

Nalcor Energy Response to Grant Thornton Question 6.2**23 May 2018****Question:**

In reference to the Lower Churchill Project Phase 1 Decision Gate 3 Support Package, please confirm the design criterion for the overland HVDC Transmission line, (i.e., return period).

Response:

The design criteria for the Labrador-Island Transmission Link (LITL) are discussed in detail in the response to Request for Information NP-NLH-004, "*Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System*", attached and also found at:

<http://www.pub.nl.ca/applications/IslandInterconnectedSystem/files/rfi/NP-NLH-004.pdf>

The design criteria for the LITL were developed following the principles outlined in CAN/CSA 22.3 No.60826. They were developed giving consideration to reference data from the standard, operational experience and identified operational risks, as well as model data for unique conditions (rime ice) not incorporated in the standard. These design criteria are as presented in Exhibit 97 (Amended) for the Muskrat Falls PUB review, attached, and also found at NAL0074240 and:

<http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit97-AppendixA-Rev1.pdf>

The as-designed structures were evaluated against the following loadings:

- a) CSA 150-year ice loadings for the line section off the Avalon Peninsula.
- b) CSA 500-year ice loadings for the route on the Avalon Peninsula.
- c) CSA 150-year wind loadings for the line section off the Avalon Peninsula.
- d) CSA 500-year wind loadings for the line section on the Avalon Peninsula.

No structure was loaded beyond 100% of its design structural capacity in any of these scenarios.

The design criteria for rime ice accretion are beyond 500-year return period loads predicted by rime ice accretion models developed by Landsvirken Power, and the design criteria for wind are beyond 500-year CSA return period winds in rime zones.

The as-designed structures were evaluated against proposed combined wind and ice criteria in IEC Standard 60826 in the following conditions:

- a) Extreme wind (72% or 85% of reference wind as applicable for 150-year and 500-year zones respectively) combined with 40% of reference ice load; and,
- b) Maximum ice (150 or 500-year loads as applicable for 150-year and 500-year zones respectively) combined with 40% of reference wind speed.

No structure was loaded beyond 100% of its as-designed structural capability in any two of these scenarios.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 1 of 57

1 Q. Reference: Public Utilities Board Muskrat Falls Review, *Manitoba Hydro*
2 *International: Report on Two Generation Expansion Alternatives for the Island*
3 *Interconnected Electrical System*, January 2012, page 11.

4 *“Design Loading Criteria – Nalcor has selected a 1:50-year*
5 *reliability return period (basis for design loading criteria)*
6 *for the HVdc transmission line, which is inconsistent with*
7 *the recommended 1:500-year reliability return period*
8 *outlined in the International Standard CEI/IEC 60826:2003*
9 *with Canadian deviations in CSA Standard CAN/CSA-C22.3*
10 *No. 60826:06, for this class of transmission line without an*
11 *alternate supply.”*

12 Please confirm the return period of climatic loads used in the design of the Labrador
13 – Island HVdc Link and provide all the detailed ice and wind weather cases as well
14 as suspension tower load cases, including the mathematical calculations supporting
15 them.

16
17 A. In order to provide context regarding the quotation in the question, the Board’s
18 review of Muskrat Falls in 2011 was undertaken prior to the completion of detailed
19 engineering for the Labrador Island Transmission Link (LITL) and considered
20 feasibility study inputs rather than completed engineering. As well, the availability
21 of the Maritime Link as a support for an alternate supply source was also not a
22 consideration as part of the review. Since then, the design criteria for the LITL have
23 been finalized and its design has been completed.

24
25 As a result, the statement that "Nalcor has selected a 1:50-year reliability return
26 period" is not reflective of the final climatic loading design criteria for the LITL, the

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 2 of 57

1 results of a comparison of LITL design loads to CSA reference loads, nor its
2 as-designed capability.

3

4 This response provides clarification of the design criteria, and also clarification of
5 the capability of the line after the completion of the design process.

6

7 The following conclusions are supported in this response:

8 • The design criteria for the LITL were developed following the principles
9 outlined in CAN/CSA 22.3 No. 60826. They were developed giving
10 consideration to reference data from the standard, operational experience
11 and identified operational risks, as well as model\data for unique conditions
12 (rime ice) not incorporated in the standard.

13 • In addition to the design criteria established for the LITL, the as-designed
14 structures were evaluated against the following loadings:
15 a) CSA 150-year ice loadings for the line section off the Avalon Peninsula.
16 b) CSA 500-year ice loadings for the route on the Avalon Peninsula.
17 c) CSA 150-year wind loadings for the line section off the Avalon Peninsula.
18 d) CSA 500-year wind loadings for the line section on the Avalon Peninsula.
19 No structure was loaded beyond 100% of its as-designed structural capacity
20 in any of these scenarios.

21 • The design criteria for rime ice accretion are beyond 500-year return period
22 loads predicted by rime ice accretion models developed by Landsvirkjun
23 Power (LVP), and the design criteria for wind are beyond 500-year CSA
24 return period winds in rime zones.

