weather stations gathered for a period of 9 to 16 years, using measurements made at exposed sites along the proposed route. MRI's analysis had extended this data base to a line route of 1,088 km, with 50-year return period extreme values. Some attention was given to local climatic conditions and topography since the whole line was divided into 11 line sections (Appendix A Table A-1). At that time, the RBD approach was still in development, particularly for lines located in uninhabited and remote areas prone to atmospheric icing. Even today this new approach is not always applied correctly, and it is still common to work only with ice deposits, glaze and rime, and to ignore the underlying atmospheric processes leading to precipitation icing and in-cloud icing.

Precipitation icing requires a statistical treatment different from in-cloud icing because precipitation icing events are usually short in duration and ice is generally shed soon after the ice storm is over. Precipitation icing and in-cloud icing events are usually considered to be independent of each other, but this is not always the case as illustrated at some TTS in the Long Range Mountains.

An ice storm is seldom measured at the location of the maximum intensity within the storm, so local point values are different than regional values. Consequently, lines designed for a given service area may require values of maximum ice thickness to be predicted for the area. The CSA recommends that the point values given in ice load maps be increased by 50%. The value of the spatial factor also accounts for the fact that the 50-year ice thickness may be somewhat higher at the conductor heights of up to 30 m above ground, compared to the values in the ice load maps that were compiled for heights of 10 m above ground. This increment has been chosen from calibration with icing data collected by some utilities.

In-cloud icing events are frequent and last longer than precipitation icing, and low clouds, which are common in maritime northern climates, are not always connected to a major storm. Subsequent events often accumulate and rime ice deposits can be the result of many icing events. Therefore, in-cloud icing events are not always independent and their statistical treatment is difficult without direct measurements. In-cloud icing is generally site specific and extrapolating values from one site to another is not necessarily valid.

Airport wind speed measurements are not always representative of wind along a particular line route, so extrapolation should be made with careful attention to topographic features that could influence local wind speeds. In contrast with atmospheric icing, wind speed is easily measured on site and modeled numerically. Wind speeds are analysed from a statistical standpoint, so values used in ice and wind combinations should be derived from the best available maximum wind speed values.

Wind speed is measured and analysed on a regular basis, not only at airports but at many other climatological stations, but statistics for combined ice and wind are sparse, so it is recommended that a combination be derived from the independent ice and wind speed statistics. A large number of combinations are possible but one or two combinations are sufficient for the design of transmission lines. The IEC or CSA approach recommends a combination of a high probability ice load, such as a 5 or 10-year return period value, with a fraction of the extreme wind speed selected for the design, for example 70% or 75% of a 300 or 500-year return period extreme value.

5.3.2 Combining Statistical and Topographical Data

MRI considered ground elevation in the modelling of precipitation icing and in-cloud icing and in the extrapolation of wind speed from airport monitoring stations to the line route. However, they did not incorporate the effect of topography on atmospheric icing, which is now known to be a major factor (CIGRE 2006). Icing precipitation is affected by topography, and is particularly sensitive to the lifting of moist air which moves faster and cools down, thereby increasing the LWC of the air and droplet size. In-cloud icing is affected in a similar way but to a larger degree by the movement of the air, so wind speed is a governing parameter of in-cloud icing and, in turn, elevation is a key factor in wind speed.

To integrate the influence of topography, Hydro-Québec has developed a simple topographical modelling methodology based on empirical knowledge. The intensity of moist air before its displacement towards high lands is estimated in a valley or a plain from PIM data, which is statistically well defined from 30 years of direct measurements. The critical altitude of the moist air is determined from past ice storms by using, when possible, upper air data from a station such as Sept-Îles or Goose Bay. The moist air is virtually moved inland along natural corridors (such as valleys or connected lakes) as a reversed moist air river. Its altitude is adjusted to the corridor's width, assuming a minimum width of 2 km. When approaching the future line route, about 2 to 5 km from the center line, the change of height between the moist air and the line is calculated directly on the topographical map. The lifting height is noted on the map and it is the basis of the calculated amplification, based on several past cases, (e.g. Mont Bélair near Québec and near Pentecôte on the Québec North Shore). For Newfoundland & Labrador, the height of moist air near the coast is assumed to be 100 m. The empirical amplification formula is the same as that used by Hydro-Québec, except that the moisture or ice load is expressed in linear weight (kg/m) and not in radial thickness (mm). (For a few years Hydro-Québec applied the same linear weight to all conductors and cables).

Since Hydro-Québec has not yet developed topographical modelling for in-cloud icing, a simple approach based on the existing knowledge that has been used in several rime load models, is used here. The critical cloud height is an important parameter since it defines the amount of water (LWC in the cloud) and the droplet size. The structure height is also important since low clouds at ground level have a moisture profile similar to the near ground wind speed profile, which is logarithmic. In the case of in-cloud icing, moist air is moving horizontally, so the air displacement, or rather the wind speed, is a key factor in ice accumulation. If the air is channelled or lifted, the wind speed is amplified as well as the moisture content and the drop sizes. In cloud icing is site specific and a fine terrain analysis is required before final line routing.

5.3.3 Amplification due to Topography

The amplification analysis due to topography has been broken down into line sections between points of inflection (PI) for each climatic region C1 to C6. The results given in Tables D-1 to D-6 in Appendix D have been derived from a methodology based on sources of moist air masses, transport of the moist air through valleys and lifting of moist air when rising toward a future line. This medium scale methodology is good at the stage of line routing, since it incorporates topographically induced icing that must be added to basic values and influence the selection of the line route.

The procedure used for this study is as follows:

1. Examine climatic differences at the geographical scale and use best available data for precipitation icing within each climatic region;
2. Examine potential icing amplification in order to pin point problem areas where future failures are likely to occur based on statistics and topography. The scale of icing amplification areas is several spans;
3. Examine in-cloud icing areas which are basically determined by local elevation and exposure. Areas prone to in-cloud icing could be only a few spans. A fine line routing analysis can often reduce line segments exposed to in-cloud icing. The height of the surrounding terrain is a key factor. Since wind speed is the first key factor in in-cloud icing, local wind speed measurements could help in locating a line. The wind profile near ground is similar to in-cloud icing profiles (moist air profiles). Wind direction is also influenced by local topography.

The amplification used for precipitation (glaze) icing is as follows :

Table 5-3
Amplification for Precipitation (Glaze) Icing

Elevation Rise (m)	50	100	150	200	250	300	350	400	450
% Amplification	10	15	25	50	75	100	125	150	175

The influence of topography is shown in the tables in Appendix D where two adjustments are estimated at the center line of line routes. One takes account of the lifting effect of moist air in the case of icing precipitation and the other estimates the effect of the surrounding ground on low clouds; lifting, filtering and sheltering.

The tables in Appendix D present the results of a detailed analysis for each climatic region between points of inflection (PI to PI) along the full length of the lines. The results illustrate an enormous variability of glaze and rime icing loads from 40 mm of radial ice to more than 450 mm of combined glaze and rime in some sections.

5.4 Study Area Regions

The HVdc line from Gull Island to Soldiers Pond crosses at least four different climate zones with a large variety of geographical features, such as the Labrador plateau, coastal areas on the Atlantic Ocean and the Gulf of St-Lawrence, mountain ranges, etc. Airports generally avoid such condition which means that airport climate is not necessarily appropriate for determining transmission line climatic loads. MRI defined 11 climatic line sections with 6 subdivisions to account for the effects of ground elevation on in-cloud icing and wind speed. The effects of topography on precipitation or in-cloud icing make it difficult to reconcile the types of icing loads, precipitation (glaze), in-cloud (rime), and terrain parameters. Therefore, it is not possible to define precise regional climatic zones for the proposed HVdc line routes from the MRI data and analysis.

Based on broad geographical features, the following six climatic regions are proposed (Figure 5.1):

C1 The Labrador plateau climatic region corresponds to the MRI line segments R1&R2, and the Gull Island to within 50 km of the Strait of Belle Isle. This region is influenced by arctic air masses in winter but may received some tropical air in late fall or early spring. Low clouds are frequent in all seasons, and wind speeds are relatively low.

C2 The Strait of Belle Isle coastal area corresponds with MRI line segments R3&R4. This region connects the Atlantic Ocean with the Gulf of St. Lawrence and acts as a moisture conduit between the two coasts. Heavy icing is possible everywhere, especially on ridges. Wind can be very strong in some areas.

C3 The Long Range Mountains correspond with MRI line segments R5&R6. This region comprises a complex terrain with high elevations and narrow valleys perpendicular to the line route. Atmospheric icing can be amplified from precipitation where moist air is lifted, and from low clouds forced over ridges.

C4 The White Bay to Grand Lake section corresponds to MRI line segment R7. This climatic region is a trough connecting the Atlantic Ocean and the Gulf of St. Lawrence, and is a transition between colder air in the north and moist maritime air in the western portion of the island.

C4A This region is an extension of C4 down to St. Georges Bay. The first portion of Taylors Brook to Cape Ray HVdc line route, P.I. #1 to P.I.#8, is located in climatic region C4, while the rest of the line is located in region C5. The southern portion of the Grand Falls option route is also located in region C4A, while the northern portion is in region C5.

C5 The Atlantic coast corresponds to MRI line segments R8&R9. This coastal area is exposed to high moisture systems from the Gulf of Mexico and strong wind speeds from the open sea.

C6 The Avalon Isthmus and Peninsula correspond to MRI line segments R10&R11. This region is exposed to high moisture and strong wind speeds from all directions.

Climatological data for each of these regions for the duration of the icing season is provided in Appendix C.

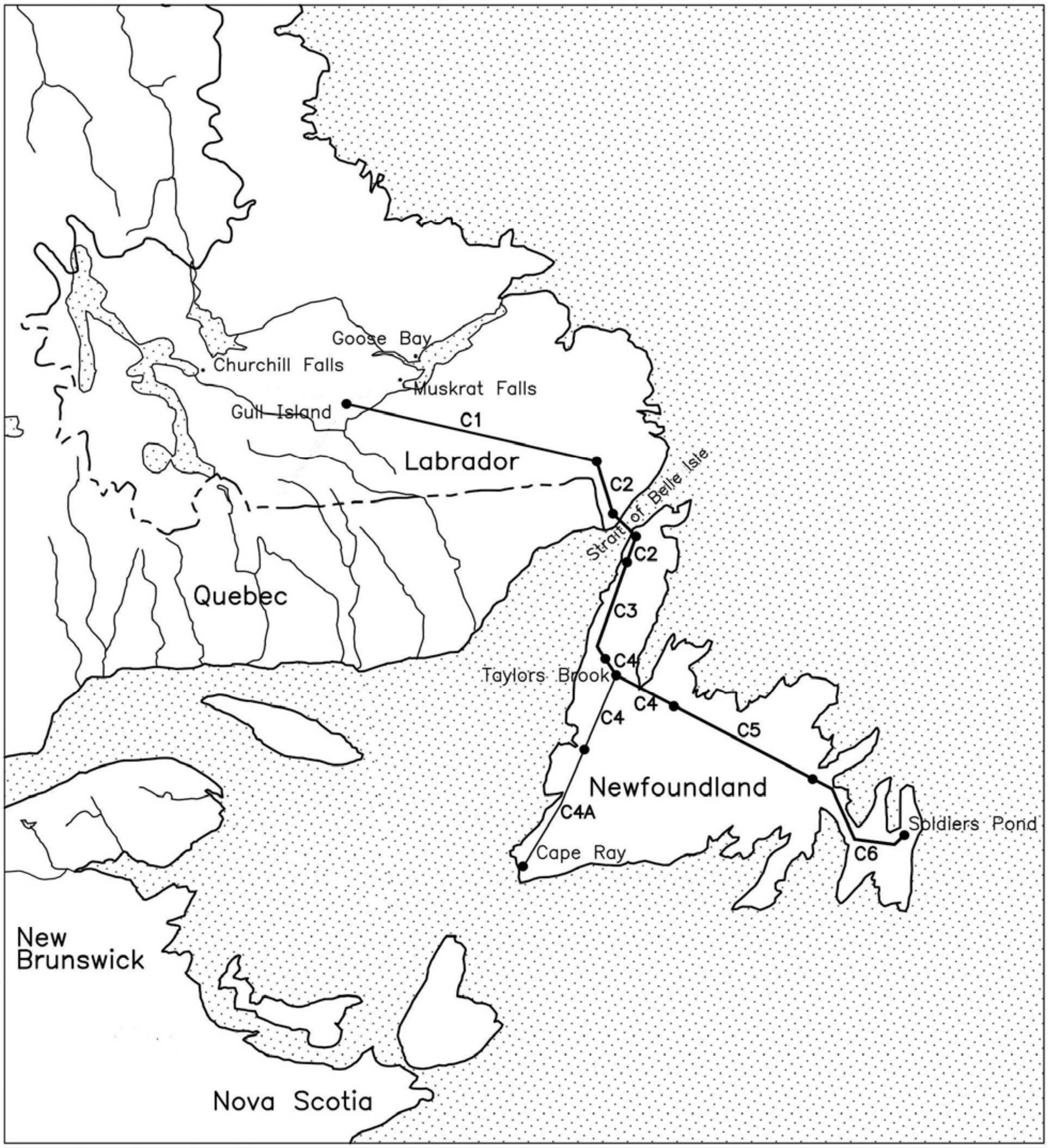

Figure 5.1
Climatic Regions C-1 to C-6

6. Proposed Design Meteorological Loads

The meteorological loads presented in this section consist of glaze, rime, and wind separately as well as glaze and wind combined and rime and wind combined. Extreme ice thickness values are in mm and extreme wind values are in km/h. In the tables shown here, the values are representative of each of the six climatic regions; however, in Appendix D, values are provided for line sections within each region. The amplification values shown in this section are ranges for the entire length of each of the six regions.

6.1 Precipitation Icing Loads

The 50-year return period for PIL is the basic or reference ice load from which other return period loads are derived.

- In region C1, the loads are based on previous studies for the 735 kV transmission lines to Québec and information from Hydro-Québec's PIM 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 Hydro PIM network program and on field observations during the field visit in October 2007.
- In regions C3, C4 and C4A, 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 Hydro design criteria.

The estimates of other return period loads are made according to a general extreme values curve in accordance with Hydro-Québec experience, as follows:

Table 6.1
Factors for Other Return Period Loads

Return Period Years	Factor X Basic PIL
5	0.5
150	1.2
300	1.3
500	1.4

Table 6.2
Precipitation Icing Loads (PIL) in mm radial (Density = 0.9 g/cc)

Climatic Regions							
Return Period (Years)	**C1 (R1/R2)**	**C2 (R3/R4)**	**C3 (R5/R6)**	**C4 (R7)**	**C4A**	**C5 (R8/R9)**	**C6 (R10/R11)**
Geography	Plateau	Coast	Ridges	Coast	Trough	Coast	Coast
MRI 50	35-60	90-100	90-100	80	-	85-90	95-110
CSA 50	30	38	38	38	38	45	60
PIM 50	-	45	21	58	-	-	-
Recommended Base Values without Amplification							
Reference 50	35	75	75	75	60	75	75
5	18	38	38	38	30	38	38
150	42	90	90	90	72	90	90
500	49	105	105	105	84	105	105
Range of Amplification Values due to Topography							
Reference 50	38-70	83-131	83-206	83-131	69-105	83-113	83-94
The 50-year return period icing loads amplified by topography are detailed in Tables D-1 to D-6 in Appendix D.							

6.2 In-cloud Icing Loads

The in-cloud icing loads (ICIL) are derived from MRI values with some reduction for high elevation terrain which is taken into account in the topography analysis as given in tables in Appendix D. Although MRI in-cloud icing values are not statistically valid, they are used here as preliminary estimates. While topography affects precipitation icing over a rather large scale, in-cloud icing is much more site specific, and a detailed analyses is required when working on the refined line routing. MRI studied ground elevation, but did not study many other factors affecting in-cloud icing, typically the slope of the terrain in the trajectory of clouds. Local wind effects were also neglected. Field observations at the TTS sites tend to indicate localised combinations of wind, relief and elevation. In some cases in-cloud icing produces very hard rime that is called in-cloud glaze.

Data gathered at the TTS is indicative of potential in-cloud icing along the Long Range Mountains where as much as 450 mm of radial hard rime has been observed over a rather short period, from 1978 to 1987. The TTS system, operated for 10 years, has shown that in-cloud icing is actually site specific.

In-cloud icing loads proposed by MRI would have to be amplified significantly according to the TTS data. Preliminary analysis of winter clouds in Labrador and in Newfoundland indicates high potential accumulations of in-cloud rime icing in the lower layers of the atmosphere as shown in Table 6.2.

In 1975, the Atmospheric Environment Service of Environment Canada produced an analysis of cloud heights and potential in-cloud icing (Environment Canada, 1975). Data of two upper air stations located in Labrador and Newfoundland (Goose Bay and Stephenville) were analysed (Table C-4). MRI used the same data for rime load modelling.

Table 6.3
Potential In-cloud Icing Accumulations Based on Cloud Height Variations (in mm)

Upper Air Station	**Return Period Years**				
	5	**10**	**50**	**150**	**500**
Goose Bay					
Ground to 550 m (950 mb)	250	300	420	490	575
550 m to 975 m (900 mb)	450	560	820	1000	1150
Stephenville					
Ground to 550 m (950 mb)	190	215	260	300	340
550 m to 975 m (900 mb)	320	370	510	610	700

Upper air stations launch an instrumented radio-balloon twice a day to measure atmospheric temperature, pressure and moisture from ground through the troposphere and above. The two first layers of the atmosphere are analysed in the above mentioned report for cloud intensity and frequency. The first layer is from MSL (Mean sea level) pressure to 950 mb pressure and the second layer is from 950 mb to 900 mb.

Figures produced by MRI have been used as the basis of this evaluation. Table 6.3 gives the basic in-cloud icing loads for each climatic region. Amplified loads due to topography are corrected for the forcing of cloud over a ridge which lifts, funnels and shields the surrounding terrain and are detailed in Tables D-1 to D-6 in Appendix D although the range of amplified loads are given in Table 6.3. Detail corrected values are 25%, 50%, 75%, 100%, 125% for a forcing respectively of 50 m, 100 m, 150 m, 200 m and 250 m. When ground elevations are greater than 100 m above the critical elevation of icing clouds, the total icing load is equal to the sum of both in-cloud icing and precipitation icing (glaze). Further corrections may be required after a refined analysis of the final line route.

The following table illustrates the in-cloud icing levels when at or above the critical cloud elevations. There are many areas where the ground elevation is below this level and no in-cloud icing is present. These sections are detailed in the topographical analysis of line routes in Appendix D.

Table 6.4
In-cloud Icing Loads (ICIL) in mm radial (Density = 0.5 g/cc)

Climatic Regions							
Return Period (Years)	**C1 (R1/R2)**	**C2 (R3/R4)**	**C3 (R5/R6)**	**C4 (R7)**	**C4A**	**C5 (R8/R9)**	**C6 (R10/R11)**
Geography	Plateau	Coast	Ridges	Coast	Trough	Coast	Coast
Critical Cloud Elevation (m)	350	300	350	300	350	250	200
MRI 50	40 - 120	80 - 70	80 - 240	55	-	120 - 130	145 - 160
Recommended Base Values without Amplification							
Reference 50	70	100	100	70	70	100	120
5	39	55	55	39	39	55	66
150	84	120	120	84	84	120	144
500	98	140	140	98	98	140	168
Range of Amplification Values due to Topography							
Reference 50	88 - 123	100 - 175	100 – 200	70 – 123	70 – 123	100 – 125	120 – 150
The detailed in-cloud icing loads including amplification are detailed in Tables D-1 to D-6 for each climatic region C1 to C6.							

6.3 Wind Loads

Wind speed is a basic factor in the design of the HVdc lines since it has an effect on precipitation and in-cloud icing, and all design parameters including vertical loads, transverse loads and longitudinal loads. Wind speed also affects the operational performance of these lines since it induces various types of conductor displacements including oscillation, vibration and galloping.

Maximum hourly wind speeds for this study have been determined from Environment Canada data measured at 20 meteorological stations and from the MRI 1973 study. Environment Canada processed this data using their extreme value analysis program in order to produce 50, 150 and 500-year return period values. Raw data are presented in Table C-2 and extreme values are presented in Table C-3.

Measurements and analyses of wind speed were carried out for the Blanc Sablon area in 1992 and 1993 for a Hydro Québec 69 kV transmission project. The extreme value analysis by Environment Canada leads to figures slightly smaller than those produced by Meteoglobe Canada Inc., who measured winds for Hydro-Québec in this region .

Comparing data gathered at the Blanc Sablon airport with that gathered near the coast, less than 10 km away, shows an 18% difference, confirming that analysis limited to airport data often underestimates local regional values. Therefore, a 15% spatial factor is used to convert a local maximum speed to a regional one (Jones, 2005).