25 • The as-designed structures were evaluated against proposed combined wind
26 and ice criteria in International Electrotechnical Commission (IEC) Standard
27 60826 in the following conditions:

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 3 of 57

- 1 a) Extreme wind (72% or 85% of reference wind as applicable for 150-
2 year and 500-year zones respectively) combined with 40% of
3 reference ice load; and
4 b) Maximum ice (150 or 500-year rime or glaze loads as applicable for
5 150-year and 500-year zones respectively) combined with 40% of
6 reference wind speed.

7
8 No structure was loaded beyond 100% of its as-designed structural capacity
9 in any of these scenarios.

10

11 Further details are provided in this response below supporting the conclusion that
12 LITL has been designed in accordance with applicable standards and that it meets
13 climatic loading conditions commensurate with its important role in the Island
14 Interconnected System.

15

16 The climatic loading criteria for the LITL were established using the principles
17 outlined in CSA standard CAN/CSA 22.3 No. 60826. Guidance on reliability levels is
18 provided for in the IEC Standard 60826, which is incorporated into CAN/CSA 22.3
19 No. 60826. Guidance to designers is provided in Section A.1.2.5 of the IEC standard,
20 as presented below:

21

22 A.1.2.5 Selection of reliability levels

23 Transmission lines can be designed for different reliability levels (or classes)
24 depending on local requirements and the line duties within a supply network.

25

26 Designers can choose their reliability levels either by calibration with existing lines
27 that have had a long history of satisfactory performance or by optimisation methods
28 found in technical literature.

29

30 In all cases, lines should at least meet the requirements of a reliability level
31 characterized by a return period of loads of 50 years (level 1).
32

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 4 of 57

1 An increase in reliability above this level could be justified for more important lines of
2 the network as indicated by the following guidelines:

- 3
- 4 • It is suggested to use a reliability level characterised by return periods of 150
5 years for lines above 230 kV. The same is suggested for lines below 230 kV
6 which constitute the principal or perhaps the only source of supply to a particular
7 electric load (level 2).
8
 - 9 • Finally, it is suggested to use a reliability level characterised by return periods of
10 500 years for lines, mainly above 230 kV which constitute the principal or
11 perhaps the only source of supply to a particular electric load. Their failure would
12 have serious consequences to the power supply.

13 The applications of the reliability for overhead lines, including corresponding voltage
14 levels, may be set differently in individual countries depending on the structure of the
15 grid and the consequences of line failures. The impacts on other infrastructure
16 installations such as railroads and motorways should be considered as well.
17

18 When establishing national and regional standards or specifications, decisions on
19 the reliability level should be made taking into consideration also the experience with
20 existing lines.
21

22 The standard indicates a minimum reliability level characterized by a 50-year return
23 period, and also identifies circumstances under which a higher reliability level
24 characterized by longer return periods could be warranted. This standard takes the
25 form of a recommended practice.
26

27 The line design for the LITL was undertaken in accordance with the principles
28 outlined in CAN/CSA 22.3 No. 60826. Multiple sources of information were used to
29 provide wind, ice, and combined loading along the transmission line route. This is
30 in accordance with Section 4.1 of the standard:
31

32 *"The climatic data provided in this Standard may be augmented by*
33 *reliable regional or local data where available."*
34

35 The multiple sources of data used to establish load conditions for the LITL
36 are listed below:

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 5 of 57

- 1 a) Reference wind and ice loading as provided in the CSA standard;
- 2 b) A study undertaken by Kathleen Jones of the Cold Regions Research and
- 3 Engineering Laboratory;¹
- 4 c) Hydro's applicable nearly 50-year operating history along the transmission
- 5 line route;² and
- 6 d) A study undertaken by Landsvirkjun Power which evaluated rime (or in-
- 7 cloud) ice loadings, which are a design consideration along the LITL's route,
- 8 but are not addressed by CAN/CSA 22.3 No. 60826.³
- 9

10 Some design aspects warranted special engineering consideration:

- 11 a) Hydro's operating experience on the Avalon Peninsula and previous icing
- 12 events resulted in increased design loading;⁴
- 13 b) A conservative approach was taken to selection of rime ice criteria in locales
- 14 where rime accretion is prevalent, as discussed later in this response; and
- 15 c) Routing decisions were taken to avoid high country and exposed areas
- 16 throughout the route.
- 17

18 These approaches were all taken to improve the reliability of the LITL and to

19 mitigate operating risk.

20

21 The standard also recognizes a level of variability in performance, and IEC 60826

22 discusses reliability levels and associated failure probabilities in Table A.2 of the

23 Annex to the standard:

¹ <http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit96.pdf>.

² Particularly on Newfoundland's Avalon Peninsula.

³ <http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit95.pdf>.

⁴ Ultimately, the 2010 version of the CSA standard further increased loadings.

Island Interconnected System Supply Issues and Power Outages

Table A.2 – Relationship between reliability levels and return periods of limit loads

Return period of limit loads, T		50	150	500
Yearly minimum reliability	P_{s1}	0,98 to 0,99	0,993 to 0,997	0,998 to 0,999
Yearly failure probability	P_{f1}	0,02 to 0,01	0,0067 to 0,0033	0,002 to 0,001
Reliability during 50 years life cycle	P_{s50}	0,36 to 0,61	0,71 to 0,86	0,90 to 0,95
Theoretical probability of failure during 50 years life cycle	P_{f50}	0,64 to 0,39	0,29 to 0,14	0,10 to 0,05

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

In considering the probability of a failure, the Annex suggests that theoretically, there is a 39% to 64% chance that a line failure will occur over the 50-year design life of the line with a 50-year return period, a 14% to 29% probability with a 150-year return period, and a 5% to 10% probability at a 500-year return period. On an annual basis, the probability of a failure is 1% to 2% with a 50-year return period, 0.3% to 0.7% with a 150-year return period, and a 0.1% to 0.2% probability with a 500-year return period.

In the context of the Island Interconnected System, the LITL will be routed adjacent to the existing 230 kV corridor from Sunnyside to Soldier’s Pond. Routing alternatives are limited because of the topography of the Avalon and limitations imposed by existing developments in the most populated area of the Province. This constraint warrants comparing the line design to a 500-year return period in this important corridor.

West of Sunnyside, the LITL takes a route that is independent of the 230 kV corridor from Bay d’Espoir. As a result, the two major transmission systems serving the Avalon Peninsula are geographically separated from each other. Given the separation and the independent generation available on each system, a 150-year return period is appropriate for the remainder of the LITL route.

Island Interconnected System Supply Issues and Power Outages

1 Consequently, the structural capability of the LITL will be compared to CSA 500-year
 2 return period loads on the Avalon Peninsula and for CSA 150-year return periods on
 3 the remainder of the LITL route.

4
 5 Given the varied conditions through which the LITL is routed, 11 different
 6 meteorological design zones were identified to address varying conditions that exist
 7 along the line’s 1,100 km length. The overall transmission line route and
 8 corresponding meteorological design zones for the Labrador and Island portions of
 9 the LITL are shown in Figures 1, 2, and 3.

10



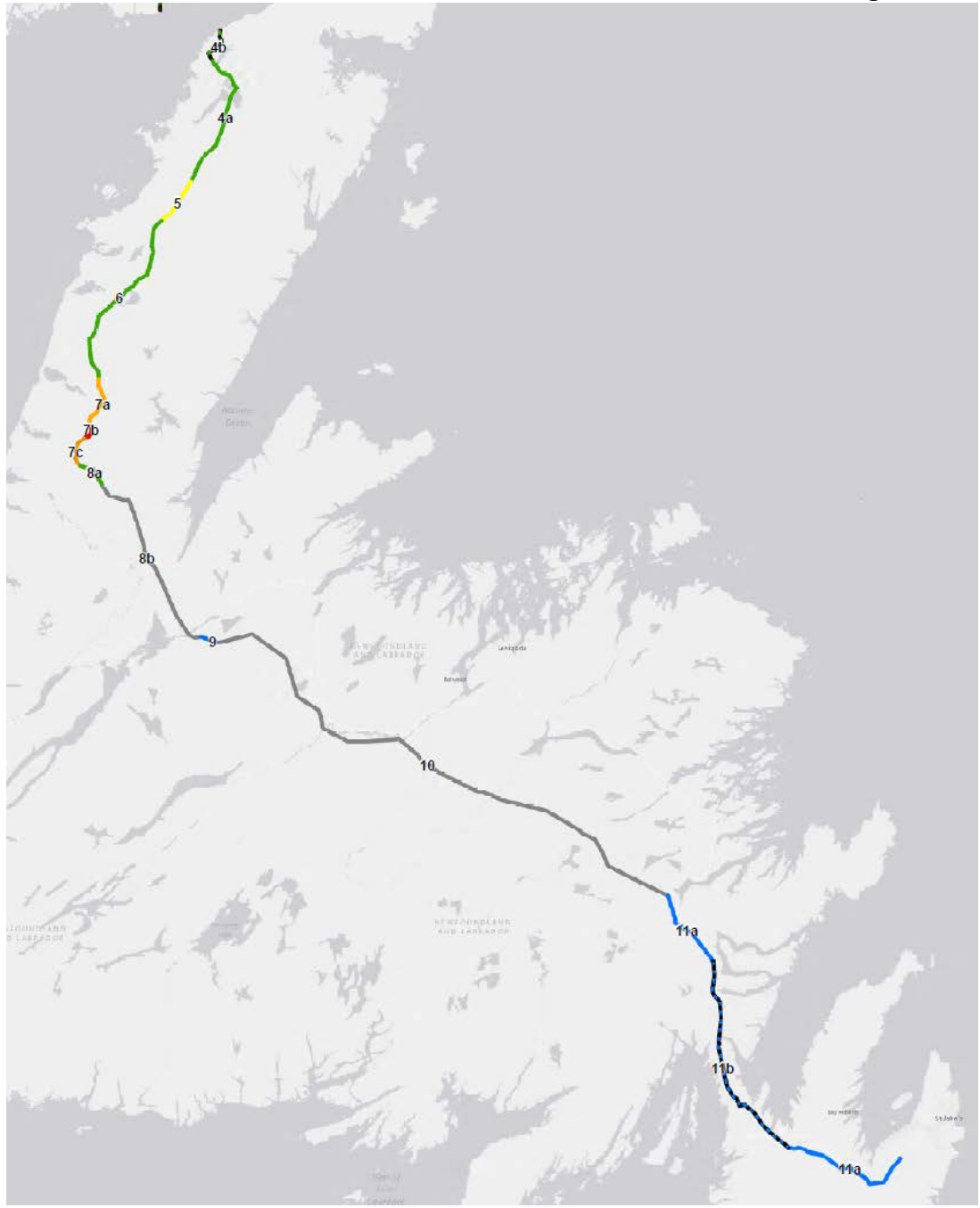
11

Figure 1 – LITL Transmission Route



1

Figure 2 – LITL Transmission Route and Meteorological Zones - Labrador



1

Figure 3 – LITL Route and Meteorological Zones - Newfoundland

Island Interconnected System Supply Issues and Power Outages

1 These 11 zones are an extension of the approach used in the design of the original
 2 Bay d’Espoir 230 kV system, where "normal" and "ice" design zones were
 3 established for the Island.⁵ The following categories are used for LITL:
 4