Data gathered at elevation 150 m or higher for the Lake Robertson project have shown wind speeds 10% higher, and maximum hourly wind speeds deduced from continuous measurements of maximum gust speeds are larger than the 2 minute maximum wind speeds by 5% inland and by 8% at the coast. (Maximum hourly wind speeds are measured 2 minutes before each hour. They can also be deduced from maximum gusts with a reduction factor of 1.26.)

The regional maximum hourly wind speed, determined for each climatic region, is as follows.

C1:	Goose Bay Airport	88 km/hr plus a spatial factor of 15%.
C2:	Blanc Sablon	156 km/hr taken from the Lake Roberson project.
C3:	Daniel's Harbour	130 km/hr plus a spatial factor of 15%. Measurements are recommended at critical mountain sites.
C4:	MRI Regional	131 km/h estimated from MRI of 165 km/h gust (165 divided by 1.26).
C4A:	Port-aux-Basques	127 km/hr plus a spatial factor of 15%.
C5:	Gander	112 km/hr plus a spatial factor of 15% and a factor of 10% for sites near the coast. Measurements are recommended at critical coastal sites.
C6:	St. John's Airport	123 km/hr plus a spatial factor of 15% and a correction of 7% for the three outliers (121, 120 and 137) included in the series of annual maximum values, suggesting a different statistical population.

Table 6.5
Regional Maximum Hourly Wind Speeds (MHWS) in km/hr

	Climatic Regions						
Return Period (Years)	**C1 (R1/R2)**	**C2 (R3/R4)**	**C3 (R5/R6)**	**C4 (R7)**	**C4A**	**C5 (R8/R9)**	**C6 (R10/R11)**
Geography	Plateau	Coast	Ridges	Coast	Trough	Coast	Coast
MRI 50	103-123	143-159	143-198	131	-	151-167	159-167
Recommended Values							
Reference 50	100	155	150	130	145	140	150
150	110	171	165	143	160	154	165
500	120	186	180	156	174	168	180

Prior to final engineering, it is recommended that wind speed figures be refined for terrain and topography, using models such as those used to estimate wind for wind generation projects. It is also recommended that wind speeds be measured at critical sites over several months to calibrate values with those of near-by airports. These site measurements are not costly and are thus excellent investments as wind speed can vary significantly from site to site. On the Lake Robertson project, for example, wind speed was measured at seven sites.

6.4 Combined Wind and Icing Loads

6.4.1 Combined Glaze and Wind

Figures given in Table 6.5 are based on one type of combination from two statistical values.

As recommended in the IEC 60826 and CSA 22.3, it is proposed to use the combination of a high probability ice load, such as a 5-year return value, with a percentage of a low probability extreme wind speed, such as 50-year return period, to determine a reference combined load.

The percentage of the extreme wind speed is variable. Inland, it can be as low as 50% while near the coast it can reach 75% as was the case for the Hydro-Québec Lake Robertson transmission line near Blanc Sablon. The fraction used in this study is 70%, but many other combinations are possible, such as a extreme ice with nominal wind, but these do not generally govern the tower design. Since the statistical process requires many icing events, it is not possible to establish wind and ice for this project using statistics. MRI attempted to establish combined loads on a statistical analysis, but without sufficient data, using a combination of ice loads varying from 50% to 75% of the reference ice load with 60% to 68% of maximum wind speed.

Table 6.6
Regional Precipitation Icing (PIL) and Wind Speed Combination

Climatic Regions							
Return Period (Years)	**C1 (R1/R2)**	**C2 (R3/R4)**	**C3 (R5/R6)**	**C4 (R7)**	**C4A**	**C5 (R8/R9)**	**C6 (R10/R11)**
Geography	Plateau	Coast	Ridges	Coast	Trough	Coast	Coast
MRI 50	15/75 25/83	65/91 70/91	65/83 65/95 85/127	50/83	-	60/99 65/99	85/99 70/91
Recommended Base Values without Amplification							
Reference 50	18/70	38/109	38/105	38/91	30/102	38/98	38/105
150	21/77	45/120	45/116	45/100	36/112	45/108	45/116
500	24/84	52/130	52/126	52/109	42/122	52/118	52/126
Range of Amplification Values due to Topography							
Reference 50	19-35 /70	38-65 /109	38-200* /105	38-127* /91	30-53 /102	38-57 /98	38-47 /105
* Areas of combined precipitation and in-cloud icing. These detailed values of amplified precipitation icing (PIL) are given in tables D-1 to D-6 for each climatic region C1 to C6.							

6.4.2 Rime and Wind Speed Combinations

As wind speed is a key parameter in the in-cloud icing process, the task of combining rime and wind speed is complex. It is best established with field investigations made over at least one winter of wind speed measurement at sites known to be prone to in-cloud icing. For mountain summits with smooth sides, in-cloud icing is mainly produced by clouds moving horizontally. But when moist air and clouds mix with precipitation and are forced to move up over a long distance, rime resulting from the in-cloud icing can be very dense similar to glaze. The density of icing accumulations can reach very high values, similar to those estimated for precipitation icing. As a consequence, each site exposed to potentially intense in-cloud icing should be studied individually. The analysis of local topography is more important than statistical analysis in these cases.

Table 6.7
Basic Regional Rime and Wind Speed Combination
(5 year rime loads in mm and 70% of max wind speeds (MWS) in km/h)

Climatic Regions							
Return Period (Years)	**C1 (R1/R2) mm/km/h**	**C2 (R3/R4) mm/km/h**	**C3 (R5/R mm/km/h**	**C4 (R7) mm/km/h**	**C4A mm/km/h**	**C5 (R8/R9) mm/km/h**	**C6 (R10/R11) mm/km/h**
Geography	Plateau	Coast	Ridges	Coast	Trough	Coast	Coast
Recommended Base Values without Amplification							
Reference 50	39/70	55/109	55/105	39/91	39/102	55/98	66/105
150	46/77	66/120	66/116	46/100	46/112	66/108	79/116
500	54/84	77/130	77/126	54/109	54/122	77/118	92/126
Range of Amplification Values due to Topography							
Reference 50	39-68 /70	55-96 /109	38-200* /105	38-127*/91	39-68 /102	55-69 /98	66-83 /105

*Areas of combined precipitation and in-cloud icing.

Detailed topographical amplification in each region must be determined from the amplified values given in tables D-1 to D-6 corresponding to climatic regions C1 to C6. The 50 year in-cloud icing value to be combined with wind is equivalent to 55% of the extreme amplified value shown in tables D-1 to D-6.

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7. Conclusions and Recommendations

7.1 Conclusions

The transmission line route crosses a unique region in North America with many different climatic regions, and the general atmospheric circulation of tropical and arctic air masses converging into this region results in variable and sometimes extreme meteorological conditions. The geography of the region is also unique with a complex coast-line comprising a large number of bays, fiords and peninsulas. Inland mountain ranges add a vertical component to a long and complex coast. All these parameters contribute to making a climatological evaluation of the HVdc line between Gull Island and the Avalon Peninsula a challenge.

Based on broad geographical features, six climatic regions are proposed as shown in Fig. 5-1.

The effects of topography on precipitation or in-cloud icing make it difficult to reconcile the types of icing loads, precipitation (glaze), in-cloud (rime), and terrain parameters. Therefore, it is not possible to define precise regional climatic zones for the proposed HVdc line routes from the available data and analysis. Each region has been studied to determine the influences of geography and topography on wind, glaze and rime.

7.1.1 Glaze

Very little information exists on local precipitation icing (glaze), except on the Avalon Peninsula with 40 years of line operating experience, and in the area of Blanc Sablon, where there are 30 years of passive ice meter data. Inland Labrador is also reasonably understood with experience from the existing Churchill Falls and Hydro-Québec's passive ice meter data from nearby. Elsewhere icing loads have been evaluated from the regional geography, a comparison with MRI values, the TTS and PIM network which operated for 10 years and the extrapolation of this data to the proposed line sections. Due to a lack of statistical data, the meteorological regional loads contain uncertainty.

The recommended 50 year values for precipitation icing (glaze) are very wide ranging with values as low as 40 mm radial ice at Gull Island to combined glaze and rime of more than 400 mm in some sections of the Long Range Mountains. The resulting loading conditions will be very challenging for the design of the transmission through these areas.

Basic values are presented in Table 6.1 while detailed values, including the influences of topographical amplification within each climatic region, are detailed in Table D-1 to D-6 in Appendix D.

7.1.2 In-Cloud Icing

While topography may affect precipitation icing over a rather large scale, in-cloud icing (rime) is site specific. Data gathered at the TTS is indicative of potential in-cloud icing along the Long Range Mountains where as much as 450 mm of radial hard rime has been observed over a rather short period. The TTS sites tend to indicate localized combinations of wind, relief and elevation. In some cases in-cloud icing is producing hard rime similar to glaze. Analysis of winter clouds in Labrador and

Newfoundland indicates high potential accumulations of in-cloud rime icing in the lower layers of the atmosphere.

Basic ICIL have been derived from MRI values. Table 6.2 gives the basic in-cloud icing loads for each climatic region at the critical icing cloud elevation. At greater elevations in-cloud icing is amplified. Below these critical elevations, there is no in-cloud icing. The range of amplified in-cloud icing levels is also provided in Table 6.2 while detailed amplified values through each climatic region are given in Appendix D. Evidence from the test tower sites indicate that when ground elevations are greater than100 m above the critical elevation of icing clouds, the total icing load is equal to the sum of both in-cloud icing and precipitation icing (glaze). In the region of the Long Range Mountains, the critical elevation is above 450 m. In an effort to bring the line below this elevation, more corrections are likely required to refine the final line route.

7.1.3 Wind

Maximum hourly wind speeds for this study have been derived from Environment Canada (EC) data from 20 meteorological stations throughout the regions and from the MRI maximum gust speeds. Environment Canada processed this data with the EC extreme values analysis program in order to produce 50, 150 and 500-year return period values.

Comparing data gathered at airports with that gathered along line routes shows important differences, confirming that analysis limited to airport data often underestimates local regional values. Therefore, a 15% spatial factor is used to convert a local maximum speed to regional ones. The transmission line route over the Long Range Mountains crosses terrain that is not at all representative of conditions gathered at regional airports where the influence of funneling and exposure is not well known. Additional wind measurements in these areas along with those most affected by in-cloud icing would be appropriate.

7.1.4 Combined Wind and Icing

As recommended in the IEC 60826 and CSA 22.3, the combination of a high probability ice load with a low probability extreme wind speed has been used. For the 50 year return period, the 5 year icing event has been combined with 70% of the 50 year extreme wind. These combined values are extrapolated to 150 and 500 year return periods in the same fashion as the separate ice and wind events are.

Tables 6.5 and 6.6 present these values for the 6 climatic regions. Topographic amplification must also be included throughout each region as detailed in Appendix D.

Very close attention must be accorded to combined ice and wind as these loads often control the design of the transmission line structures.

7.2 Recommendations

7.2.1 Reliability

The use of a Reliability Based Design Approach, comprising limit loads, statistical extreme climatological loading values and appropriately chosen reliability levels is recommended and is the basis for the current studies. The proposed meteorological loads are limit loads based on the best information available, including a general knowledge of regional climate, knowledge of icing processes, the operating information of several existing lines, and the analysis of available field observations and measurements.

7.2.2 Risk Assessment

It is recommended that a risk assessment be implemented to define the optimal reliability level.

IEC and CSA Standards provide guidance and minimal requirements for line design, including reliability levels, but the owner must select the optimal reliability of the line and the design climatic loads based on local conditions and on an economical optimization between the cost of increased reliability and the present worth of the consequences of future failures costs. The design load selection must be a management decision based on the risk that the utility is ready to take considering its commitment to customers or agreements with clients.

Also, a fast reconstruction strategy should be put in place and the most exposed sections should be determined and accessibility studied. Mitigation measures to limit line failure consequences should be considered.

7.2.3 Route Selection and Towers Site

As amplification icing and in cloud-icing are a major problem in mountainous regions, the transmission line route should be refined to avoid as much as possible these site specific areas. The most critical areas are found along the Long Range Mountains at elevations greater than 450 m where the combined effects of in-cloud icing and glaze are apparent. Routing the line through the least exposed areas protected from prevailing winds will be essential.

7.2.4 Additional Work

Prior to final engineering, it is recommended that wind speed figures for terrain and topography be refined. This can be done with models such as those used to estimate wind for wind generation projects. It is also recommended that wind speed be measured at the above mentioned critical sites over several months to calibrate values with those of nearby airports. These site measurements are not costly and are an excellent investment as wind speed varies significantly from site to site. In addition to improving local estimates on extreme wind values, these measurements would improve in-cloud icing estimates at particular sites and would validate ice and wind combinations. An estimate for wind measurement towers is included in Appendix I.

References

1. Bell, N., Hydro-Québec: Increasing the reliability of transmission lines rebuilt after the January 1998 ice storm, CIGRE 2000, paper 22-106.
2. Binette, L., CIGRE 2004, paper B2-309.
3. CIGRE Technical Brochure 291: Guidelines for meteorological icing models, statistical methods and topographical effects, April 2006.
4. CIGRE Draft Technical Brochure : Guidelines for evaluating special topographical effects in determining wind speed for design of overhead lines in local terrain.
5. Chaîné, P.M. and Skeates, P. Ice Accretion Handbook, Environment Canada, 1974, cited in Haldar, 1996.
6. Chaîné, P.M., Wayman, A.R., and Bondy, D.A. In-Cloud Icing, James Bay and Churchill Falls Power projects, Atmospheric Environment Service, Environment Canada, Toronto 1975.
7. Butt Desmond, Hydro, IWAIS 86 Vancouver, Canada.
8. Ghannoum, E., Hydro-Québec: Use of reliability techniques in the design of Hydro-Québec's 1100 km Radisson-Nicolet-Des Cantons $\pm$ 450 kV HVDC line, CIGRE 1988.
9. Haldar, A., Pon, C., McComber, P., Marshall, M.A., Ishac, M., Goel, A., Kastelein, M. Validation of Ice Accretion Models for Freezing Precipitation Using Field Data, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec a Chicoutimi, June, 1996.
10. Haldar, A., Twenty Years of Ice Monitoring Experience on Overhead Lines In Newfoundland And Labrador, Asim Haldar, 2007.
11. Haldar, A., Upgrading of a 230kV Steel Transmission Line System using Probabilistic Approach, Asim Haldar, June 2006.
12. Haldar, A., Validation of Ice Accretion Models for Freezing Precipitation Using Field Data. CEA 331-T-993, Montreal. Asim Haldar, 1998.
13. Haldar, A., Reliability Study of Transmission Lines System on the Avalon and Connaigre Peninsulas, Asim Haldar, April 1996.
14. Haldar, A., Validation of Ice Accretion Models Due to Freezing Precipitation, IWAIS 7th Chicoutimi. Asim Haldar, 1996.
15. Haldar, A., Wind and Ice Load Monitoring on a Test Line, IWAIS 6th Budapest. Asim Haldar, 1993.
16. Haldar, A., Failure of a Transmission Line Due to Ice in Newfoundland, IWAIS 5th Tokyo. Asim Haldar, 1990.
17. Haldar, A., Assessment of Probabilistic Climatic Loadings on Existing 230 kV Steel Transmission Lines, IWAIS 4th Paris. Asim Haldar, 1988.
18. Henry, K., Atmospheric Icing of Transmission Lines, Cold Regions Technical Digest No. 87-2, Cold Regions Research and Engineering Laboratory, Hanover, NH, 1987, cited in Schaub, W., Jr.,

Methods to Estimate Ice Accumulations on Surface Structures, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec at Chicoutimi, June, 1996.

19. Jones K., Spatial Factors for Extreme Ice and Extreme Wind : Task 2 – Calculation of spatial factors from ice and wind data CEATI report T033700-3316B-2 January 2005.

20. Jones, K.F., A Simple Model for Freezing Rain Ice Loads, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec at Chicoutimi, June, 1996.

21. Makkonen, L and al, . Fifty Years of Progress in Modeling the Accumulation of Atmospheric Ice on Power Network Equipment. International Workshop on Atmospheric Icing of Structures held in Montreal 2005.

22. Makkonen, L., Modeling Ice Accretion on Wires, J. of Glaciology,34, no.116 cited in Jones, K. F., A Simple Model for Freezing Rain Ice Loads, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec at Chicoutimi, June, 1996.

23. Makkonen, L., Modeling Power Line Icing in Freezing Precipitation, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec at Chicoutimi, June, 1996.

24. Richmond, M.C., Icing and Combined Wind and Ice Design Loadings for Transmission Lines in Remote Areas. Meteorology Research Inc, Proceedings of First International Workshop on Atmospheric Icing of Structures, Hanover, USA, 1982. CRREL Special Report 83-17.

25. Meteorology Research, Inc. (MRI), Meteorological Study of the Gull Island-Stephenville-Holyrood Transmission Line Routes, Report for Teshmont Consultants Ltd., November,1973.

26. MRI, A meteorological evaluation of the combined wind and ice loadings for a portion of the Gull Island Transmission Line. MRI 74R – 1255, September 20, 1974.

27. MRI, The follow on meteorological evaluation of the proposed Gull Island Transmission Line network. MRI 75 FR-1378, October 31, 1975.

28. MRI, Ontario Hydro Wind and Ice Loading Model, MRI 77 FR-1496, cited in Jones, K. F., A Simple Model for Freezing Rain Ice Loads, 7th International Workshop on Atmospheric Icing of Structures, Universite du Québec at Chicoutimi, June, 1996.

29. Newfoundland & Labrador Hydro, Report on design parameters for HVdc Transmission Lines and Stations Engineering Review Board. July 30, 1976.

30. Newfoundland & Labrador Hydro, Revised wind and ice loadings for a portion of the Gull Island Transmission line. January 30, 1975.

31. RSW-EDM, Feasibility Study on the Development of EHV Transmission Lines in Labrador, Report for Newfoundland and Labrador Hydro, February, 1999.

32. RSW, Upgrading of 735 kV Structures for OHGW Icing, Report for Churchill Falls (Labrador) Corporation Ltd., December, 1999.

33. RSW, Study to Establish a Maximum Foreseeable Loss for the CF(L)Co. 735 kV Transmission Lines in Labrador, Report to CF(L)Co., April, 1995

34. Yip, T.C. and Mitten, P., Comparisons between Different Ice Accretion Models, Canadian Electrical Association, 1991 cited in Jones, K. F., A Simple Model for Freezing Rain Ice Loads, 7th International Workshop on Atmospheric Icing of Structures, Université du Québec at Chicoutimi, June, 1996.
35. Hydro-Québec: Using Steam to De-Ice Energized Substation Disconnect Switch, R. Lanoie, IWAIS 2005.
36. Hydro-Québec: Thermal de-icing of HV conductors by using an external dc source by Breault S., CIGRE 2006.