Description	Zone
“Normal” conditions found in the interior of Labrador and Newfoundland	1,8b, 10
Light rime accretion areas	2a, 2c, 5, 7a, 7c
Heavy rime accretion areas	2b, 7b
Coastal areas	3, 4, 6, 8a
Highlands/Avalon Peninsula	9, 11

5
 6 Design criteria for ice (glaze and rime), wind, and combined wind/ice loading are:
 7
 8

Table 1: LITL Climatic Design Criteria

Loading Zone	Ice	Type	Wind	Combined		
				Ice	Type	Wind
1	50 mm	Glaze	105 km/hr	25 mm	Glaze	60 km/hr
2a	115 mm	Rime	135 km/hr	60 mm	Rime	95 km/hr
2b	135 mm	Rime	135 km/hr	70 mm	Rime	95 km/hr
2c	115 mm	Rime	135 km/hr	60 mm	Rime	95 km/hr
3	50 mm	Glaze	120 km/hr	25 mm	Glaze	60 km/hr
4	50 mm	Glaze	120 km/hr	25 mm	Glaze	60 km/hr
5	115 mm	Rime	150 km/hr	60 mm	Rime	105 km/hr
6	50 mm	Glaze	120 km/hr	25 mm	Glaze	60 km/hr
7a	115 mm	Rime	180 km/hr	60 mm	Rime	125 km/hr
7b	135 mm	Rime	180 km/hr	70 mm	Rime	125 km/hr
7c	115 mm	Rime	180 km/hr	60 mm	Rime	125 km/hr
8a	50 mm	Glaze	120 km/hr	25 mm	Glaze	60 km/hr
8b	50 mm	Glaze	105 km/hr	25 mm	Glaze	60 km/hr
9	75 mm	Glaze	130 km/hr	45 mm	Glaze	60 km/hr
10	50 mm	Glaze	105 km/hr	25 mm	Glaze	60 km/hr
11	75 mm	Glaze	130 km/hr	45 mm	Glaze	60 km/hr

⁵ <http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit85.pdf>, page 35.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 11 of 57

1 These design criteria, together with topography and routing constraints, including
2 land features, water bodies, structures, and roads, were then used as the basis for
3 structure location selection. The development of each design criterion is discussed
4 in the following sections.

5

6 It should be understood that the final design for the LITL has greater structural
7 capability than the design criteria alone might indicate. This is the result of the
8 design constraints other than climatic loading ruling the line design by limiting span
9 lengths and subsequently reducing the structure loading. It is therefore important
10 to understand that the 'as-designed' capability of the line must be assessed in order
11 to fully understand its structural capability; these assessments are completed for
12 ice, wind, and combined wind and ice loads in this response.

13

14 Evaluation of LITL Against CSA Climatic Loadings

15

16 The following sections of this response compare the design criteria for the LITL as
17 well as its as-designed capability against the applicable meteorological loadings
18 presented in CAN/CSA 22.3 No. 60826.

19

20 Four criteria are considered:

- 21 • Glaze ice accretion, applicable in Zones 1, 3, 4, 6, 8, 9, 10, and 11;
- 22 • Rime ice accretion, applicable in Zones 2, 5, and 7;
- 23 • Wind loading, applicable to the entire route; and
- 24 • Combined ice (glaze or rime ice, as applicable) and wind.

1 Glaze Ice

2 As will be seen in this section, the as-designed LITL structures will be capable of
3 withstanding 150-year CSA return period glaze ice loadings for the portion of the
4 LITL off the Avalon Peninsula and 500-year CSA return period glaze loadings for the
5 portion on the Avalon Peninsula.⁶ Manitoba Hydro International's (MHI's)
6 conclusions in their DG3 report are also reviewed in this section.

7

8 CAN/CSA 22.3 No. 60826 provides a methodology for translating *reference* glaze ice
9 loadings – predictions made for a 10-metre reference height and for a 50-year
10 return period – to structure loadings for a desired return period. Factors are
11 provided in the standard to adjust for tower/conductor height,⁷ return period⁸, and
12 to adjust for uncertainty from the limited number of observing stations in a given
13 area.⁹ The steps are followed below to establish CSA structure loadings.

14

15 It should be noted that when the engineering design criteria for the LITL were
16 developed, the 2006 version of the CSA standard (CAN/CSA No. 22.3 60826:2006)
17 was applicable. This was superseded by the 2010 version during LITL design.