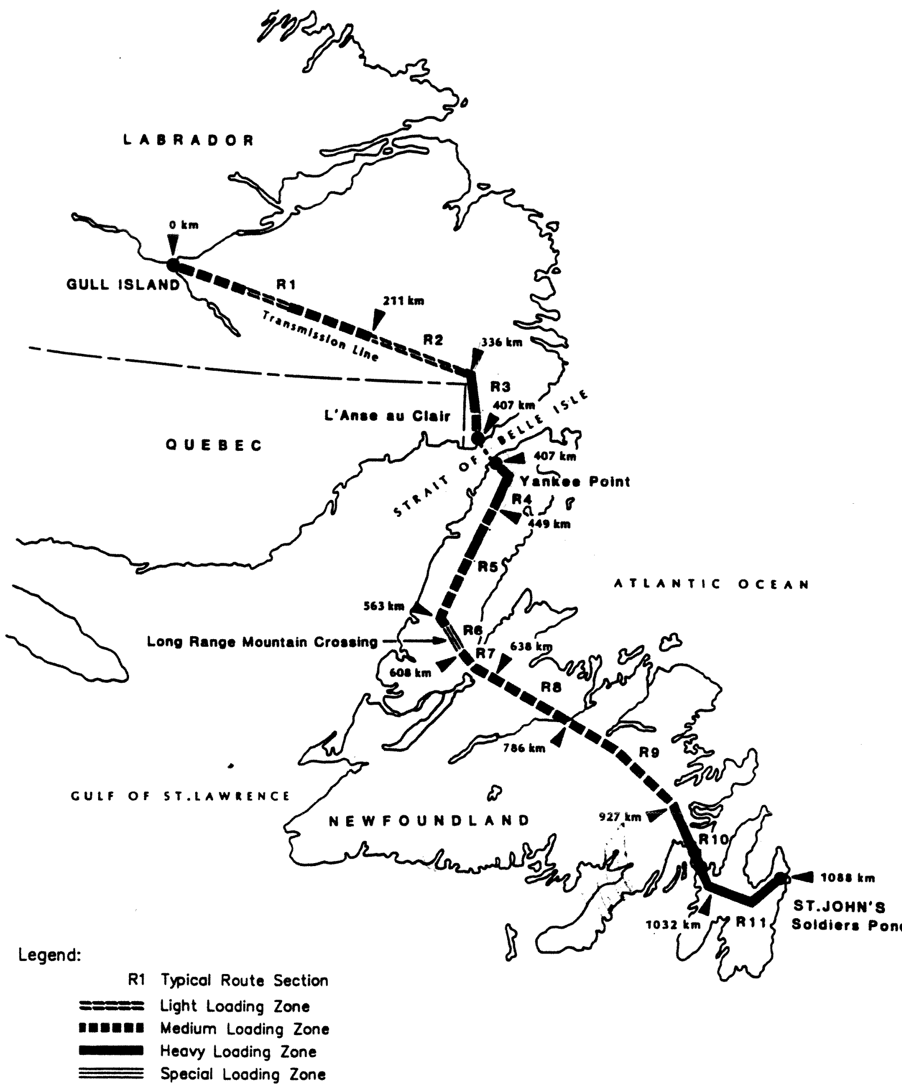
Appendix A

MRI Loadings

Table A-1
Summary of MRI's Extreme Values Produced in 1975

Climate		Line length km		Glaze mm	Rime mm	Wind[1] km/h	Topography
RSW	**MRI**	**Segment**	**Sum**				
C1	**R1a**	68	68	55	120	155 (123)	Plateau
	R1b	38	106	35	40	130 (103)	Valley
	R1c	105	211	60	110	150 (120)	Plateau
	R2	125	336	55	55	150 (120)	Plateau
C2	**R3a**	44	380	100	170	200 (159)	Coast
	R3b	12	392	100	170	200 (159)	Coast
	R3c	15	407	90	80	180 (144)	Coast
	R4	42	449	100	145	180 (144)	Coast
C3	**R5a**	19	468	90	80	180 (144)	Plateau
	R5b	28	496	90	155	190 (151)	Ridges
	R5c	67	563	90	80	180 (144)	Plateau
	R6	45	608	110	240	250 (198)	Ridges
C4	**R7**	30	638	80	55	165 (124)	Valley
C5	**R8**	148	786	90	130	210 (168)	Coast
	R9	141	927	85	120	190 (151)	Coast
C6	**R10**	105	1032	110	160	210 (168)	Coast
	R11	56	1088	95	145	200 (159)	Coast

[1] *The first figure is a gust speed and the figure in bracket is a calculated hourly wind speed.*



Transmission Line Distances and Weather Sections
Figure 4.2-1

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Appendix B

Passive Icing Meter Tables

Table B-1
Maximum Glaze in mm for Each Season
(Raw Data from NLH PIM Program)

Station Name	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87
Wabush	**T**	2	1	trace	3	trace	4	nm	nm	nm
Churchill Falls	**h**	10	10	0	trace	0	2	nm	nm	nm
Goose Bay	**i**	5	5	20	20 to 50	10	2	4	3	trace
Point Amour	**s**	13	13	15	19	64	20	nm	nm	nm
St. Anthony		10	trace	closed	closed	closed	closed	closed	closed	closed
Yankee Point	**r**	13	0	nm	6	50 / 64	trace	13 to 20	25	13
Plum Point	**e**	0	2	2	1	25 ici	trace	trace	trace	3
Hawkes Bay	**p**	13	16	0	16	6	6	0	3	6
Daniels Hr.	**o**	10	trace	trace	trace	trace	12 ici	0	trace	0
Gros Morne	**r**	0	10	9	0	4	30	5 ici	2	2
Stephenville	**t**	nm	trace	closed	closed	closed	closed	closed	closed	closed
Port aux Basques		13	trace	5	20 to 30	0	13	6	10	10
Burnt Pond	**i**	13	4	6	trace	21	3	0	trace	5
Buchans	**s**	6	10	5	45	8	18	13	nm	nm
Deer Lake		trace	nm	trace	4	5	nm	nm	closed	closed
Hampden	**m**	76 to 83	9	0	closed	closed	closed	closed	closed	closed
Springdale	**i**	32	trace	25	trace	trace	6 to 32 ici	13	8 to 26	18
Stony Brook	**s**	5	5	0	4	0	6	trace	nm	nm
Gander	**s**	5	5	9	40	8 ici	12 to 17	7	2 to 9	17
Bay d'Espoir	**i**	5	0	trace	0	0	2	0	0	0
Sunnyside	**n**	0	trace	0	trace	0	1	0	nm	trace
St. Lawrence	**g**	2	20	closed	closed	closed	closed	closed	closed	closed
S Turn		0	0	closed	closed	closed	closed	closed	closed	closed
Long Harbour		nm	0	nm	0	closed	closed	closed	closed	closed
Western Avalon		0	17	20	4	8	10	0	nm	closed
Holyrood		0	trace	trace	0	3	trace	0	3	2
St. John's		25	13	nm	nm	nm	nm	nm	4 to 9	nm
Harbour Deep		13	0	0	0	25	5	8	38	trace
Port Blandford		2	2	0	trace	0	0	0	2	nm

Note: "nm" indicates "not monitored"
"Trace" indicates less than 1 mm
"ici" indicates "icicles"

Table B-2
Maximum Radial Ice in mm for Each Season NLH PIM Program

Station Name	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87
Wabush	T	1	1	trace	2	trace	3	nm	nm	nm
Churchill Falls	h	7	7	0	trace	0	1	nm	nm	nm
Goose Bay	i	4	4	14	14 to 35	7	1	3	2	trace
Point Amour	s	9	9	11	13	45	14	nm	nm	nm
St. Anthony		7	trace	closed	closed	closed	closed	closed	closed	closed
Yankee Point	r	9	0	nm	4	35 / 45	trace	9 to 14	18	9
Plum Point	e	0	1	1	1	28	trace	trace	trace	2
Hawkes Bay	p	9	11	0	11	4	4	0	2	4
Daniel's Harbour	o	7	trace	trace	trace	trace	13	0	trace	0
Gros Morne	r	0	7	6	0	3	21	6	1	1
Stephenville	t	nm	trace	closed	closed	closed	closed	closed	closed	closed
Port aux Basques		9	trace	4	14 to 21	0	9	4	7	7
Burnt Pond	i	9	3	4	trace	15	2	0	trace	3
Buchans	s	4	7	4	**32**	6	13	9	nm	nm
Deer Lake		trace	nm	trace	3	4	nm	nm	closed	closed
Hampden	m	53 to 58	6	0	closed	closed	closed	closed	closed	closed
Springdale	i	22	trace	18	trace	trace	7 to 35	9	6 to 18	12
Stony Brook	s	4	4	0	3	0	4	trace	nm	nm
Gander	s	4	4	6	28	9	8 to 12	5	1 to 6	12
Bay d'Espoir	i	4	0	trace	0	0	1	0	0	0
Sunnyside	n	0	trace	0	trace	0	1	0	nm	trace
St. Lawrence	g	1	14	closed	closed	closed	closed	closed	closed	closed
S Turn		0	0	closed	closed	closed	closed	closed	closed	closed
Long Harbour		nm	0	nm	0	closed	closed	closed	closed	closed
Western Avalon		0	12	14	3	6	7	0	nm	closed
Holyrood		0	trace	trace	0	2	trace	0	2	1
St. John's		18	9	nm	nm	nm	nm	nm	3 to 6	nm
Harbour Deep		9	0	0	0	18	4	6	27	trace
Port Blandford		1	1	0	trace	0	0	0	1	nm

Table B-3
Maximum Ice Accumulation in mm from the Rosemont Ice Detector Sites

Site	1978 /1979	1979 / 1980	1980 / 1981	1981 / 1982
Yankee Point	6 (03/01/1979)	15 (01/24/1980)	closed	closed
Sunnyside	6 (02/27/1979)	3 (01/20/1980)	18 (11/19/1980)	closed
4 Mile Pond	56 (02/03/1979)	72 (02/27/1980)	282 (01/24/1981)	70 (12/30/1982)
	during 21 hours	during 20 hours	during 15 hours	during 3 hours
		they had problem with	229 (01/22/1981)	
		the recorder during	during 8 hours	
		this season		

Table B-4
Maximum Glaze and Rime in Inches for Some Test Tower Sites

Station Name	An	Ms	Jr	Description
1978/1979				
1- Sheffield lake	1979	2	16	2 to 2.5'' ice on tower legs 5' and top tower 6 to 8'' of ice.
2- Portland Creek	1978	12	14	12'' to 14'' of hard rime on guys covered by soft rime.
2a- Portland Creek	1979	2	21	Glaze 2.5'' thick and 2.5'' wide formed on NE tower face.
2b- Portland Creek	1978	12	14	Tower completely encased in 10'' of rime.
3- Hills of St. John	1979	2	12	Massive accumulation of glaze 7'' thick at 5' on tower leg.
4- L'Anse au Loup	1978	12	12	2'' to 2.5'' of glaze at tower top.
	1979	2	14	8'' to 10'' of hard rime on rods.
4a- L'Anse au Loup	1979	2	14	Glaze on tower leg measuring 2'' to 2.5''.
6- East Blue Mountain	1979	2	12	10 to 12'' of glaze on tower. 9'' of glaze on guy.
9- 28 Mile Section	1979	2	16	3'' of glaze at 5' on tower leg. 2.5'' of glaze on guys.
1979/1980				
2- Portland Creek	1979	12	20	6 to 8'' of hard rime on tower.
2b- Portland creek	1980	1	16	5'' to 6'' of hard rime on bottom tower and 10'' at top.
	1980	3	29	Large deposit of rime ice 10'' to 12'' at top tower.
4- L'Anse au Loup	1980	2	12	Huge glaze covered by soft rime on guy 7'' to 8''.
4a- L'Anse au Loup	1980	2	12	Tower covered by 2.5'' of glaze and soft rime.
6- East Blue Mountain	1980	1	10	7'' of hard rime on tower leg.
7- Torrent R Hawkes B	1980	3	27	3'' of glaze on tower leg.
1980/1981				
2- Portland Creek	1981	1	10	6 to 8'' of hard rime at top tower.
2b-Portland Creek	1981	2	18	Hard rime 9'' at 5' level of leg and 12'' to 14'' at tower top.
2d- Portland Creek	1981	3	16	3'' to 7'' of glaze on the ground.
3- Hills of St. John's	1981	4	13	2'' to 4'' of glaze on the ground.
4- L'Anse au Loup	1981	1	10	4'' hard rime over 2'' glaze on tower. 12'' hard rime on rods.
1981/1982				
2- Portland Creek	1982	2	6	Tower filled with 36'' of hard rime at 5' level.
2b- Portland Creek	1982	2	18	Tower filled with 28'' of hard rime at 5' level of leg.

Table B-4
Maximum Glaze and Rime in Inches for Some Test Tower Sites

Station Name	An	Ms	Jr	Description
1982/1983				
2a- Portland Creek	1983	4	5	7'' of hard rime.
2b- Portland Creek	1983	4	5	6'' of hard rime.
2d- Portland Creek	1983	4	5	8'' of hard rime.
4- L'Anse au Loup	1983	3	2	8'' of glaze on tower leg guys base.
1983/1984				
2b- Portland Creek	1984	3	8	12'' of rime.
4- L'Anse au Loup	1984	3	8	18'' of rime underlain by 2'' of glaze.
1984/1985				
2- Portland Creek	1984	12	14	18'' of pendant Glaze.
2b- Portland Creek	1985	2	13	30'' of rime on tower.
2d- Portland Creek	1985	2	13	10'' of rime on tower and 6 inches of rime on guys.
1985/1986				
2b- Portland Creek	1985	12	12	6'' of pendant Glaze.
1986/1987				
2- Portland Creek	1987	3	12	20'' of rime on tower.
2b- Portland Creek	1986	12	12	18'' of rime on tower.

Table 4a
Extreme Values Analysis of Amplified In-cloud Icing on Test Towers*

TT	Site	Seasons n	Altitude m	50 year mm	Dominant icing Type	Direction
# 1	Shiffield Lake	1	450	200	glaze	E
# 2	Portland Creek	9	610	800	Hard rime	SW
# 2a	Portland Creek	6	550	240	Hard rime	Variable
# 2b	Portland Creek	9	630	700	Hard rime	SW
# 2c	Portland Creek	6	530	70	Hard rime	SSW
# 2d	Portland Creek	4	610	320	Hard rime	SSW
# 2e	Portland Creek	1	230	80	Rime	?
# 3	Hills of St-John	5	460	160	Hard rime	E
# 4	L'Anse au Loup	6	530	400	Hard rime	NE
# 4a	L'Anse au Loup	6	460	100	Glaze	E
# 6	East Blue Mountain	2	460	300	Glaze	SW
# 7	Torrent River Hawkes Bay	3	400	170	Hard rime	W
# 9	28 mile Section	7	500	275	Glaze	E
#13	Parsons pond	2	400	100	Glaze	?
#14	Parsons pond	8	600	600	Hard rime	W

** This analysis is not statistically valid but is presented as an indicator for future studies.*

Table B-5
In-cloud icing potential accumulations based on cloud height variations1
(in mm radial)

Upper air station[2]	Return period years				
	5	10	50	150	500
Goose Bay					
Ground to 550 m (950 mb)	250	300	420	490	575
550 m to 975 m (900 mb)	450	560	820	1000	1150
Stephenville					
Ground to 550 m (950 mb)	190	215	260	300	340
550 m to 975 m (900 mb)	320	370	510	610	700

[1] *These accumulations are based on a study produced in 1975 by the Service of Atmospheric Environment in Toronto: 'In-Cloud Icing, James Bay and Churchill Fall power Projects'. The duration of icing conditions within two atmospheric layers (surface to 950 mb and 950 mb and 990 mb) for a ten year period (1961-1970) were analysed and potential icing was computed. In 1973, MRI had made a similar analysis for Labrador and Newfoundland. Test Tower sites installed at elevation around 600 m and operated from 1983 to 1986 have demonstrated that in-cloud icing is a major challenge in Newfoundland and Labrador, see Table B4.*

[2] *Upper air stations are launching an instrumented radio-balloon twice a day to measure atmospheric temperature, pressure and moisture from ground through the troposphere and above. The two first layers of the atmosphere are analysed in the above mentioned report for cloud intensity and frequency. The first layer is from MSL (Mean sea level) pressure to 950mb pressure and the second layer is from 950 mb to 900 mb.*