18

19 As a first step, the reference loadings from the standard were considered. In the
20 following table, reference loadings from the standard are presented for each zone
21 along with the corresponding 50-year structure loads, calculated after the
22 applicable adjustments.¹⁰

⁶ Considering the 2010 edition of the CSA standard.

⁷ CAN/CSA 22.3 No. 60826:2010, Section 6.3.4.1.

⁸ CAN/CSA 22.3 No. 60826:2010, Table CA.2.

⁹ CAN/CSA 22.3 No. 60826:2010, Section 6.3.4.1.

¹⁰ In the 2006 version of the standard, the structure load is derived by multiplying the reference load by 1.5.

Island Interconnected System Supply Issues and Power Outages

Zone	Area	2006 CSA Reference	2006 CSA Structure (50 yr)
1	Inner Labrador	20 mm	30 mm
3	Labrador Coast	25 mm	38 mm
4	Northern Pen. Coast	25 mm	38 mm
6	Northern Peninsula	25 mm	38 mm
8a	Central-West NF	25 mm	38 mm
8b	Central-West NF	25 mm	38 mm
9	Birchy Narrows	25 mm	38 mm
10	Central-East NF	25 mm	38 mm
11	Eastern NF	40 mm	60 mm

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Although the standard permits calibration to existing lines with a long history of satisfactory performance,¹¹ (which is Hydro’s experience for significant portions of the LITL route) no reductions to the design loadings were considered in these areas.

Kathleen Jones of the Cold Regions Research and Engineering Laboratory, US Army Corp of Engineers, was engaged to provide an estimate of extreme loading values for Newfoundland and Labrador. Her report is available as Exhibit 96 of the Muskrat Falls review.¹² Her analysis predicted estimated loadings that are lower than those in the CSA standard, but no reductions to the design loadings were considered.

Table CA.2 of CAN/CSA No. 22.3 60826-06 provided factors to convert glaze ice loads from the 50-year reference to other desired return periods. The table is reproduced below and the factors presented in this table are used to convert 50-year loadings to 150 or 500-year loadings as applicable:

Return Period (years) ¹³	Factor
150	1.15
500	1.30

¹¹ IEC 60826, Section A.1.2.5.

¹² <http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit96.pdf>.

¹³ 2006 edition factors.

1 MHI compared the LITL design criteria to 2006 CSA criteria during its DG3 review,
 2 noting:

3
 4 “The climatic loadings for each line section are approximately
 5 equivalent to the climatic loadings calculated assuming Canadian
 6 Standards Association (CSA) 1:500-year return periods.”

7
 8 MHI prepared the following figure¹⁴ to illustrate this:

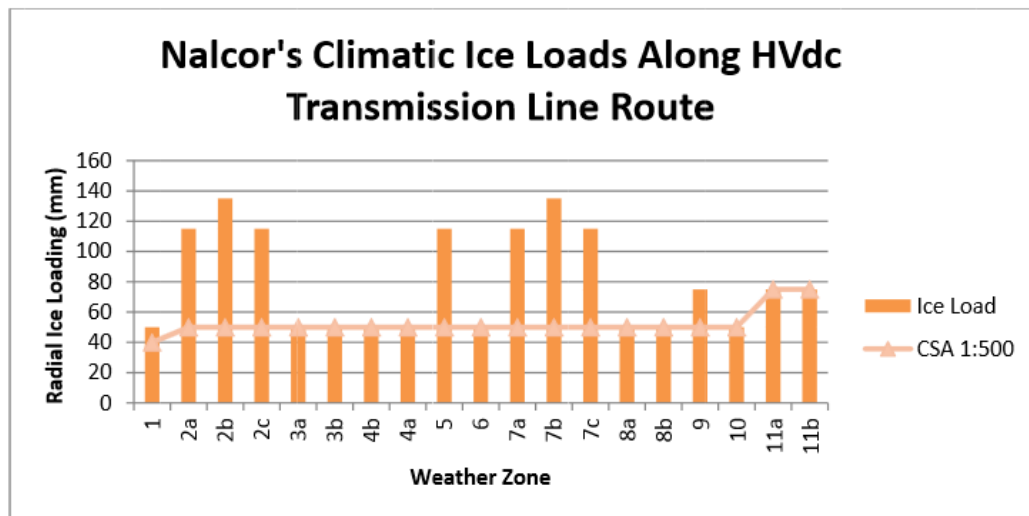


Figure 9: Climatic Ice Loads along the HVdc Transmission Line Route compared to the CSA Standard 1:500-year return period limit

9 **Figure 4 – Climatic Ice Loads from MHI DG3 Report**

10

11 MHI’s DG3 analysis indicated that the LCP design glaze ice loadings were equivalent
 12 to or greater than CSA 1:500-year return period loads as shown in the following
 13 table:

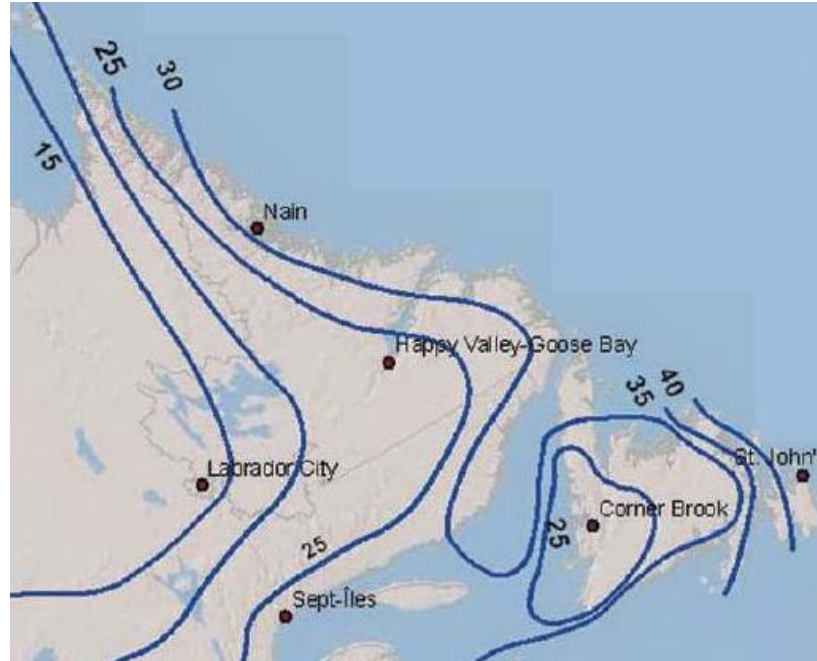
¹⁴ <http://muskratfalls.nalcorenergy.com/wp-content/uploads/2013/03/MHI-Review-October-2012.pdf>, Fig. 9.
<http://www.powerinourhands.ca/pdf/MHI.pdf>, page 47.

Island Interconnected System Supply Issues and Power Outages

Section	Area	Glaze Ice Design	CSA 2006 500-yr
1	Inner Labrador	50 mm	39 mm
3	Labrador Coast	50 mm	49 mm
4	Northern Pen. Coast	50 mm	49 mm
6	Northern Peninsula	50 mm	49 mm
8a	Central-West NF	50 mm	49 mm
8b	Central-West NF	50 mm	49 mm
9	Birchy Narrows	75 mm	49 mm
10	Central-East NF	50 mm	49 mm
11	Eastern NF	75 mm	78 mm ¹⁵

1
2
3
4
5
6

The 2006 version of the CSA standard was updated (CAN/CSA No. 22.3 60826:2010), and with the release of the 2010 version of the CSA standard, reference glaze ice loadings for various locations in Newfoundland and Labrador were increased. The 2010 reference glaze ice loads are presented below for Newfoundland and Labrador, as shown in the following extract from Figure CA.10 in the standard:¹⁶



7

Figure 5 – CSA Glaze Ice Loading Zones for NL

¹⁵ Approximately equivalent.

¹⁶ Contours represent reference ice in mm.

Island Interconnected System Supply Issues and Power Outages

1 The 2006 and 2010 CSA reference glaze ice loadings for each zone are shown below
 2 and higher resolution maps are provided in Appendix A of this response. Given the
 3 heavier loading on the Avalon Peninsula, Zone 11 (Eastern Newfoundland) was
 4 separated into sub-zones with the loading for each segment taken from Figure
 5 CA.10:¹⁷

6

Zone	Area	2006 CSA Reference	2010 CSA Reference
1	Inner Labrador	20 mm	25 mm
3	Labrador Coast	25 mm	30 mm
4	Northern Pen. Coast	25 mm	30 mm
6	Northern Peninsula	25 mm	25 mm
8a	Central-West NF	25 mm	25 mm
8b	Central-West NF	25 mm	25 mm
9	Birchy Narrows	25 mm	25 mm
10-1	Central-East NF	25 mm	25 mm
10-2	Eastern NF: Gander Lake to Port Blandford	25 mm	25 mm
11-1	Eastern NF : Port Blandford to Sunnyside	40 mm	32.5 mm
11-2	Eastern NF : Sunnyside to Whitbourne	40 mm	37.5 mm
11-3	Eastern NF: Whitbourne to Rod and Gun Club	40 mm	40 mm
11-4	Eastern NF: Rod and Gun Club to Soldier’s Pond	40 mm	40 mm

7

8 Using the 2010 CSA Reference loads, the 50-year structure loads are:¹⁸

9

Zone	Area	2010 CSA Reference	2010 CSA Structure (50 yr)
1	Inner Labrador	25 mm	38 mm
3	Labrador Coast	30 mm	45 mm
4	Northern Pen. Coast	30 mm	45 mm
6	Northern Peninsula	25 mm	38 mm
8a	Central-West NF	25 mm	38 mm
8b	Central-West NF	25 mm	38 mm

¹⁷ Subzones 10-2 and 11-4 were created for wind analysis but have the same ice loads as for subzones 10-1 and 11-3 respectively.

¹⁸ Structure loads are obtained by multiplying the reference load by a spatial factor of 1.3 and a height factor of 1.15, as per Clause 6.3.4.1 of the Standard.