Figure B-1
Gumbel Distribution

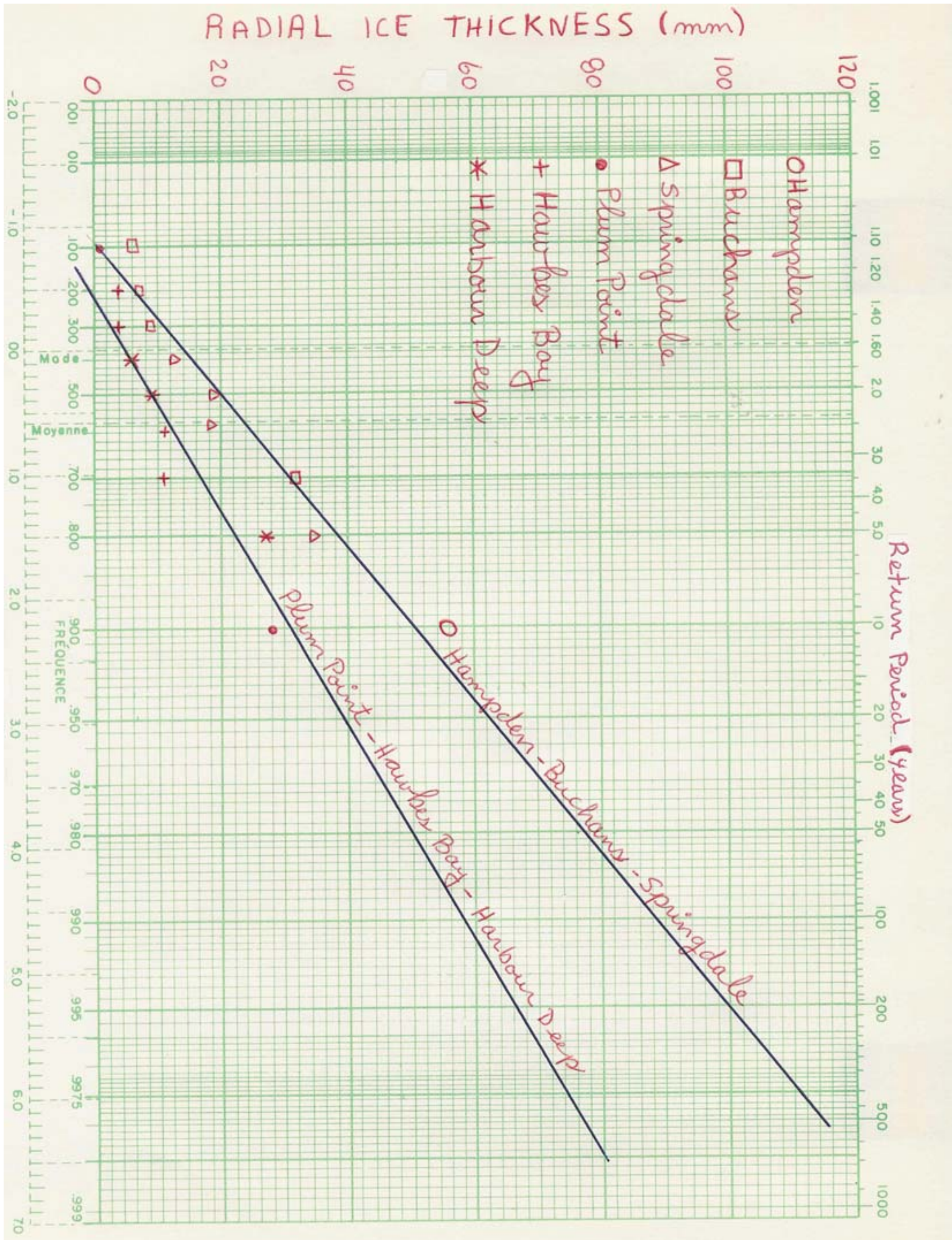


Figure B-2
Location of TTS and PIM Sites

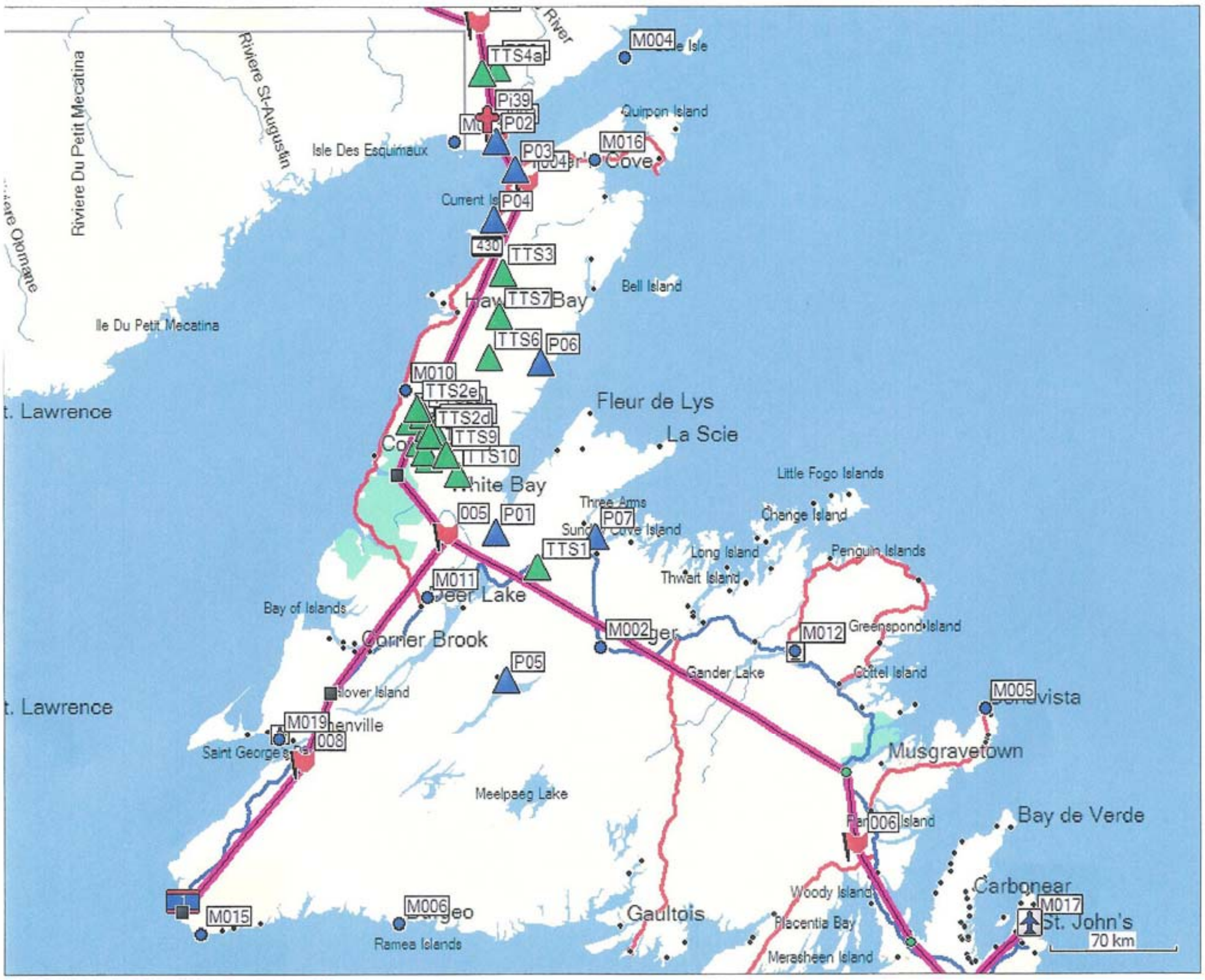
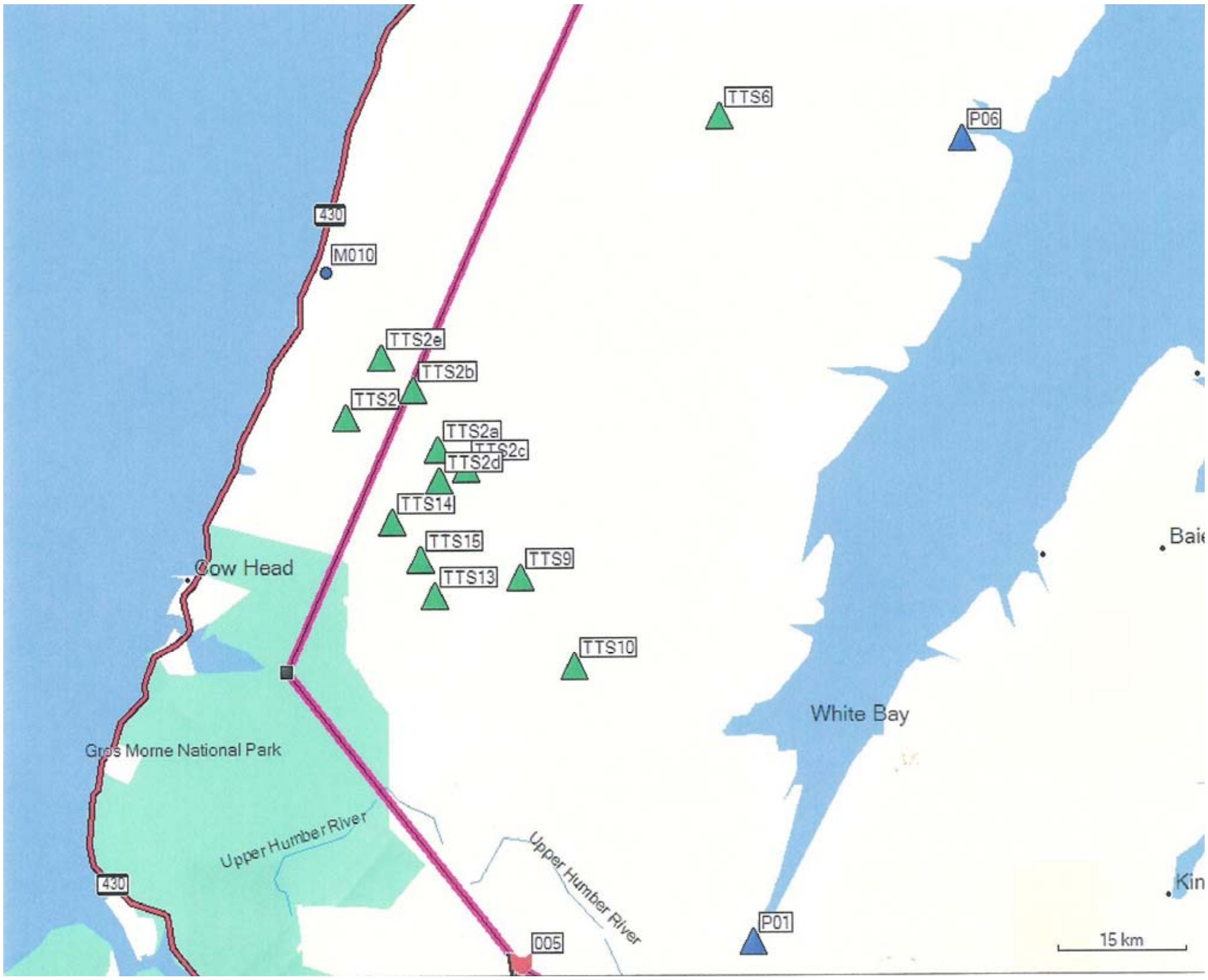


Figure B-3
Location of TTS and PIM Sites Long Range Mountains



Appendix C

Environment Canada Wind Data

Table C-1
Mean Temperature, Rainfall, Days with Rain and Freezing Rain
Canadian Climate Normals 1971 - 2000

Station	Climatological Parameters	NOV	DEC	JAN	FEB	MAR	APR
Wabush Lake A	Mean temperature °C	-8,6	-18,6	-22,7	-20,7	-13,5	-4,6
C1	Rainfall (mm)	7	3	1	2	3	12
	Days with rain	3	1	1	1	2	4
	Days with freezing rain*	1	1	2	1	3	2
Churchill Falls A	Mean temperature °C	-8,6	-19,2	-22,3	-20,6	-13,6	-5,0
C1	Rainfall (mm)	8	3	1	1	4	10
	Days with rain	3	1	1	1	1	4
	Days with freezing rain*	1	1	2	1	3	2
Goose A	Mean temperature °C	-4,5	-13,9	-18,1	-16,3	-9,6	-1,7
C1	Rainfall (mm)	20	6	2	3	5	19
	Days with rain	5	2	1	1	3	5
	Days with freezing rain*	3	3	2	2	2	1
Cartwright	Mean temperature °C	-2,4	-9,9	-14,8	-14,1	-9,0	-2,3
C2	Rainfall (mm)	36	15	4	4	10	23
	Days with rain	7	4	2	2	4	6
	Days with freezing rain*	2	3	2	2	3	3
Blanc-Sablon A	Mean temperature °C	-2,0	-8,7	-13,3	-12,8	-7,6	-1,1
C2	Rainfall (mm)	38	21	10	7	13	20
	Days with rain	9	4	3	2	5	7
	Days with freezing rain*	na	na	na	na	na	na
St. Anthony	Mean temperature °C	-1,7	-7,6	-11,6	-11,7	-7,1	-1,9
C3	Rainfall (mm)	68	29	11	6	17	37
	Days with rain	9	5	3	2	5	7
	Days with freezing rain*	na	na	na	na	na	na
Daniel's Harbour	Mean temperature °C	0,9	-4,7	-8,4	-9,6	-5,4	0,6
C4	Rainfall (mm)	80	28	21	13	27	35
	Days with rain	12	6	4	2	5	8
	Days with freezing rain*	1	2	2	2	2	1
Deer Lake A	Mean temperature °C	0,5	-5,4	-8,9	-9,8	-5,0	1,4
C4	Rainfall (mm)	61	29	21	12	27	42
	Days with rain	11	6	4	3	7	9
	Days with freezing rain*	1	3	3	2	2	2

Table C-1
Mean Temperature, Rainfall, Days with Rain and Freezing Rain
Canadian Climate Normals 1971 - 2000

Station	Climatological Parameters	NOV	DEC	JAN	FEB	MAR	APR
Grand Falls	Mean temperature °C	1,5	-4,3	-7,7	-8,2	-3,7	2,3
C4	Rainfall (mm)	71	40	33	26	38	50
	Days with rain	11	6	5	3	6	9
	Days with freezing rain*	na	na	na	na	na	na
Gander A	Mean temperature °C	1,0	-4,3	-7,4	-7,9	-4,0	1,3
C5	Rainfall (mm)	68	36	30	24	35	47
	Days with rain	13	9	7	6	10	12
	Days with freezing rain*	3	6	6	6	7	6
Bonavista	Mean temperature °C	2,7	-2,0	-5,0	-6,0	-3,0	1,1
C5	Rainfall (mm)	81	53	37	34	49	53
	Days with rain	14	10	7	6	10	11
	Days with freezing rain*	1	3	4	5	6	5
Stephenville A	Mean temperature °C	2,3	-3,0	-6,2	-7,5	-3,6	2,3
C4	Rainfall (mm)	90	47	35	29	38	55
	Days with rain	13	7	6	5	7	10
	Days with freezing rain*	1	2	2	2	2	1
Port aux Basques	Mean temperature °C	2,6	-2,2	-5,2	-6,4	-3,5	1,0
C4	Rainfall (mm)	126	97	53	39	61	102
	Days with rain	14	9	6	5	8	12
	Days with freezing rain*	1	1	3	3	4	2
Burgeo	Mean temperature °C	3	-3	-6	-7	-3	1
C5	Rainfall (mm)	146	108	84	61	82	112
	Days with rain	13	9	7	5	8	11
	Days with freezing rain*	1	1	2	2	3	1
St. Lawrence	Mean temperature °C	3,1	-1,5	-4,3	-5,0	-2,4	1,6
C6	Rainfall (mm)	135	92	75	58	82	106
	Days with rain	14	11	8	7	9	11
	Days with freezing rain*	na	na	na	na	na	na
St. John's A	Mean temperature °C	2,6	-2,2	-4,8	-5,4	-2,5	1,6
C6	Rainfall (mm)	116	88	74	61	77	94
	Days with rain	16	12	10	8	12	13
	Days with freezing rain*	1	4	7	7	9	8

Table C-2
Mean Wind Speeds and Most Frequent Direction
Canadian Climate Normals 1971 – 2000

Station	Climatological Parameters	NOV	DEC	JAN	FEB	MAR	APR
Wabush Lake A	Mean speed all directions (km/h)	15,1	13,3	14,0	14,5	15,7	15,0
	Most frequent direction	W	W	W	W	W	N
Churchill Falls A	Mean speed all directions (km/h)	14,6	14,0	14,2	15,1	16,7	16,4
	Most frequent direction	W	W	W	W	NW	NW
Goose A	Mean speed all directions (km/h)	16,6	17,0	16,9	15,9	16,3	15,3
	Most frequent direction	W	SW	SW	W	W	NE
Cartwright	Mean speed all directions (km/h)	24,1	24,8	22,3	22,0	22,5	20,6
	Most frequent direction	S	S	S	S	S	S
Blanc-Sablon A	Mean speed all directions (km/h)	22,7	24,8	22,7	22,3	23,1	21,2
	Most frequent direction	W	W	W	W	SW	NE
Daniel's Harbour	Mean speed all directions (km/h)	24,8	25,8	26,2	22,6	22,1	20,1
	Most frequent direction	SW	W	W	SW	SW	SW
Stephenville	Mean speed all directions (km/h)	21,2	23,5	24,9	22,0	20,9	19,6
	Most frequent direction	W	W	W	W	NE	NE
Port aux Basques	Mean speed all directions (km/h)	27,4	31,5	32,3	29,6	26,7	24,5
	Most frequent direction	W	W	W	W	E	E
Burgeo	Mean speed all directions (km/h)	26,1	28,0	28,6	27,1	26,6	24,0
	Most frequent direction	W	W	W	W	W	E
St. Lawrence	Mean speed all directions (km/h)	28,0	31,0	32,0	32,0	30,0	27,0
	Most frequent direction	W	W	W	W	W	W
St. John's A	Mean speed all directions (km/h)	24,5	26,6	27,6	26,5	26,1	22,5
	Most frequent direction	W	W	W	W	SW	SW
Bonavista	Mean speed all directions (km/h)	36,2	39,1	38,9	35,7	33,9	29,3
	Most frequent direction	SW	W	W	W	SW	SW
Gander A	Mean speed all directions (km/h)	21,9	23,4	24,2	23,0	23,1	20,6
	Most frequent direction	W	W	W	W	W	SW
Deer Lake A	Mean speed all directions (km/h)	15,0	15,4	16,0	15,8	16,6	16,0
	Most frequent direction	SW	SW	SW	SW	SW	NE

Table C-3
Maximum Hourly Wind Speed (km/h)
and 50, 150 and 500 Years Return Period

Station	Climatological Parameters	NOV	DEC	JAN	FEB	MAR	APR
Wabush Lake A	Maximum hourly speed (km/h)	80	65	72	65	59	60
(1961 - 2006)	50 years return period	65	65	72	64	63	58
46 years	150 years return period	73	72	80	71	70	64
	500 years return period	81	80	89	78	76	70
Churchill Falls A	Maximum hourly speed (km/h)	74	72	67	65	63	65
(1969 - 2006)	50 years return period	67	71	74	64	66	70
38 years	150 years return period	74	78	82	70	73	77
	500 years return period	82	86	90	76	80	86
Goose A	Maximum hourly speed (km/h)	81	81	84	77	77	65
(1953 - 2006)	50 years return period	80	81	83	77	73	69
53 years	150 years return period	89	90	92	85	80	76
	500 years return period	98	99	101	94	88	83
Cartwright	Maximum hourly speed (km/h)	97	103	117	103	105	100
(1953 - 2006)	50 years return period	106	103	110	101	111	98
53 years	150 years return period	118	113	122	111	124	108
	500 years return period	131	124	136	122	138	120
Mary's Harbour A	Maximum hourly speed (km/h)	93	93	80	81	83	74
(1984 - 2006)	50 years return period	84	88	93	88	86	75
23 years	150 years return period	93	97	103	97	95	82
	500 years return period	103	108	114	108	105	89
Blanc-Sablon	Maximum hourly speed (km/h)	95	98	104	107	111	95
(1982 - 2006)	50 years return period	97	103	117	107	114	105
25 years	150 years return period	106	111	128	116	125	115
	500 years return period	116	121	141	126	137	127
Belle Isle	Maximum hourly speed (km/h)	140	129	145	145	137	145
(1953 - 1969)	50 years return period	153	151	172	159	158	157
17 years	150 years return period	171	167	192	176	176	179
	500 years return period	191	184	214	195	196	202
St. Anthony	Maximum hourly speed (km/h)	80	83	100	113	90	87
(1953 - 2006)	50 years return period	85	91	104	97	98	85
46 years	150 years return period	93	99	116	106	107	93
	500 years return period	102	108	128	116	118	102
Daniel's Harbour	Maximum hourly speed (km/h)	100	132	120	126	121	84
(1953 - 2006)	50 years return period	107	118	123	117	111	90
53 years	150 years return period	118	131	138	131	124	99
	500 years return period	131	145	153	147	139	109
Deer Lake A	Maximum hourly speed (km/h)	78	70	93	65	72	64
(1966 - 2006)	50 years return period	70	71	84	68	67	65
41 years	150 years return period	79	78	94	74	74	71
	500 years return period	88	87	106	81	81	78

Table C-3
Maximum Hourly Wind Speed (km/h)
and 50, 150 and 500 Years Return Period

Station	Climatological Parameters	NOV	DEC	JAN	FEB	MAR	APR
Badger (aut)	Maximum hourly speed (km/h)	65	76	80	83	48	44
(1977 - 2006)	50 years return period	60	64	74	76	51	45
30 years	150 years return period	67	72	85	87	56	48
	500 years return period	75	81	97	99	61	52
Gander A	Maximum hourly speed (km/h)	96	107	117	105	83	80
(1953 - 2006)	50 years return period	93	102	104	100	87	78
53 years	150 years return period	103	113	115	111	94	84
	500 years return period	114	125	126	126	103	91
Bonavista	Maximum hourly speed (km/h)	127	119	130	124	116	104
(1960 - 2006)	50 years return period	121	131	130	130	116	99
47 years	150 years return period	133	145	142	145	128	108
	500 years return period	147	160	156	161	141	118
Stephenville A	Maximum hourly speed (km/h)	83	93	93	89	91	83
(1953 - 2006)	50 years return period	88	100	100	99	93	87
53 years	150 years return period	98	112	111	111	104	98
	500 years return period	110	125	124	124	116	109
Port aux Basques	Maximum hourly speed (km/h)	106	115	116	120	109	100
(1967 - 2006)	50 years return period	109	112	115	126	116	100
40 years	150 years return period	119	122	125	141	128	109
	500 years return period	131	132	135	157	141	119
Burgeo	Maximum hourly speed (km/h)	105	104	129	115	111	111
(1967 - 2006)	50 years return period	102	103	115	113	118	106
40 years	150 years return period	111	111	125	125	130	116
	500 years return period	121	120	137	137	143	128
St. Lawrence	Maximum hourly speed (km/h)	100	107	145	145	116	96
(1967 - 2006)	50 years return period	101	114	129	124	117	96
40 years	150 years return period	111	125	145	138	130	104
	500 years return period	121	137	163	154	145	114
Argentia	Maximum hourly speed (km/h)	100	105	109	111	87	87
(1953 - 2006)	50 years return period	96	105	107	111	98	89
38 years	150 years return period	106	116	118	124	108	98
	500 years return period	116	128	130	138	119	108
St. John's A	Maximum hourly speed (km/h)	105	97	120	137	121	93
(1953 - 2006)	50 years return period	101	102	108	114	103	87
53 years	150 years return period	112	111	119	127	114	96
	500 years return period	124	121	130	141	125	105
Cape Ray	Maximum hourly speed (km/h)	95	113	113	122	105	100
(1953 - 2006)	50 years return period	102	115	121	124	111	111
41 years	150 years return period	109	125	132	137	120	123
	500 years return period	118	136	144	152	130	136

Appendix D

Influence of Topography

Topographical Analyses

Topographical effects should be added to the basic meteorological loads taking into account statistical variations within each climatic region, which is individually determined from general climate and geographical features. In the following tables two adjustments are estimated at the center line of line routes. One is taking in account of the lifting effect of moist air in the case of icing precipitation. Another one is assuming the effect of the surrounding ground on low clouds; lifting, filtering and sheltering. At a given elevation the precipitation icing load and the in-cloud icing load could often coincide and they should then be combined, as it has been observed at TTS (Appendix B).