Island Interconnected System Supply Issues and Power Outages

Zone	Area	2010 CSA Reference	2010 CSA Structure (50 yr)
9	Birchy Narrows	25 mm	38 mm
10-1	Central-East NF	25 mm	38 mm
10-2	Eastern NF: Gander Lake to Port Blandford	25 mm	38 mm
11-1	Eastern NF : Port Blandford to Sunnyside ¹⁹	32.5 mm	49 mm
11-2	Eastern NF : Sunnyside to Whitbourne	37.5 mm	56 mm
11-3	Eastern NF: Whitbourne to Rod and Gun Club	40 mm	60 mm
11-4	Eastern NF: Rod and Gun Club to Soldier's Pond	40 mm	60 mm

1

2

3

4

5

6

7

The conversion factors for adjusting 50-year reference return periods to longer return periods were also increased over those in the 2006 standard. It is noteworthy that the conversion factors for 150 and 500-year return periods were increased by 4% and 18% respectively in the 2010 standard over the 2006 standard. The factors are shown below:

Return Period (years)	2006 Factors	2010 Factors
150	1.15	1.20
500	1.30	1.42

8

9

10

The glaze ice design criteria, along with 50, 150, and 500-year return period CSA loadings, are compared in the table on the following page.



NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 18 of 57

Zone	Area	LITL Glaze Ice Design Criteria	CSA 50-yr Structure (2010)	CSA 150-yr Structure (2010)	CSA 500-yr Structure (2010)	Notes
1	Inner Labrador	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
3	Labrador Coast	50 mm	45 mm	54 mm		See discussion below
4	Northern Pen. Coast	50 mm	45 mm	54 mm		See discussion below
6	Northern Peninsula	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
8a	Central-West NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
8b	Central-West NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
9	Birchy Narrows	75 mm	38 mm	46 mm		LITL criterion > CSA 150-year
10-1	Central-East NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
10-2	Eastern NF: Gander Lake to Port Blandford	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
11-1	Eastern NF : Port Blandford to Sunnyside	75 mm	49 mm		70 mm	LITL criterion > CSA 500-year
11-2	Eastern NF : Sunnyside to Whitbourne	75 mm	56 mm		80 mm	See discussion below
11-3	Eastern NF: Whitbourne to Rod and Gun Club	75 mm	60 mm		85 mm	See discussion below
11-4	Eastern NF: Rod and Gun Club to Soldier's Pond	75 mm	60 mm		85 mm	See discussion below

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 19 of 57

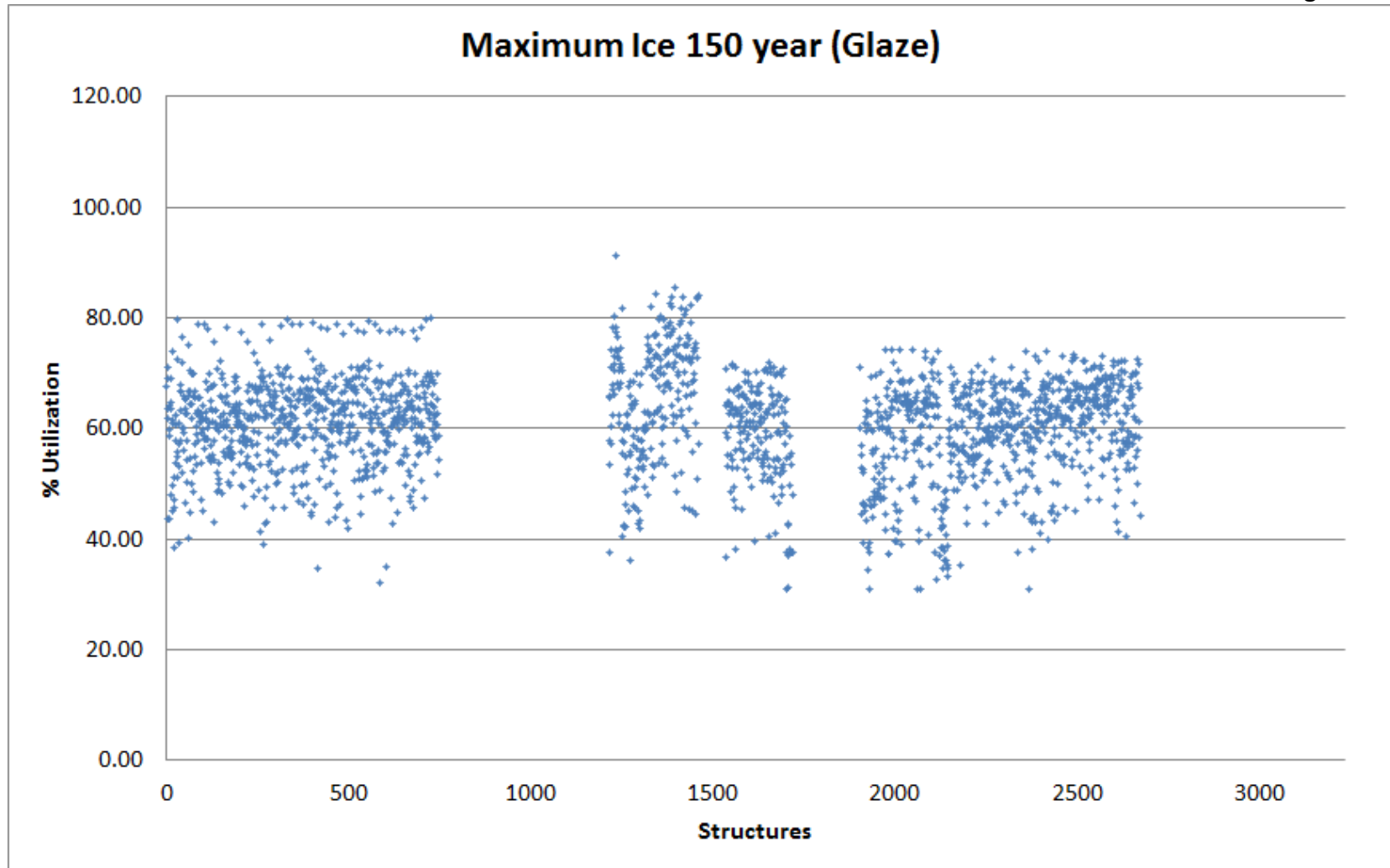
1 In Zones 3 and 4, the structures would be required to withstand a design loading of
2 54 mm rather than 50 mm to achieve the desired 150-year design return period.
3 The as-designed structures in Zones 3 and 4 were re-analyzed at 54 mm²⁰ radial
4 glaze ice loads, and all structures were confirmed to be loaded to less than their
5 design capabilities, thus indicating that they are designed in a manner to withstand
6 glaze ice loads in excess of CSA 150-year loadings.