Table D.1 Topographical Analysis of Line Routes
Climatic Region C1 (R1/R2) Labrador Plateau

Region parameters: 50-year precipitation icing load PIL = 35 mm
50-year in-cloud icing load ICIL = 70 mm
Critical Elevation of Icing Clouds CEIC = 350 m[c]

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond				
1-2	300	100	200	53	nil	0	Churchill River
2-4	400	100	300	70	50	88	Churchill River
4- 5	450+	250	200	53	100	105	Remote
5-7	450+	350 [c]	100	40	100	105	Remote
7-10	350	350 [c]	0	35	even	70	Kenamu River
10-12	450+	250	200	53	100	105	Kenamu River
12-22	450	400[c]	50	38	50	105	remote
22-27	450+	350 [c]	100	40	100	105	St-Paul River
27-28	500+	350 [c]	150	44	150	123	St-Paul River
26-29	400	300	100	40	50	88	St-Paul River
29-33	350	300	50	38	even	70	Bujeau River
33-35	400	350 [c]	50	38	50	88	Pinware River

[C] The Critical Elevation of Icing Clouds (CEIC) is always even or above the Moist Air level
+ When ground elevation is 100m above the actual CEIC, the total icing load should = PIL + ICIL

Table D.2 Topographical Analysis of Line Route
Climatic Region C2 (R3/R4) Strait of Belle Isle

Region parameters: 50-year precipitation icing load PIL = 75 mm
50-year in-cloud icing load ICIL = 100 mm
Critical Elevation of Icing Clouds CEIC = 300 m

P.I.	Ground elevation m	M. Air Level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond				
35-38	400+	300	100	83	100	150	Strait of Belle Isle
38-39	450+	200	250	131	150	175	Strait of Belle Isle
39-40	300	200	100	86	Even	100	Strait of Belle Isle
40-42	300	150	150	94	Even	100	Strait of Belle Isle
42-44	200	100	100	86	Nil	0	Strait of Belle Isle
44-45	150*	100	50	83	Nil	0	Strait of Belle Isle
44-47	150*	100	50	83	Nil	0	Strait of Belle Isle
			Strait of Belle Isle Cable Crossing				
1-5	75*	100	Nil	75	Nil	0	Strait of Belle Isle
5 -7	150*	100	50	83	Nil	0	Strait of Belle Isle
5-8B	150*	100	50	83	Nil	0	Strait of Belle Isle
5-8A	250	100	150	94	Nil	0	Strait of Belle Isle

** Possible salty air*
+ When ground elevation is 100m above the actual CEIC, the total icing load should = PIL + ICIL

Table D.3 Topographical Analysis of Line Routes
Climatic Region C3 (R5/R6) Long Range Mountains
Region parameters: 50-year precipitation icing load PIL= 75 mm
50-year in-cloud icing load ICIL= 100 mm
Critical Elevation of Icing Clouds CEIC = 350 m

P.I.	Ground level m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond (P.I. 7 –19)				
7-8	300	100	200	113	Nil	0	Gulf of St-Lawrence
8-9	450+	100	350	169	100	150	Gulf of St-Lawrence
9-10	400	100	300	150	50	125	Gulf of St-Lawrence
10-11	300	100	200	113	nil	0	Gulf of St-Lawrence
8A-9A	350	100	250	131	even	100	Gulf of St-Lawrence
9A-10A	400	100	300	150	50	125	Gulf of St-Lawrence
10A-10	350	100	250	131	even	100	Gulf of St-Lawrence
8B-9B	450+	100	350	169	100	150	Gulf of St-Lawrence
9B-10B	450+	100	300	169	50**	125	Gulf of St-Lawrence
10B-13B	300	100	200	113	nil	0	Gulf of St-Lawrence
13B-14B	200	100	100	86	nil	0	Gulf of St-Lawrence
14B-12	100*	100	nil	75	nil	0	Gulf of St-Lawrence
11-14B	100*	100	nil	75	nil	0	Gulf of St-Lawrence
11-11A	100*	100	nil	75	Nil	0	Gulf of St-Lawrence
14B-11A	100*	100	Nil	75	nil	0	Gulf of St-Lawrence
12-13	100*	100	nil	75	nil	0	Gulf of St-Lawrence
13-16	100*	100	nil	75	nil	0	Gulf of St-Lawrence
11A-12A	150*	100	50	83	nil	0	Gulf of St-Lawrence
12A-14A	100*	100	nil	75	nil	0	Gulf of St-Lawrence
14A-16	150*	100	50	83	nil	0	Gulf of St-Lawrence
16-19	150*	100	50	83	nil	0	Gulf of St-Lawrence

** Possible salty air*
*** Some sheltering effect from surrounding ground has been included.*
+ When ground elevation is 100m above the actual CEIC, the total icing load should =PIL +ICIL

Table D.3a Topographical Analysis of Line Routes
Climatic Region C3 (R5/R6) Long Range Mountains

Region parameters: 50-year precipitation icing load PIL = 75 mm
50-year in-cloud icing load ICIL = 100 mm
Critical Elevation of Icing Clouds CEIC = 350 m [c]

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond (P.I. 19 – 32)				
19-20A	150	100	50	83	Nil	0	Gulf of St-Lawrence
20A-21A	200	100	100	86	Nil	0	Gulf of St-Lawrence
21A-22A	350	150	300	150	100	150	Gulf of St-Lawrence
22A-23A	500+	250	250	131	100*	150	Gulf of St-Lawrence
23A-24A	550+	150	400	188	200	200	Inner Pound
24A-25A	550+	100	450	206	200	200	Inner Pound
25A-26A	550+	200	350	169	150*	175	Inner Pound
26A-27A	450+	250	200	113	50*	125	Inner Pound
27A-28A	550+	300	250	131	150*	175	Inner Pound
28A-29A	550+	400 [c]	150	94	150*	175	Main River
29A-32	550+	400 [c]	150	94	150	175	Main River
19-25	150*	100	50	83	nil	0	Gulf of St-Lawrence
25-27	550+	100	450	206	200	200	Inner Pound
27-28	550+	200	350	169	200	200	Inner Pound
28-30	550+	300	250	131	200	200	Inner Pound
30-31	600+	400 [c]	200	113	200*	200	Inner Pound
31-32	550+	450 [c]	100	86	100*	155	Main River

C The CEIC is always even or above the Moist Air level
** Some sheltering effect from surrounding ground has been included.*
+ When ground elevation is 100m above the actual CEIC, the total icing load should = PIL + ICIL

Table D.3c Topographical Analysis of Line Routes
Climatic Region C3 (R5/R6) Long Range Mountains

Region parameters: 50 year precipitation icing load PIL = 75 mm
50 year in-cloud icing load ICIL = 100 mm
Critical Elevation of Icing Clouds CEIC = 350 m c

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond (P.I. 31–40)				
31-32C	550+	450 c	100	86	100	150	Inner Pound
32C-33C	450+	400 c	50	83	50	125	Inner Pound
33C-34C	500+	400 c	100	86	100	150	Inner Pound
34C-35C	450	400 c	50	83	50*	125	Inner Pound
35C-36C	450	400 c	50	83	50	125	Main River
36C-37C	500+	350 c	150	94	150	175	Main River
37C-37	500+	300	200	113	150*	175	Main River
37C-36*	450+	300	150	94	100*	150	Main River
31-32	550+	450 c	100	86	100*	150	Main River
32-34	450	400 c	50	83	50*	125	Main River
34-35	400	350 c	50	83	50	125	Main River
35-36	350	350 c	Nil	75	even	100	Main River
36-39	450+	300	150	94	100	150	Main River
39-40	400	300	100	86	50	125	Main River

C The CEIC is always even or above the Moist Air level
** A short cut from alternative route #C to the proposed route analysed in table 10.*
+ When ground elevation is 100m above the actual CEIC, the total icing load should = PIL + ICIL

Table D.4 Topographical Analysis of Line Routes
Climatic Region C4 (R7) Grand Lake-White Bay Alley

Region parameters: 50-year precipitation icing load PIL= 75 mm
50-year in-cloud icing load ICIL= 70 mm
Critical Elevation of Icing Clouds CEIC= 300 m

P.I.*	Ground elevation m	M. Air Level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Gull Island to Soldiers Pond (P.I. 40-49)				
40-41	450+	200	250	131	150	123	Atlantic Ocean
41-42	250	100	150	94	Nil	0	Atlantic Ocean
42-43	250	150	100	86	Nil	0	Atlantic Ocean
43-43A	250	150	100	86	Nil	0	Atlantic Ocean
43A-44A	150	150	0	75	Nil	0	Atlantic Ocean
44A-45A	400+	150	250	131	100	105	Atlantic Ocean
45A-46A	450+	200	250	131	150	123	Atlantic Ocean
46A-48	400+	200	200	113	100	105	Atlantic Ocean
43A-44	200	200	0	75	Nil	0	Atlantic Ocean
44-45	200	200	0	75	Nil	0	Atlantic Ocean
45-46	300	200	100	86	even	70	Atlantic Ocean
46-47	450+	200	250	131	150	123	Atlantic Ocean
47-48	300	200	100	86	even	70	Atlantic Ocean
48-49	250	200	50	83	nil	0	Atlantic Ocean
			Taylor's Brook to Cape Ray (P.I. 1-17)				
T.B. -1	150	100	50	83	Nil	0	White Bay
1 -12	100	100	Nil	75	Nil	0	Sandy Lake
12-13	150	100	50	83	Nil	0	Grand Lake
13-15	200	100	100	86	Nil	0	Grand Lake
15-16A	250	200	50	83	Nil	0	Grand Lake
16A-17A	400+	200	200	113	100	105	Grand Lake
15-16	300	200	100	86	even	70	Grand Lake
16-17	350	200	150	94	50	88	Grand Lake

+ When ground elevation is 100m above the actual CEIC, the total icing load should =PIL +ICIL

Table D.4A Topographical Analysis of Line Routes
Climatic Region C4A St-Georges Bay-Grand Lake Alley

Region parameters: 50-year precipitation icing load PIL= 60 mm
50-year in-cloud icing load ICIL= 70 mm
Critical Elevation of Icing Clouds CEIC = 350 m

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL mm	Geographical source of moist air
			Taylor's Brook to Cape Ray (P.I. 17–58)				
17-18	350	150	200	90	even	70	Deer Lake
17A-18	400	150	250	105	50	88	Deer Lake
18-22	350	200	150	75	even	70	Humber River
22-23	450+	300	150	75	100	105	Humber River
23-24	500+	300	200	90	150	123	Humber River
24-25	450+	250	200	90	100	105	Humber Bay
25-27A	300	250	50	66	nil	0	Humber Bay
27A-28	250	250	Nil	60	Nil	0	Pinchgut lake
28-32	300	200	100	69	Nil	0	Georges Lake
32-36	200	100	100	69	Nil	0	St-Georges Bay
36-47	100*	100	Nil	60	Nil	0	St-Georges Bay
47-49	150*	150	Nil	60	Nil	0	St-Georges Bay
49-58	150*	100	50	66	nil	0	St-Georges Bay

** Possible salty air*
+ When ground elevation is 100m above the actual CEIC, the total icing load should =PIL +ICIL

Table D.5 Topographical Analysis of Line
Climatic Region C5 (R8/R9) Atlantic Coast

Region parameters: 50-year precipitation icing load PIL= 75 mm
50 year in-cloud icing load ICIL= 100 mm
Critical Elevation of Icing Clouds CEIC= 250 m

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL Mm	Geographical source of moist air
			Gull Island to Soldiers Pond (49-65)				
49-52	250	150	100	86	even	100	Atlantic Ocean
52-53	200	150	50	83	Nil	0	Atlantic Ocean
53-57	150	150	nil	75	Nil	0	Atlantic Ocean
57-58	300	100	200	113	50	125	Gander River
58-59	200	100	100	86	Nil	0	Gander River
59-62	300	150	150	94	50	125	Gambo Pond
62-63	250	100	150	94	Even	100	Maccles Lake
63-64	150*	100	50	83	Nil	0	Clode Sound
64-65	150*	100	50	83	nil	0	Clode Sound

** Possible salty air*

Table D.6 Topographical Analysis of Line Routes
Climatic Region C6 (R10/R11) Avalon Isthmus and Peninsula

Region parameters: 50-year precipitation icing load PIL = 75 mm
50-year in-cloud icing load ICIL = 120 mm
Critical Elevation of Icing Clouds CEIC = 200 m

P.I.	Ground elevation m	M. Air level m	M. Air Rising m	New PIL mm	Cloud Forcing m	New ICIL Mm	Geographical source of moist air
Gull Island to Soldiers Pond (65-102)							
65-68	150*	100	50	83	Nil	0	Atlantic Ocean
68-76	100*	100	nil	75	Nil	0	Atlantic Ocean
76-83	150*	100	50	83	Nil	0	Atlantic Ocean
83-97	100*	100	Nil	75	Nil	0	Atlantic Ocean
97-99	150*	100	50	83	Nil	0	Atlantic Ocean
99-101	250	100	150	94	50	150	Atlantic Ocean
101-102	200	100	100	86	even	120	Atlantic Ocean

** Possible salty air*

Appendix E

Field Trip Investigation

Field Trip Investigation

The helicopter field trip from October 26 to 31, 2007 was used to look for evidence of broken tree tops, especially for balsam fir and spruce, to quantify the amount of ice that has affected the region. The approach has been developed for the most part by the authors of this report, and has been used for Hydro-Québec ice storm analysis. It is especially useful in the analysis of extensive ice storms in valleys and mountainous areas. Tree tops are generally broken under eccentric glaze or wet snow loads while coniferous tree tops survive heavy rime and dry snow.

The following text is the site visit report issued at the conclusion of the helicopter field-trip.

"For this project, we had planned to fly from Gull Island to Soldiers Pond and from Taylors Brook to Cape Ray. The section in Labrador was visited by our geotechnical representative while the meteorological and route selection group started from the Strait of Belle Isle to PI – 37 inland from the coast on Friday afternoon, October 26. There are almost no trees in this section and we could not quantify any icing events.

At Pointe Amour, we found the exact location of the PIM site and obtained information about the observer, Mr. Shepperd, the lighthouse keeper. Mr Shepperd has passed away, but we met with his two sons. They remembered that their father was making ice observations, but they were unable to remember if there was a big freezing rainstorm in January 1983, that gave 45 mm radial ice. The oldest son remembers times when there was a lot of ice on the lighthouse, but it was not due to the freezing rainstorm. The lighthouse was just in front of the ocean and received it as a lot of water brought by the wind.

We visited around Point Amour with Mr. Andre Jones, who is the observer for the Hydro-Québec PIM station at the Blanc Sablon airport. From Point Amour we went as far as Pinware Bay stopping many times along the road, looking for broken tree tops. About 10% broken tree tops were observed, which indicates about 15 to 25 mm radial ice in accordance with the scale that was established in 2004. Mr Jones had no recollection about a big freezing rainstorm in January 1983. The maximum glaze that he registered in January 1983 is only15 mm, which is equivalent of 11 mm radial ice (15 x 0.7 correction factor when there is no icicle). Eighteen (18) mm is the maximum radial ice recorded at the Blanc Sablon airport, since the beginning of the Hydro-Québec PIM network operation. The station at Blanc Sablon has been operating since the fall of1975 providing 32 years of data to date. According to Mr Jones, who has been the observer for the weather station for 41 years, freezing rain is rare at Blanc Sablon and the amount of glaze has never exceeded one inch (25 mm). The Point Amour PIM site doesn't have the same exposure as the Blanc Sablon airport PIM site, so it's possible that the 45 mm radial ice estimated at Point Amour is correct. There are very few trees around Point Amour that can help us to estimate this amount of ice. So, we took into consideration this data, when we established the regional precipitation icing loads for the C2 climatic regions in table 3-2.

We flew by helicopter over Newfoundland from Saturday October 27 to Wednesday October 31 but were unable to fly on Sunday October 28 because of bad weather conditions. During the morning of Saturday October 27, we searched for two PIM stations, one at Plum Point and the other one at Yankee Point. Both of these two stations reported a heavy ice in January 1983. Plum Point reported from 20 to 60 mm of glaze with icicles, which is the equivalent of 22 to 66 mm of radial ice (20 x 1.1 and 60 x 1.1, correction factor with icicles) and Yankee Point reported 64 mm of glaze without icicles, which is the equivalent of 45 mm of radial ice (64 x 0.7 correction factor without icicle). We found the PIM station at Plum Point and we were able to meet the *observer, Elva Spence. She was the observer for the PIM for the whole period of observation (1977 to 1987) and has been the observer for the Newfoundland climatological network since 1972. She showed us the book of weather observations for January 1983 and has all the records since the beginning. The records from January 13 - 14, 1983 show freezing rain started during the afternoon of the 13th continuing until the 14th along with 16.1 mm of rain.*

With 36 years of observations to the present, she has observed very little freezing rain at Plum Point. Of the 20 to 60 mm of glaze that she measured on January 1983, she recalled that the 60 mm included icicles. The amount of ice without the icicle was about 1 inch (25 mm), which is the equivalent of 28 mm of radial ice (25 x 1.1 correction factor with icicles). As per her recollection, there were no tree tops broken in January 1983. Accordingly, balsam fir and spruce need at minimum 25 mm of freezing rain before the tops break off. We investigated around Plum Point and found less than 10 percent of trees with broken tops. No observer For the Yankee Point PIM station was found. With the geographic coordinates of the site, we passed over and around but we were unable to see any evidence to confirm 45 mm of radial ice. As with Plum Point, we observed about 10 percent of the tree tops broken. Like Point Amour PIM station, it is possible that the 45 mm radial ice at Yankee Point is correct. We have considered this data in establishing the regional precipitation icing loads for the C2 climatic regions in table 3-2 for the southern part of the Strait of Belle Isle from PI – 1 to PI – 6 on the route selection maps (WTO DC1050).

During the afternoon of Saturday October 27, we flew from Strait of Belle Isle to Deer Lake. From the Strait of Belle Isle to PI – 19 we observed about 10 percent of broken tree tops representing about 15 to 25 mm radial ice. On Sunday October 28, we didn't fly because of bad weather conditions. On Monday October 29, we flew back and forth from Taylors Brook to PI – 19, from Taylors Brook to Grand Falls and back and forth and from Taylors Brook to Cape Ray. From Taylors Brook to PI – 19, we flew over the west option going and the east option on the way back. There were a lot of places without trees and other places with very small trees. In this case, it is very difficult to make an estimation about the amount of icing for the region. Along the Long Range Mountains, the percentage of the broken tree tops was estimated around 10 to 20 percent, except between PI – 25 and PI – 26 where we noted from 20 to 30 percent. Between these two PIs, a rise in elevation from 50 to 500 m in three kilometres was observed. According to the scale established in 2004, 20 percent broken tree tops translates into about 25 to 40 mm radial ice.

From PI – 6 to PI – 40, in the Long Range Mountains, we know that a lot of ice and rime was registered during the Climatological Monitoring Program from 1977 to 1987. In Table B-4, we note at the Hills of St John test tower site, located 460 meters above sea level, registered 7 inches of glaze in February 12, 1979. At East Blue Mountain test tower site, located at 475 m above sea level, from 10 to 12 inches of glaze on tower was observed on February 12, 1979. The Portland Creek test tower site, located at 630 m above sea level, registered 36 inches of hard rime. These values are extreme values and were registered at the top of the mountains on the exposed summits. In determining the regional precipitation icing loads and the regional in-cloud icing loads for the C3 climatic region in Tables 3-2 and 3-3, we have considered these important values. As the line route selection passes through the Long Range Mountains area for more than 100 km, where amplification icing and in-cloud icing are major problems, tone should avoid placing towers on mountain summits which are well exposed. Should there be no choice, mitigation measures could be required.

From PI – 40 to Pi – 55, Taylors Brook to Grand Falls, we noted less than 20 percent broken tree tops, which means about 25 to 40 mm radial ice. Between PI – 41 and PI – 43, we expected to find 40 to 50% broken tree *tops in some places, because the important value registered at the Hampden PIM station, 58 mm radial ice (table B-4), in January 1979. We flew to Hampden but didn't find the exact location of the PIM station, we landed and looked around for broken tree tops. There were less than 20%. The distance between Hampden PIM station and PI - 41 to PI – 43 is about 10 to 15 km. This area has the same pattern as the area of Pentecôte, between Baie-Comeau and Sept-Îles, on the Québec north shore of the gulf of Saint Lawrence, where tower collapses have occurred on two occasions due to icing amplification (April 1973, 32 towers and April 2005, 14 towers). For these two events in Pentecôte, radial ice from 50 to 75 mm was observed. A corresponding 50 to 80 percent of tree tops were broken. At the test tower site at Sheffield Lake, 10 km from PI – 47 to PI – 49, from 2.0 to 2.5 inches (50 to 65 mm) of ice was measured on the tower leg at 5 feet (1,5 m) from the ground while the top tower was encased in 6 to 8 inches (150 to 22 mm) of ice. We flew over the region of the Sheffield Lake test tower site, but as there were almost no trees, we weren't able to quantify any amount of ice. This section of the line route is located in the C4 climatic regions. We have considered the measurements at Hampden PIM station and at Sheffield test tower site to establish the 75 mm base icing loads for 50 years return period presented in Table 3-2.*

For the last section, from Grand Falls to Soldiers Pond, PI – 55 to PI – 102, we estimated the percentage of broken tree tops at 20 percent, which means around 25 to 40 mm radial ice. We expected more than that, especially in the Avalon Peninsula. In this section of the line route selection, there were 8 PIM stations (Stony Brook, Gander, Port Blandford, Sunnyside, S Turn, Western Avalon, Holyrood and St. John's) during the program. The maximum value registered was 28 mm radial ice in Gander in April 1982. The PIM stations and the broken tree tops in this region did not register a lot of ice. However, we know that the Avalon Peninsula has experienced considerable icing on many occasions; 1970, 1984, 1988 and 1994, as reported in the article "Twenty Years of Ice Monitoring Experience on Overhead Lines in Newfoundland and Labrador". We have used this information to estimate the precipitation icing loads for C5 and C6.

From Taylors Brook to Cape Ray, we did not find many broken tree tops which we have estimated at 10 percent except for Taylors Brook (PI – 1 to PI – 17), where it was about 20 percent. For this first part of the line route selection, however, we keep in mind the important value registered at the Hampden PIM station in January 1979 with 58 mm radial ice. This section of the line is in the C4 climatic region for precipitation icing loads where 75 mm of radial is retained for 50-year return period. From PI – 18 to PI – 58, as we mentioned above, there were about 10% broken tree tops observed, translating into 15 to 25 mm radial ice. In this area, there were three PIM's during the Climatological Monitoring Program, at Deer Lake, Stephenville and Port aux Basques. The Stephenville PIM station operated for just one season in 1979/1980, the Deer Lake PIM station operated for three seasons (1980 to 1983) and the Port aux Basques PIM stations operated for the whole period (1977 to 1987). The maximum radial ice measured was 21 mm at Port aux Basques during the 1981/1982 season. Very little ice was measured in this region during the program otherwise. This program ran for just 10 years, which is a short period of time for the measurement of icing precipitation. This section, PI – 18 to PI – 58, is located in the C4A climatic region for precipitation icing loads, with 60 mm radial ice for a 50-year return period."

Figure E-1
Broken Trees – Plum Point (about 25 years)

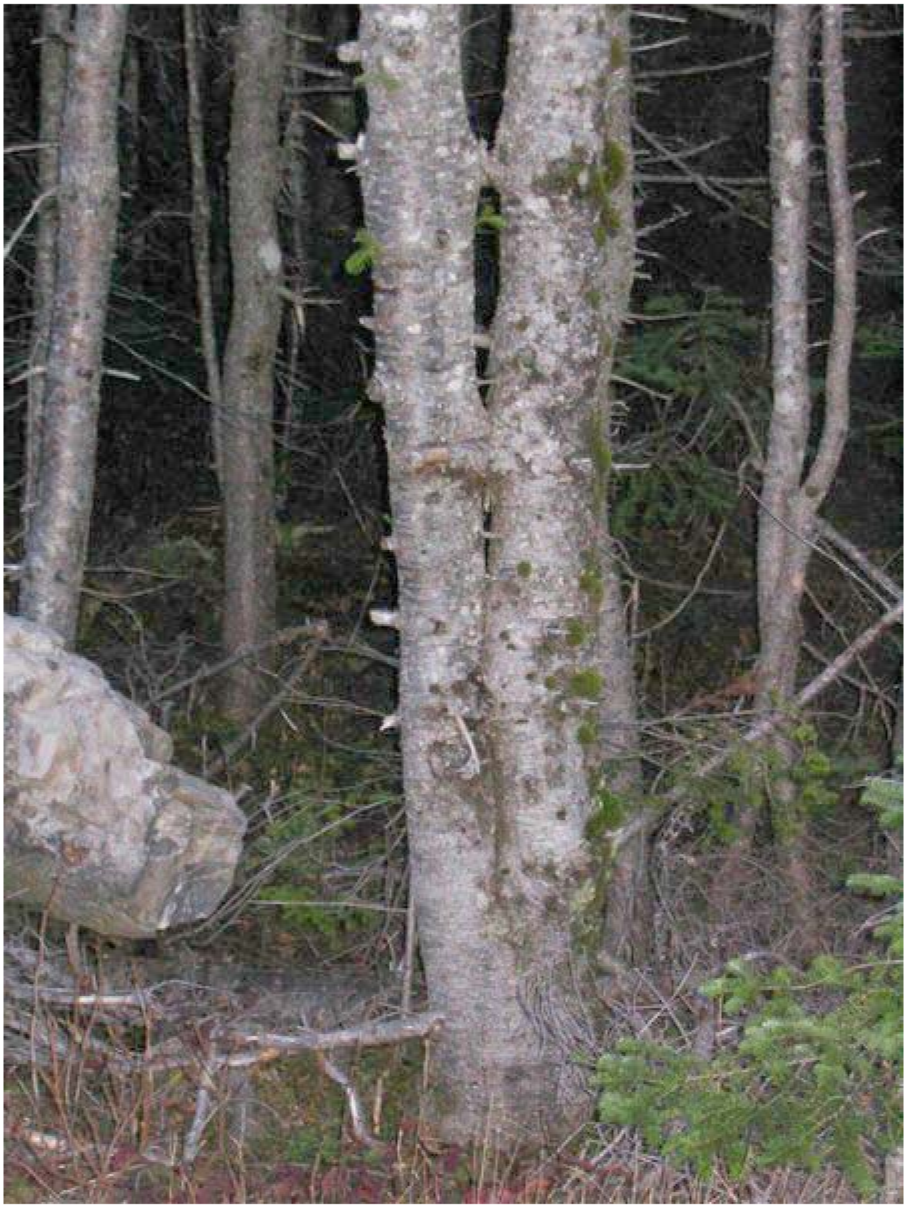
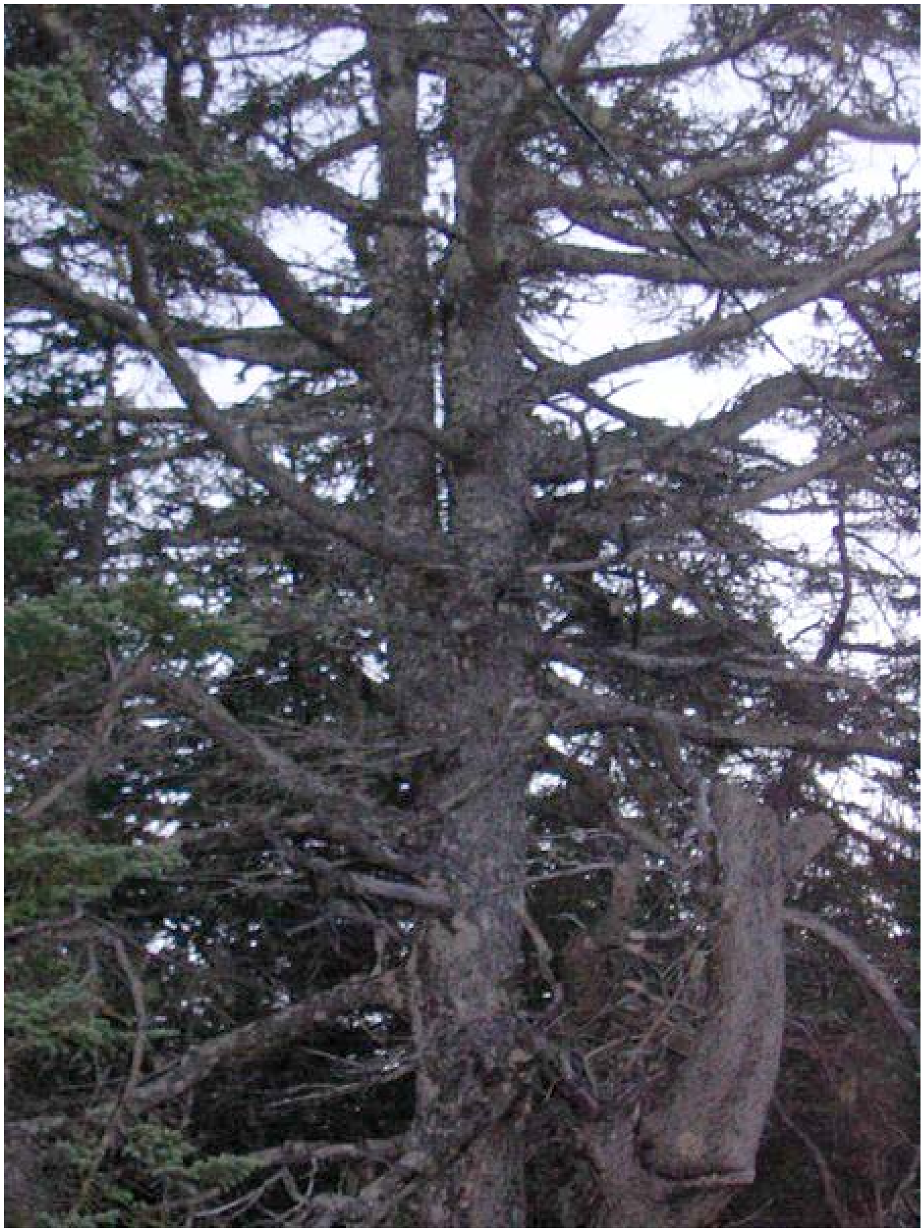


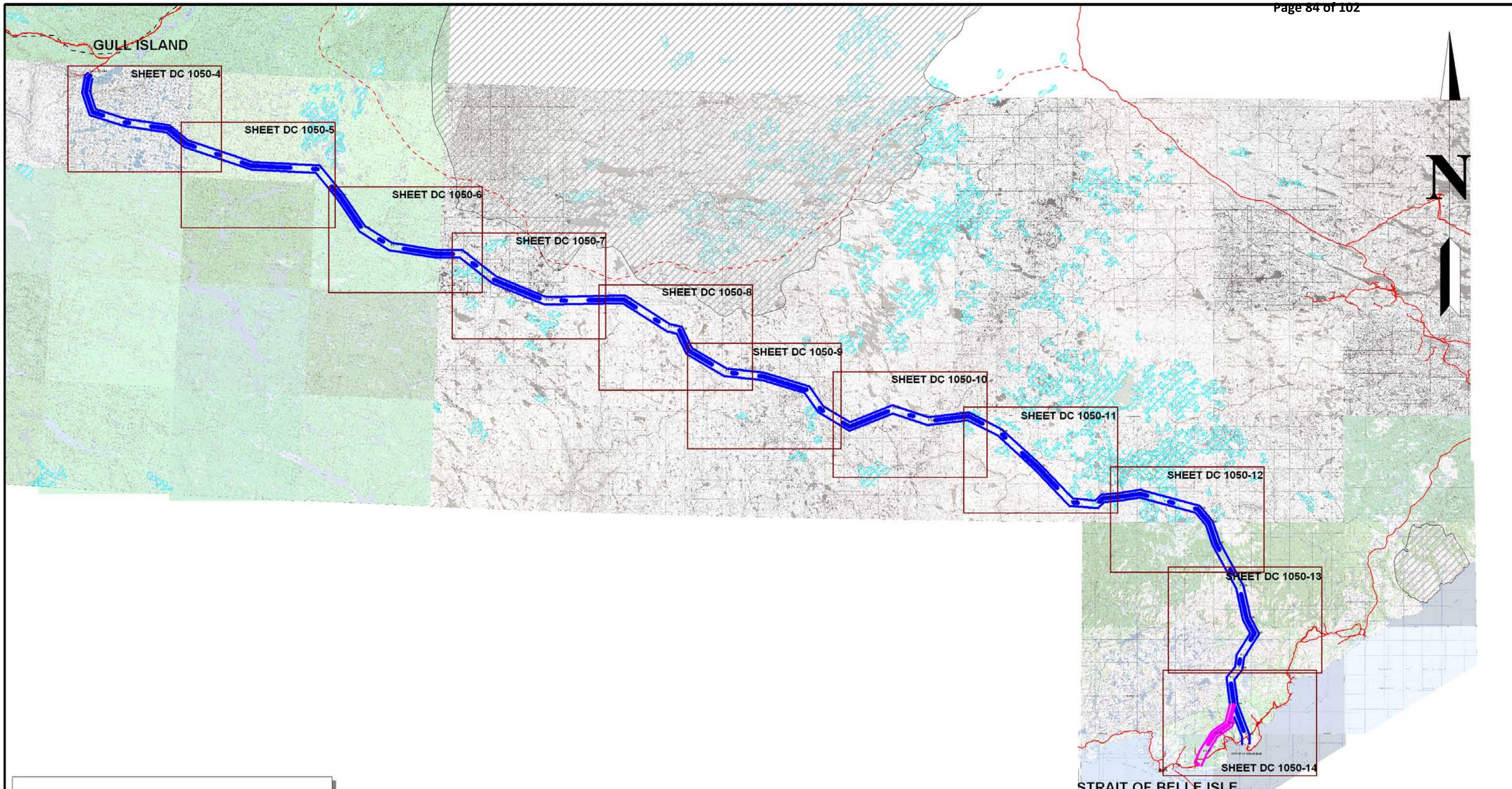
Figure E-2
Broken Trees – Plum Point (about 25 years)



Appendix F

Key Plan Routes

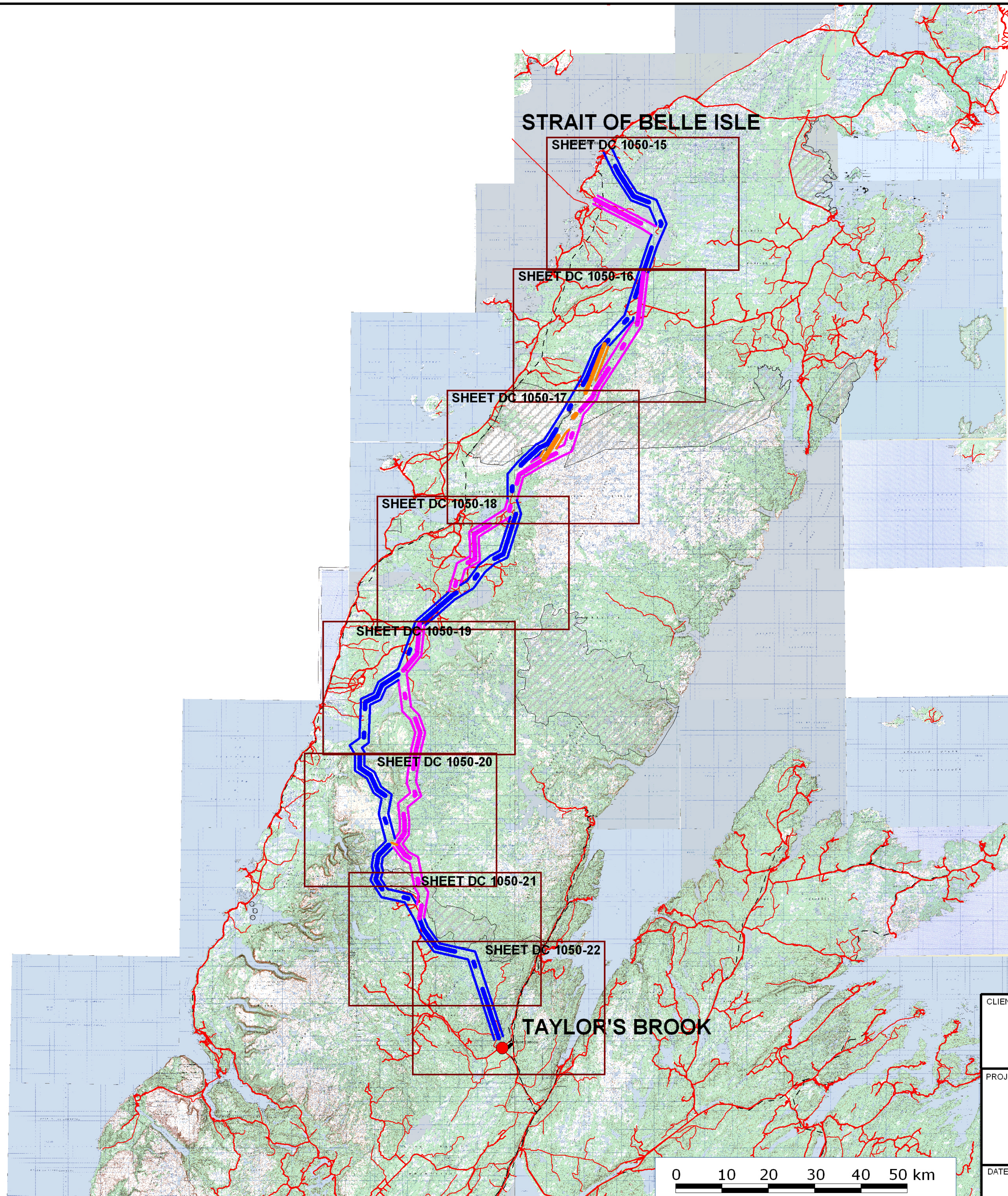
(from WTO's DC1050 and DC1060)



LÉGENDE

- PREFERRED CORRIDOR CENTER LINE
- PREFERRED CORRIDOR LIMITS
- OPTION 1 CORRIDOR CENTER LINE
- OPTION 1 CORRIDOR LIMITS

CLIENT	PRIME CONSULTANT	SUBCONSULTANT
HYDRO THE POWER OF COMMITMENT	HATCH	RSW inc.
PROJECT TITLE LOWER CHURCHILL HYDROELECTRIC PROJECT ENGINEERING STUDIES	WTO NUMBER & TITLE DC 1050 CORRIDOR SELECTION AND CONSTRUCTION INFRASTRUCTURE	DRAWING TITLE LOT 1: GULL ISLAND TO STRAIT OF BELLE ISLE KEY MAP SHEET 1 OF 35
DATE: MARCH 2008	PROJECT No. H325967	DRAWING No. DC 1050-1-REV 1

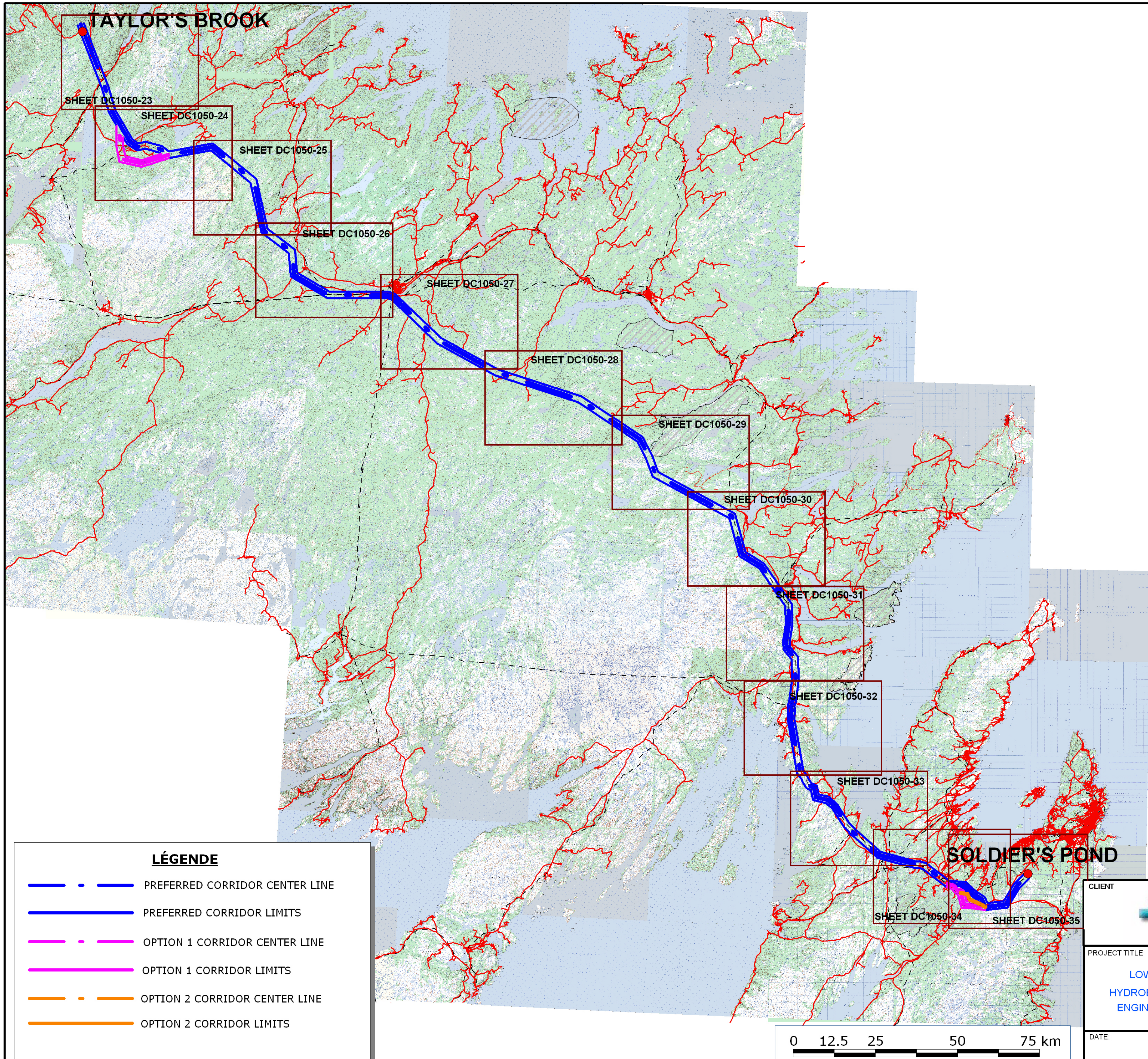


N

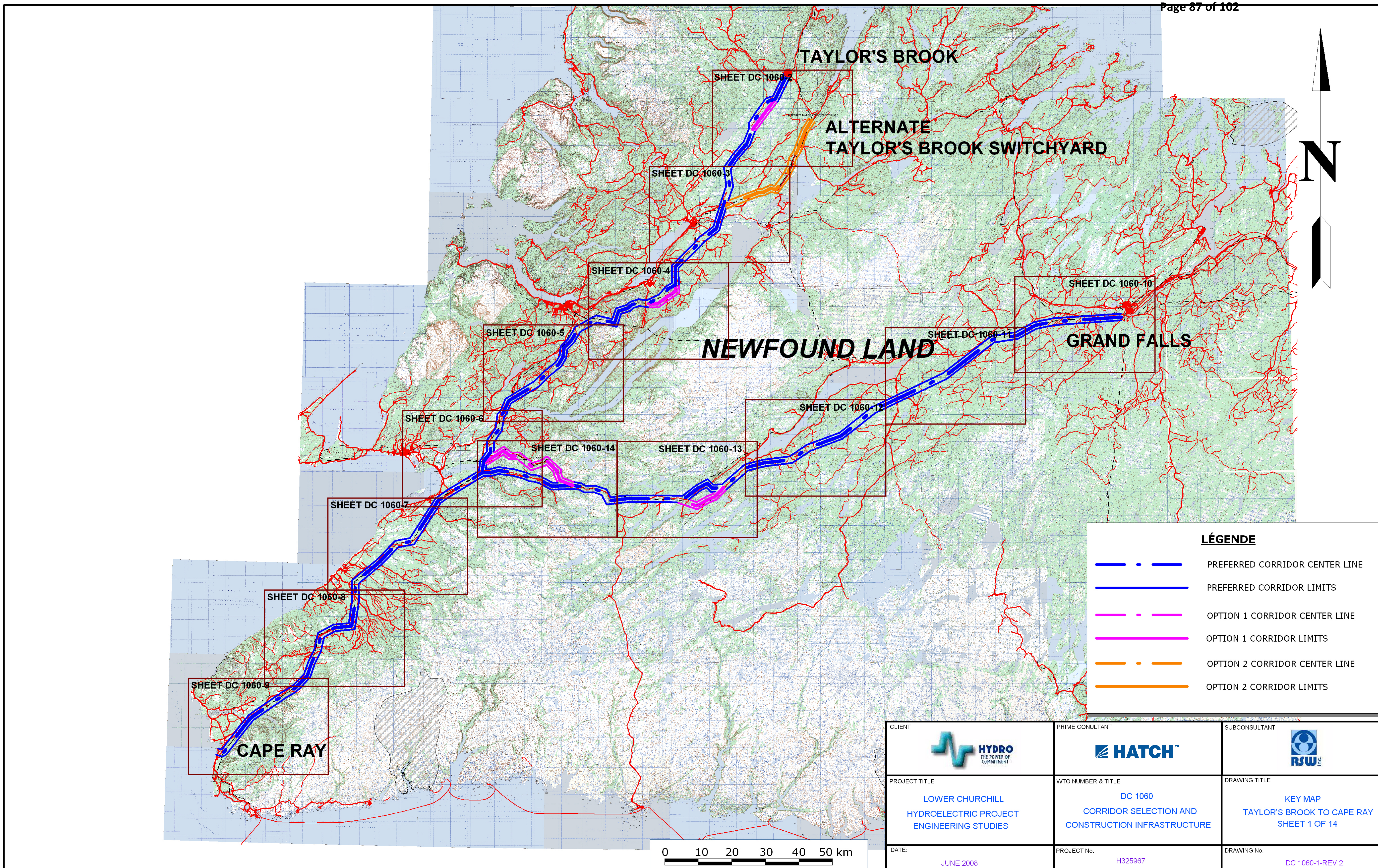
LÉGENDE

- PREFERRED CORRIDOR CENTER LINE
- PREFERRED CORRIDOR LIMITS
- OPTION 1 CORRIDOR CENTER LINE
- OPTION 1 CORRIDOR LIMITS
- OPTION 2 CORRIDOR CENTER LINE
- OPTION 2 CORRIDOR LIMITS

CLIENT	PRIME CONULTANT	SUBCONSULTANT
HYDRO THE POWER OF COMMITMENT	HATCH	RSW inc.
PROJECT TITLE LOWER CHURCHILL HYDROELECTRIC PROJECT ENGINEERING STUDIES	WTO NUMBER & TITLE DC 1050 CORRIDOR SELECTION AND CONSTRUCTION INFRASTRUCTURE	DRAWING TITLE LOT 2: STRAIT OF BELLE ISLE TO TAYLOR'S BROOK KEY MAP SHEET 2 OF 35
DATE: JUNE 2008	PROJECT No. H325967	DRAWING No. DC 1050-2-REV 2



CLIENT	PRIME CONSULTANT	SUBCONSULTANT
HYDRO THE POWER OF COMMITMENT	HATCH	RSW inc.
PROJECT TITLE LOWER CHURCHILL HYDROELECTRIC PROJECT ENGINEERING STUDIES	WTO NUMBER & TITLE DC 1050 CORRIDOR SELECTION AND CONSTRUCTION INFRASTRUCTURE	DRAWING TITLE LOT3: TAYLOR'S BROOK TO SOLDIER'S POND KEY MAP 3 SHEET 3 OF 35
DATE: JUNE 2008	PROJECT No. H325967	DRAWING No. DC 1050-3-REV 2


TAYLOR'S BROOK
ALTERNATE
TAYLOR'S BROOK SWITCHYARD
NEWFOUND LAND
GRAND FALLS
CAPE RAY
SHEET DC 1060-2
SHEET DC 1060-3
SHEET DC 1060-4
SHEET DC 1060-5
SHEET DC 1060-6
SHEET DC 1060-7
SHEET DC 1060-8
SHEET DC 1060-9
SHEET DC 1060-10
SHEET DC 1060-11
SHEET DC 1060-12
SHEET DC 1060-13
SHEET DC 1060-14
N
LÉGENDE
PREFERRED CORRIDOR CENTER LINE
PREFERRED CORRIDOR LIMITS
OPTION 1 CORRIDOR CENTER LINE
OPTION 1 CORRIDOR LIMITS
OPTION 2 CORRIDOR CENTER LINE
OPTION 2 CORRIDOR LIMITS
0 10 20 30 40 50 km
CLIENT
HYDRO THE POWER OF COMMITMENT
PRIME CONULTANT
HATCH
SUBCONSULTANT
RSW inc.
PROJECT TITLE
LOWER CHURCHILL HYDROELECTRIC PROJECT ENGINEERING STUDIES
WTO NUMBER & TITLE
DC 1060
CORRIDOR SELECTION AND CONSTRUCTION INFRASTRUCTURE
DRAWING TITLE
KEY MAP
TAYLOR'S BROOK TO CAPE RAY
SHEET 1 OF 14
DATE:
JUNE 2008
PROJECT No.
H325967
DRAWING No.
DC 1060-1-REV 2

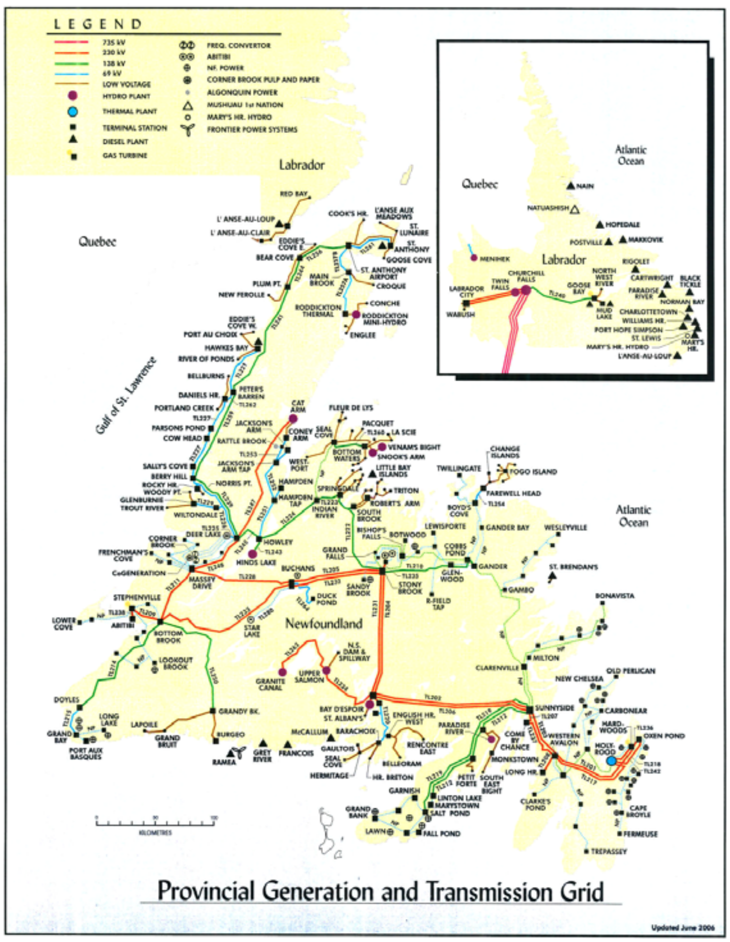
Appendix G

Hydro Transmission Line Loadings

Transmission Line Loading - LC Engineering

Line	Location	Voltage (kV)	Construction	Design	Loading: Max Ice (inch)	Loading: Max Wind (mph)	Loading: Combined Ice (inch)	Loading: Combined Wind (mph)
TL 240	(Labrador) Churchill Falls to Gull Island	138	Wood		2.25	72	0.5	55
TL 240	(Labrador) Gull Island to Goose Bay	138	Wood		1.75	72	0.5	55
TL 241	(Northern Peninsula) Plum Point to Peter's Barren	138	Wood		1.75	110	1	55
TL 227	(Northern Peninsula) Cow Head to Rocky Hr.	69	Wood		1	110	0.5	60
TL 251	(Northern Peninsula) Howley to Hampden	69	Wood		2	83	0.5	55
TL 252	(Northern Peninsula) Hampden to Jackson's Arm	69	Wood		2	83	0.5	55
TL 239	(Northern Peninsula) Berry Hill to Deer Lake	138	Wood		1	110	0.5	55
TL 232	(Central Newfoundland) Buchans to Grand Falls	230	Wood & Steel		2	110	0.5	55
TL 233	(Western Newfoundland) Buchans to Bottom Brook	230	Wood & Steel		1.5	110	0.5	55
TL 248	(Western Newfoundland) Deer Lake to Massey Drive	230	Steel		1.75	110	0.5	73
TL 211	(Western Newfoundland) Massey Drive to Stephenville	230	Steel		1	110	0.5	73
TL 214	(Westcoast Newfoundland) Bottom Brook to Doyles	138	Steel & Alum.		1	117	0.5	55
TL 215	(Westcoast Newfoundland) Doyles to Grand Bay	69	Wood		1.5	150	1	73
TL 210	(Central Newfoundland) Grand Falls to Gander	138	Wood & Steel		1	110	0.5	73
TL 207*	(Avalon) Sunnyside to Come By Chance	230	Steel	1:50	3	110	1.5	55
TL 237*	(Avalon) Come by Chance to Western Avalon	230	Steel	1:25	2.6	110	1	55
TL 203	(Avalon) Sunnyside to Western Avalon	230	Wood		1.5	110	1	55
TL 201	(Avalon) Western Avalon to Hardwoods	230	Wood		1.5	110	1	55
TL 217*	(Western Avalon) Western Avalon to Holyrood	230	Steel	1:50	3	110	1.5	55
TL 217*	(Avalon) Western Avalon to Holyrood	230	Steel	1:25	2.6	110	1.5	55

* Line was upgraded in 2000



Appendix H

Note on January 1998 Ice Storm in Québec

Note on January 1998 Ice Storm in Québec

The following is a short description of the damages incurred by Hydro-Québec during the January 1998 ice storm and the measures implemented to mitigate, in the future, such catastrophic events.

From January 5 to 9, 1998 Québec and neighboring Provinces and US States were hit by three consecutive catastrophic freezing rain ice storms.

In Québec, on Friday, January 9 at the end of the storm, freezing rain accumulations was 49.4 mm at Mirabel (North of Montreal) and 78.4 mm at St-Hubert (South of Montreal) with 20 to 40 km/h wind speed. The damages affected the regional network, essentially the south shore of Montréal, the Montérégie area and the Outaouais area 1,400,000 customers were left without electricity and downtown of Montréal was under a black out. The most affected line sections were perpendicular to wind coming from the north.

- 3000 km of lines were damaged;
- 116 lines were out of operation;
- 513 steel towers crashed (735,315 and 230 kV);
- 1091 120-kV steel towers collapsed;
- 1500 wood poles structures damaged; and
- 14,000 distribution poles were destroyed.

This storm struck also, with a lesser intensity, the neighboring provinces (eastern Ontario and New Brunswick) and US states (Northern New York state, Vermont, New Hampshire and Maine), causing many line collapses and also ground wire and conductor breakages. Many hundreds of thousands of customers were without electricity for many days, and even several weeks.

- Ontario Hydro lost: 2,500 kV lines; 12,230 kV lines; and 9,115 kV lines with total of 130 tower collapses. A large part of the distribution network in the east was completely destroyed;
- NYPA lost a 765 kV line near Massena substation;
- NEEPOL lost the +/- 450 kV d.c. bipole line;
- In New England many 345, 230; 115 and 69 kV were also damaged; and
- Maine State was declared a disaster area by the US President.

An equivalent radial ice thickness on the conductors of 40 mm to 75 mm was estimated, with wind speeds varying between 20 and 40 km/h. Equivalent ice thicknesses of 75 mm were estimated from the data recorded at the PIM stations located at Huntington and Iberville.

Meteorological experts from Hydro Québec and Environment Canada consider that the January ice storm of 1998 was an exceptional event in terms of the area affected as well as its intensity and its duration. A similar storm has never been recorded in Québec and this ice storm is given a 400 year return period. The total freezing accumulation was double that of the most important ice storms which hit these regions in 1942, 1961 and 1986.

Given the socioeconomic impact of the storm and to prevent Québec residents from having to experience such an event ever again, TransÉnergie established strategies to improve the design of the transmission system and facilities and defined measures for accelerating the restoration of service in the event of a similar situation. These strategies have included:

- Set up strategic corridors according to the three high-risk areas identified. This will help maintain the supply to 735 kV substations and would evacuate minimum generation (for ecological and contractual reasons) from the Manic Outardes–Bersimis–Churchill Falls hydroelectric complexes (about 2600 MW). This is being implemented by the installation of a DC de-icer at the Levi substation near Québec city to melt the ice on certain strategic 735 kV and 315 kV lines;
- Increase the supply capacity on the transmission system during exceptional events by building an interconnection with the Ontario network. (Not yet implemented);
- Ensure diversified supply in downtown Montréal by adding a loop between Aqueduc and Atwater substations;
- Ensure the supply of priority loads for high-risk areas in conjunction with the distribution system, regardless of the load block involved;
- Provide a supply in high-risk areas of at least 50% of the peak load for load blocks greater than 200 MW by ensuring a diversified supply (two separate sources) or by using strategic corridors;
- Designate, for load blocks less than 200 MW in high-risk areas, potential backup sources and reinforcement projects that will allow all substations to be reconnected within three weeks;
- Review existing overhead line standards and issue a new standard to specify new weather loads all across Québec. Define containment measures and safety measures and identify most exposed lines sections; and
- A new weather load map has been issued and the following table shows the weather loads adopted before the storm, and the new loads selected for the new lines;
- Improve existing weather loads monitoring all across the network;
- Design the new lines in strategic corridors in high-risk areas so that their reliability is two levels higher in relation to projections of climatic loads with a 50-year rate of recurrence. These lines will thus be strengthened to handle climatic loads corresponding to a period of recurrence of 1:500 years instead of 1:50 years, i.e. radial icing load of 65 mm instead of 45 mm in the southern service area;
- Other measures along these lines to minimize the risk of cascading;
- Check existing lines to ensure that their strength still complies with new design criteria and, if not, strengthen the weak points or replace any defective or aged components;

Table 5.3
Examples of Three Levels of Climatic Load for Restoration Projects

	Original Loads	**Loads for Restoration**	
	Level 45	**Level 55**	**Level 65**
Freezing rain only	45 mm	55 mm	65 mm
Combined freezing rain and wind*	20 m 80 km/h (600 Pa)	25 mm 85 km/h (680 Pa)	30 mm 85 km/h (680 Pa)
Maximum wind*	110 km/h (1140 Pa)	120 km/h (1360 Pa)	120 km/h (1360 Pa)
Level retained			
230 kV B. St-C.			x
735 kV B. Hertel			x
735 kV Hertel-Nic.		x	

* ***Note**: Reference velocities at 10 m from the ground. The pressures are typical affective pressure values at mean cable height.*

- Review certain maintenance and operating procedures, such as rapid reconstruction, the availability of replacement parts in case of emergency; and
- Emphasize research and development with respect to ice-related phenomena in order to find innovative, reliable and cost-effective solutions.

Risk analyses have shown that de-icing methods combined with targeted line reinforcement are the most efficient solutions to secure power supply.

The following solutions were developed:

- 250 MW direct current converter de-icer capable of supplying a 7200 A current at $\pm$ 22 kV;
- A ground wire de-icing robot;
- A remotely-operated steam deicing vehicle to de-ice substation apparatus;
- A shock-wave de-icer for conductor and ground wire; and
- About 120 circuits from 69 kV up to 315 kV were identified as potential candidates for load transfer de-icing by forcing more load current through a particular circuit by transferring loads from other circuits linking the same two substations.

Hydro One was less affected by the storm, because ice loads were not as great. They lost essentially old lines in eastern Ontario which were designed for lower loads than the lines built since 1980 (designed for 55 mm of glaze ice). They implemented many measures to reinforce old lines and an emergency restoration plan was developed and spare parts were ordered and stored in different regions.

Following this storm many utilities decided to review the design of their network. NYPA has reviewed their line designs, investigated the weather loads and decided to reinforce some sections. An Emergency restoration plan was also implemented.

BC Hydro has reviewed completely its network to identify the most vulnerable line sections, to select adequate reliability levels according to the importance of each line and to implement some reinforcements.

Appendix I

Estimate for Wind Measurement Towers

RSW INC.
CONSEILLERS EN INGÉNIERIE • ENGINEERING CONSULTANTS
1010, de la gauchetière ouest, bureau 500, montréal (québec) canada H3B 0A1
téléphone : (514) 878-2621 • télécopieur : (514) 397-0085
1010, de la gauchetière west, suite 500, montréal (québec) canada H3B 0A1
telephone : (514) 878-2621 • fax : (514) 397-0085

July 29th, 2008

Mr. Kyle B. Tucker
Senior Transmission Engineer
NEWFOUNDLAND AND LABRADOR HYDRO
P.O. Box 12400
St-John's, Nfld
A1B 4K7

O/Ref. : P44 0630 E0347 GEN COR.EX
Subject : Estimate for Wind Measurement Towers

Dear Kyle,

In the report DC 1070 – Meteorological Load Review, it was recommended that additional wind speed measurements be undertaken at critical sites along the line route in order to calibrate values with those of nearby airports in addition to improving in-cloud icing estimates.

We have received quotations for the supply (ATT Inc.) and installation (Prowind Tower) of 10 towers each 25 m high equipped with the following :

SUPPLY				
Items	Unit Price	Quantity	Price	Height
Humidity Sensor NRG	405 $	10	4 050 $	10
Temperature NRG	230 $	10	2 300 $	10
C3C Anemometer	278 $	10	2 780 $	10
C3C Anemometer	278 $	10	2 780 $	25
Wind Vane 200P NRG	245 $	10	2 450 $	25
Nomad 2 Satellite modem kit	2 975 $	10	29 750 $	
Nomad 2 Data Logger	1 499$	10	14 990 $	
Cable 3C	0,98 $	600	588 $	
Cable 2C	0,78 $	450	351 $	
Measuring boom 60" long (1/2" dia.)	120 $	30	3 600 $	
Scout 25 m	4 750 $	10	47 500 $	
TOTAL (CAD) 111 139 $				

...2

RSW inc.

The anemometers would be installed at 10 m and 25 m height and the system would include a data collector and remote communication system, either by cell phone or satellite.

The quoted "Scout" tower is the most robust of ATT's pre-designed units and can withstand a wind gust of 180 km/h and separately 22,6 mm radial ice. More robust towers may be required along certain areas of the transmission line route. The installation of these 10 towers and equipment is estimated at 41 200 $ (see attachment) bringing the total for supply and installation to 152 339 $ for ten sites.

Considering unforeseen difficulties and more robust towers a budget estimate of 200 000 $ for ten sites would seem appropriate.

Should Hydro wish to proceed with this endeavour, we would be pleased to follow-up with a more detailed proposal including the proposed location of tower sites and a detailed quotation for engineering, supply, erection, data collection and analysis.

Sincerely,

Joe Hanson, Eng.
Project Manager
RSW Inc.

JH/mr
p.j.

AAT inc. formerly Ohmega Group Inc.

3 rue Des Cerisiers
Gaspe, Quebec, Canada, G4X 2M1
Tel: (418) 360-1228 *Web: www.aat-solutions.com*
Fax (418) 360-1268 *E-Mail: sales@aat-solutions.com*

Numéro 1020 **Numéro Révision:** 1 **Date** 2008-04-09

Client RSW ***Preparé par: Jean-Pierre Rozon***

Contact	Marc-André Lussier
Téléphon	
Cell	
Fax	
Courriel	marc-andre.lussier@rswinc.com

Montréal
Québec
Canada

Il nous fait plaisir de vous présenter une soumission sur nos produits, acoompagnée des spécifications techniques. Il est à noter qu'une grue n'est pas requise pour l'érection de la tour, seulement une gin pole, flèche de manoeuvre, est nécessaire.

Nous vous remercions pour l'intérêt porté à nos produits.

Si vous désirez plus d'informations, veuillez s.v.p. communiquer avec nous.

Items	*Prix Unitaire*	*Qté*	*Prix*	*Hauteur*
Humidity Sensor NRG	405,00 $	10	4 050,00 $	10
Temperature NRG	230,00 $	10	2 300,00 $	10
C3C Anemometer	278,00 $	10	2 780,00 $	10
C3C Anemometer	278,00 $	10	2 780,00 $	25
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Nomad 2 Satelite modem kit	2 975,00 $	10	29 750,00 $	
Nomad 2 Data Logger	1 499,00 $	10	14 990,00 $	
Cable 3C	0,98 $	600	588,00 $	
Cable 2C	0,78 $	450	351,00 $	
Measuring boom 60" long (1/2" dia.)	120,00 $	30	3 600,00 $	
Scout 25m	4 750,00 $	10	47 500,00 $	

Total (CAD) 111 139,00 $

Droits et taxes en sus.

Termes de paiement: 40% avec le bon de commande (44455,60$) S.v.p. noter que la production ne débutera qu'une fois ce montant reçu.
60% avant l'expédition, aucune expédition de matériel tant que ce montant n'aura été reçu par AAT (66683,40$)

FOB Gaspé, Canada

S.v.p noter que précédant l'expédition, le paiement doit être fait par virement bancaire ou chèque certifié pour un relâchement im-médiat du matériel. Autrement, un délai additionnel de 10 jours ouvrables sera ajouté pour une confirmation de la validité du paiement.

Soumission valide pour 30 jours à partir de la date de la soumission.

Si nous recevons votre commande et premier paiement immédiatement, le produit quittera l'usine dans 5 semaines. Si les conditions sont rencontrées plus tard, le délai de livraison sera basé sur la charge courante de travail et sera confirmée lorsque les conditions qui précèdent sont complètement remplies.

Nous voudrions attirer votre attention sur l'exceptionnel degré de glace que peut supporter la Scout 25. Le degré de tenu à la glace de la Scout 25 est le plus haut de sa catégorie. Notez que nous pouvons inclure à cette soumission un adapteur pour une gin pole d'un diamètre de 8'' et d'une hauteur de 46'8'' de tierce compagnie, pour l'érection d'une tour de la série Scout de AAT.

Notez s'il vous plaît que le règlement de la navigation aérienne peut exiger un système de marquage et un éclairage. Ces options ne sont pas incluses dans cette soumission. Si elles étaient requises, s.v.p nous en informer et la soumission sera révisée. Selon notre expérience, nous recommandons fortement le marquage colorée puisqu'en Amerique du Nord il est souvent exigé et s'il n'était pas inclus au moment de la commande mais demandé par après, des délais additionnels pour l'envoie et frais additionnels pour la manipulation du matériel déjà emballe, pourraient être demandé.

Il est de la responsabilité du client de vérifier que les spécifications techniques du marquage et de la balise lumineuse fournis par AAT Inc. satisfassent les exigences de la réglementation aérienne du pays d'installation. Il est de la responsabilité du client de s'assurer que les données de vent et de glace existantes sur le site d'installation proposé, rencontrent les spécifications de la garantie limitée des produits de AAT.

Les ancrages fournis avec la tour sont de type « deadman » qui nécessitent un creusage

Un bon de commande de tour, pour être valide, doit être accompagné d'un document de garantie initialisé

Veuillez s.v.p. noter que l'ensemble de base comprend des anémomètres calibrés seulement

Notez s'il vous plaît qu'une gin pole, un treuil et d'autres équipements sont nécessaires pour ériger la tour. La gin pole, le treuil et les autres équipements ne font pas partie de cette proposition. Cependant, ils peuvent être ajouté à cette soumission comme une révision si exigé.

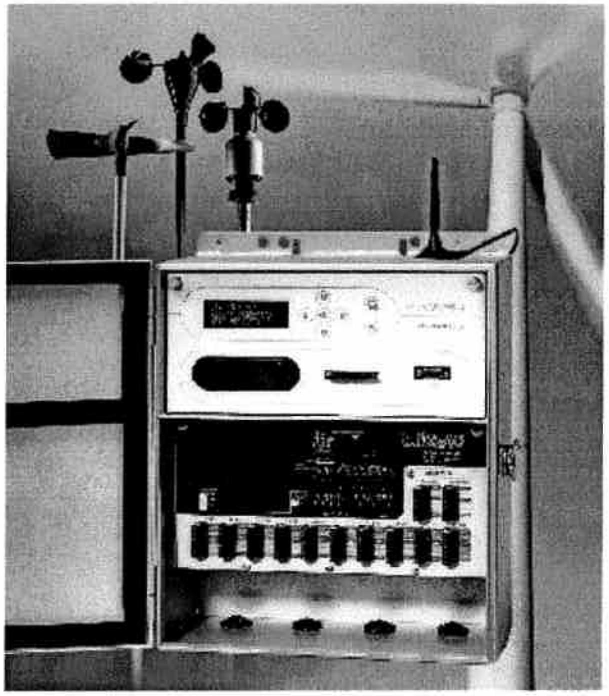
Notez s'il vous plaît qu'un treuil de capacité de 3200kg (pour la tour de 67 mètres ou moins) ou 6000kg (pour la tour de 80 mètres) avec une génératrice sont nécessaires pour l'installation et que ces articles ne sont pas inclus dans cette soumission.

Cette soumission n'inclut pas d'installation. AAT recommande fortement d'utiliser les services d'installateurs certifiés par AAT. Sur demande, AAT peut fournir une liste d'installateurs certifiés. Notez qu'il est possible de recevoir une formation en cours d'installation donnée par une compagnie spécialisée indépendante, qui est autorisée par AAT pour fournir une telle formation.

Tous les permis requis pour l'installation de tour sont de la responsabilité du client.

Client: ________________________ ***Manufacturier:*** ________________________

NOMAD 2 Data Logger for Wind Resource Assessment



The NOMAD 2 data logger offers advanced functionality and simplified installation while reducing system costs. With its advanced low-power circuitry, real-time operating system, and Windows™-compatible Compact Flash Cards, NOMAD 2 collects and secures the data you need.

Field Friendly

We know field visits have to be made in the cold, wind, and snow. NOMAD 2's vacuum fluorescent display (VFD) option gives a clear bright readout in temperatures down to -40°C and in full sunshine. The LED "heartbeat" provides assurance of normal operation independent of the display. The breakthrough integrated shelter box design uses innovative mini-rack mounting for power and communications components, so installations are easy to maintain. Field-proven lightning protection circuitry is built in, reducing the number of connections to wire. Larger, color-coded cage-clamp terminals make wiring faster and easier, even with gloves on. A built-in serial port lets you use NOMAD Desktop on site. No laptop? NOMAD 2's easy-to-use front panel and menuing system tells you everything you need to know. Reprogram the logger in seconds by uploading a configuration from your Compact Flash card.

Smart Power Management

NOMAD 2 will run on two standard 9V alkaline batteries for six months. If that isn't enough, add internal 12V batteries to run longer, even with your preferred transducers and remote communications gear. NOMAD 2 manages transducer power and sensor excitation to get the most out of whatever batteries you use. Add a solar package for perpetual operation. A built-in relay provides control for your needs, including sensor heating for icing conditions.

More Sensor Inputs

Connect up to 12 anemometers or other frequency or state devices to the NOMAD 2, including rain gauges, energy meters, and relays. Another 8 analog inputs connect directly to wind vanes, thermistors, and transducers measuring air pressure, electric power, sound level, or anything else that concerns you at your wind site. Get remarkable ±0.02% accuracy on counter inputs and ±0.2% accuracy on analog inputs. Connect most transducers and sensors with no need for extra modules.

Get Your Data Your Way

NOMAD 2 makes it easier than ever to get your data. Whether your connection is GSM, CDMA, AMPS, satellite, or landline, NOMAD 2 will answer your call and send you e-mail. Robust Compact Flash cards provide solid-state storage and can be read by any PC using off-the-shelf readers. NOMAD 2 comes with NOMAD Desktop™ software to check in on your logger and see real time values with the Zoom feature. Refine study parameters by uploading a new configuration to NOMAD 2 remotely - NOMAD Desktop's advanced database system will keep all your data organized and labeled.

Weatherproof

The NOMAD 2 data logger is designed to withstand the harshest of climates in its lockable steel shelter box. The wide-temperature display, batteries, and data cards allow the data logger to operate fully from -40° to 185°F (-40° to 85°C).

From Second Wind

Second Wind has over 20 years experience making equipment for wind prospectors. From the award winning AL-2000 data logger to the trend setting NOMAD data logger, Second Wind products have a track record of reliability and versatility. NOMAD 2 draws on Second Wind's experience at wind prospecting sites from Antarctica to Sub-Saharan Africa. NOMAD Desktop software brings the power and flexibility of Second Wind's Advanced Distributed Monitoring System (ADMS) for windfarms to your desktop, providing powerful analytical tools previously unavailable without customer programming. Count on Second Wind to make it easy for you.

SECONDWIND

Second Wind Inc. 366 Summer Street, Somerville MA 02144 USA
Tel. 617 776-8520 • Fax 617 776-0391 • www.secondwind.com

NOMAD 2 Specifications

Sensor Inputs

12 Counter Inputs:
- Configurable for AC & pulse anemometers, other frequency-output devices, and high/low digital or relay state signaling
- Frequency range DC to 2 kHz
- High display resolution with low frequency anemometers
- Input high/low threshold configurable for 0V or 3V
- Configurable filtering for low frequency devices
- 1-second count integration, ±0.02% accuracy

8 Analog Inputs:
- Configurable range of 0 to 2.5V or 5V
- 12-bit analog to digital conversion
- 1-second sampling, ±0.2% accuracy
- Direct interface to potentiometer wind vanes, 10k thermistors, and analog-output transducers

Fault Detection:
- Feedback input from 2.5V+ excitation output for wiring and device fault detection

Internal Temperature:
- 1-second sampling, ±2°C accuracy

Power Supplies:
- Measurement of two 9V batteries and 12V power
- 1-second sampling, ±0.1V accuracy

Outputs

2.5V+ Excitation:
- 2.5V+ smart-switched excitation distributed to all input terminal blocks for energy-conserving measurement of potentiometers and thermistors
- Calibrated to ±5mV, 25 ppm/°C, 250 mA max

12V Transducer Power:
- 12V+ smart-switched transducer power output distributed to all input terminal blocks for energy-conserving operation of electronic transducers
- 1 Amp maximum

12V Modem Power:
- 12V+ configurable switched modem power output for energy-conserving operation of cellular & other modems
- 1 Amp maximum

Relay Output:
- For de-icing or other control applications
- SPST dry contact, 1 Amp maximum, AC or DC
- Modbus-controlled

Power Supply

9 Volt Batteries:
- 2 parallel standard 9V batteries in sliding receptacles
- Up to 6 months operation with alkaline, up to one year with lithium (-40°C) batteries that have no shipping restrictions

12 Volt Power:
- 12V (10-18V DC) input for internal primary or rechargeable batteries, external DC power supply, or regulated solar panel
- Two-screw removable internal mounting for lead-acid batteries for higher power transducer, controls, and communication gear, standard sizes up to 20 AH, extreme environment sizes up to 8 AH

Solar:
- Optional on-board solar charging regulator/controller

Serial Ports

- 3 independent RS232C serial ports, up to 115 kBaud

Local Port:
- Direct straight-cable connection to laptop or PC
- Standard pinout DB9, DCE

Remote Port:
- Connects to modem, radio, or asynch network adapter
- Auto-wakeup Rx input
- Internally connected for SWI-supplied modem options
- Field-wireable terminals for customer-installed devices

Device Port:
- Connects to and logs from communicating transducers including multifunction Phaser* power transducers & ultrasonic anemometers
- Pollable Modbus RTU for SCADA and other general applications

ESD Protection

- All inputs, outputs, and serial port signaling transient and fault protected
- No additional lightning protection needed

User Interface

Local Display:
- 4 x 20 alphanumeric character display, LCD or VFD
- Configurable smart-switched power
- Automatic temperature-compensating LCD contrast

Keypad:
- 7-key sealed membrane keypad

Remote Interface:
- Full display, configuration, data transfer, & firmware upgradability by local port or modem connection to any PC via NOMAD Desktop™

Status Light:
- Heartbeat LED indicates operational status independent of display

Input and Data Processing

Wind Speed:
- Slope & offset scaling, auto-zeroing for counter inputs

Wind Direction:
- Modulo 360° and true vector processing
- Deadband location correction

Temperature:
- Thermistor linearization to device accuracy (±0.1°C)

Math Functions:
- Average, standard deviation, maximum, time of maximum, minimum, time of minimum, total, cycles, sample value

Recording Intervals:
- 1 minute, 10 minutes, hourly, or daily in any combination for all inputs and math functions

Data Storage

Media:
- Industry/consumer standard Compact Flash, up to 256MB
- Read/write-able by any notebook or desktop PC via PCMCIA adapter or any USB-type Compact Flash adapter
- Full -40° to 85°C operation rated devices available

Formats:
- Card directory & file formats are fully Windows™ compatible
- Any FAT (PC) formatted Compact Flash card fully usable
- Data written to daily files in named monthly subdirectories
- Each datum in standard IEEE floating point format, indexed for positive database ID independent of file name/location
- Each datum time-stamped in Universal Time (UT/GMT), configurable for time zone & daylight savings offsets

Transfer:
- Files transferable by card removal, local serial connection, remote dial-up connection, or as e-mail attachments

Physical

Operating Temp:
- -40° to 85°C all specifications (Vacuum Fluorescent Display)

LCD Temperature:
- LCD operates from -20° to 70°C, storage -30° to 80°C

Internal RT Clock:
- ±1 minute/month accuracy, internet time-server adjustable
- Backed up by socketed 2032 Lithium coin cell (10 year life)

Wire & Cabling:
- 12 six-screw, 0.2" (5mm) cage clamp style terminal blocks
- Signal, ground, excitation, switched & unswitched 12V power distributed to each of 8 terminal blocks
- Standard SMA-F bulkhead connector for external antennas
- Four 3/4" npt/pg21 knockouts for cable & conduit installation

Enclosure:
- Integrated waterproof instrument enclosure, wire and cable junction box, and lockable rain shed
- Upper section NEMA4/IP66 (watertight), lower section NEMA3R (rain tight) or NEMA4 with cable glands
- 16 ga. steel, 14 ga. mounting flanges, TGIC powdercoated
- 14 x 12 x 5.5 inches (350 x 300 x 140mm), 20 lbs. (9 kg)
- Mini-rack mounting for internal modem options
- Swing-out panels for modem and 12V battery access
- Surface, truss-tower, or tube-tower mounting
- Single no-tools padlockable hasp closure

Available Options

- Vacuum Fluorescent Display
- GSM/GPRS, CDMA, and AMPS cellular modems
- Satellite modem (Iridium)
- Landline telephone (POTS) modem
- Integrated solar charging systems, including charge regulator, panel, mounting brackets, and lead-acid batteries

Garantie limitée

La Méga 80, Méga 80HD comme la série Scout sont garanties pour une période d'une année à compter de leur livraison contre tout bris structurel lorsque la tour est soumise aux conditions pour lesquelles elles sont conçues.

Toute tour AAT subissant un bris structurel dans la limite de conception sera réparée ou remplacée sans frais, FAB Gaspé lorsque le bris survient à l'intérieur d'une année débutant à la date de livraison. Le remplacement ou la réparation peut s'appliquer aux sections de la tour, à la base, au bras de croix, aux collets de haubans et/ou aux anti-torques (si applicable).

Les haubans sont utilisés en lots et testés pour une limite de rupture conforme. Cette garantie couvre les dommages causés par la défaillance d'un ou plusieurs haubans seulement si un test indépendant, à la charge du client, sur plusieurs portions du hauban confirme que la limite de rupture de ce dernier est à 90% ou inférieure à la limite prescrite. Cette garantie ne couvre pas les dommages causés par la défaillance d'un ou plusieurs ancrages, d'un défaut de fondation, du vandalisme ou de la chute d'arbres ou autre impact sur la tour ou ses haubans. Tout le matériel doit-être installé selon les recommandations de AAT.

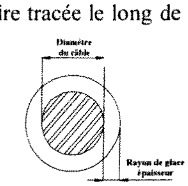
Cette garantie ne couvre aucun dommage résultant d'un bris structurel autre que celui spécifiquement décrit ci-dessus. Tout équipement, instrument, appareil, qu'il soit de fourniture AAT ou non, qui subirait un dommage résultant d'un bris structurel n'est pas couvert par la garantie. Tout bris ou dommage aux véhicules, bâtiments ou autres n'est pas couvert par cette garantie si il survient dans la zone d'exclusion prescrite soit un rayon de une fois et demi (1,5) la hauteur de la tour ayant son centre à la base de la tour. Cette garantie ne couvre pas la récupération de la tour sur le terrain, ni sa réinstallation.

Pour tout dommage et pour que la garantie s'applique, le client doit fournir une preuve acceptable par AAT, que la tour n'a pas subi de conditions supérieures à ses paramètres de conception. Tout bris structurel doit-être rapporté dans le délai prescrit au paragraphe suivant par courriel à info@aat-solutions.com. Le client devra fournir, à la demande de AAT et sans frais, photos, données de vent et évaluation météorologique d'une source entièrement indépendante du site du bris ou d'un site environnant accepté par AAT.

Aucune réclamation de garantie ne sera acceptée si AAT est informé après 36 heures suivant le bris de la tour, si les conditions de glace sont susceptibles d'avoir causées ce bris ou un délai de 48 heures suivant la découverte du bris dans les autres cas. Une installation inadéquate de la tour, toute anomalie au niveau des ancrages ou de la fondation annule cette garantie. Pour que la garantie s'applique, le client devra faire parvenir dans un délai de 72 heures suivant la levée de la tour, un porte-folio complet de la tour indiquant la date et l'heure de la levée, l'étude géotechnique du sol, le nom de l'installateur, une photo de chaque ancrage, une série de photos de la tour en provenance des 4 points cardinaux à une distance suffisante pour voir la tour en entier et une deuxième série prise au bas de la tour en pointant vers le sommet de la tour de ces même points cardinaux. Les photos devront être de 3 Méga pixels ou plus.

AAT peut également, au frais du client, exiger que la tour soit expédiée à ses bureaux pour inspection avant de statuer sur la recevabilité de la garantie. Le refus de se conformer à cette requête annule automatiquement la garantie. Dans l'éventualité ou l'analyse conclurait à la non garantie de la tour, la ré-expédition au client ou les frais de disposition de la tour seront assumés par le client. Dans l'éventualité ou l'analyse conclurait à la garantie de la tour, les frais d'expédition de la tour endommagée et/ou de disposition seront aux frais d'AAT.

Conditions de conception des tours AAT:
Série MEGA:
Vitesse de vent maximale (rafale): 150km/h (Mega 80) ou 162km/h (Mega 80HD) en l'absence de toute trace de glace ou de givre
Vitesse de vent maximale (rafale): 120km/h lors de présence même négligeable de glace ou de givre
Accumulation maximale de glace: Aucun chargement, même local, de plus de 8.5mm (0.33 pouce) (Mega 80) ou 15 mm (0.6 pouce) (Mega 80HD) de rayon de glace*.
Inclinaison maximale par rapport à la verticale: Inférieure à 50% du diamètre de la tour.
Droitesse de la tour: Aucun écart supérieur à 25% du diamètre de la tour à partir de n'importe quel ligne verticale imaginaire tracée le long de la tour.



Série SCOUT:
Vitesse de vent maximale (rafale): 180km/h en l'absence de toute trace de glace ou de givre
Vitesse de vent maximale (rafale): 150km/h lors de présence même négligeable de glace ou de givre
Accumulation maximale de glace: Aucun chargement, même local, de plus de 22.6 mm (0.9 pouce) de rayon de glace*.
Inclinaison maximale par rapport à la verticale: Inférieure à 50% du diamètre de la tour.
Droitesse de la tour: Aucun écart supérieur à 25% du diamètre de la tour à partir de n'importe quel ligne verticale imaginaire tracée le long de la tour.

* La glace est spécifiée tel que le rayon de glace avec une densité de 900 kg/m^3.

Init

PROWIND TOWER

206 Corte-Real
Gaspé, P.Q
G4x 6S2
Tel; (418)368-6990
Fax; (418)368-6501

date: April 07 2008

Approximate estimate for ten 25 meters.
Newfoundland island

- Installation cost 3500$/25meters (cost approximately for 10= 35000$)
- Travelling Hours; 40$/h par technicians
- Meals 60$/day/technician (3600$)
- Motel, gas, ferry, bacho: cost + 15% adm. fees
- Kilometers (truck+ trailer) 0,50$/km. (approximately 1500$)
- Anchors 55$/hr (for 10 towers approximately 1100$)

Total approximate of; 41,200.00$

The expenses will be charged at cost + 15% administration fees.

We ask for a down payment of 60% of the estimate before we start the job (24,720.00$).

In the event of weater conditions, independent of PRO WIND TOWERS'S control, that prevent the installation work to be performed, the lost time is charged to the client at rate of 55$ per hour per employee for a maximum of 8 hours per day.

Sincerely yours

Raymond Fournier

For any more information you can contact Raymond Fournier at; (418)368-6990 or (418) 360-7301, Fax: 1(418)368-6501 E-mail: raymondfournier007@hotmail.com

Estimate accepted

Signature	Name	Date