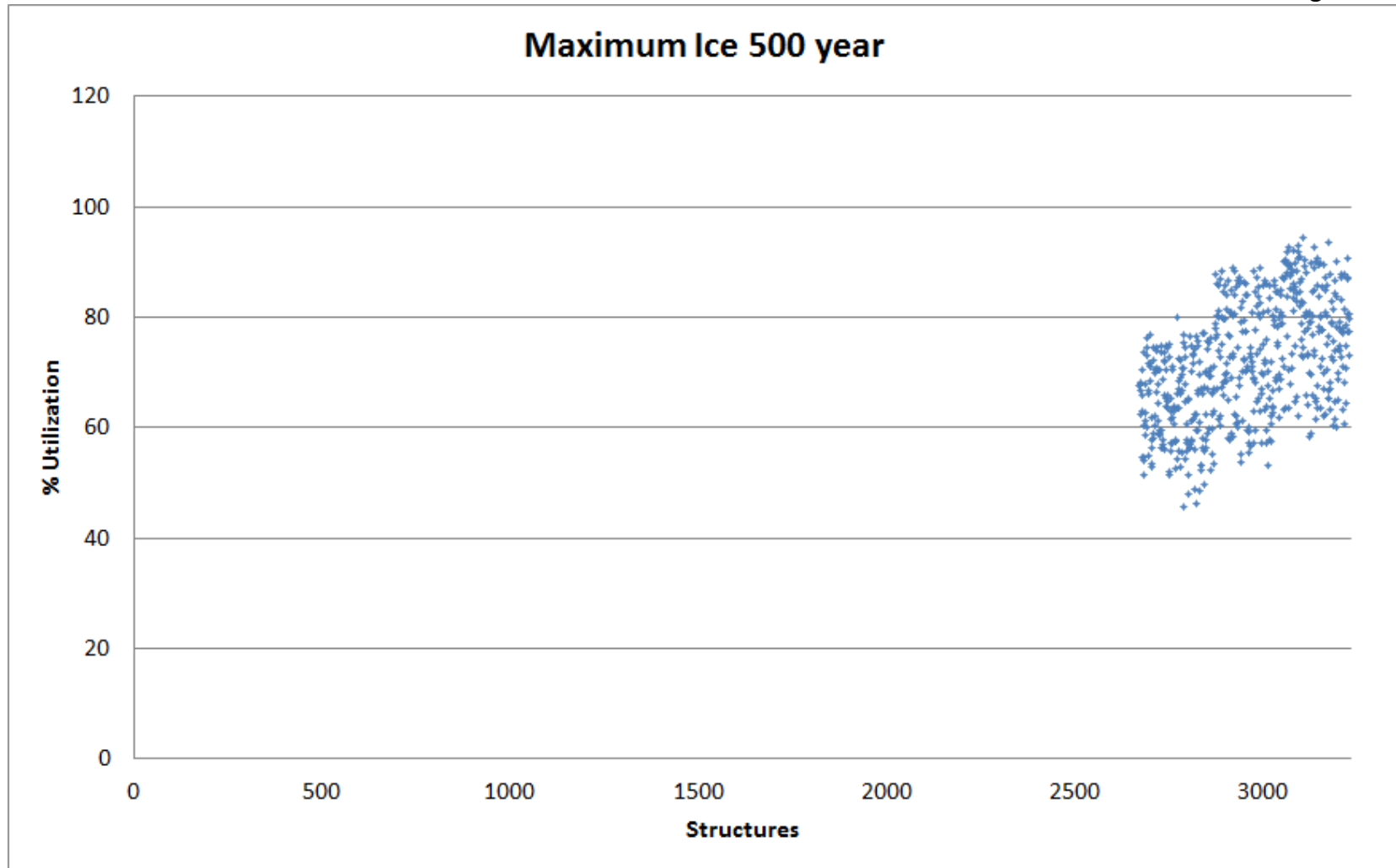
7
8 Further analysis was also undertaken to verify the as-designed structural capacity of
9 the LITL in Zones 11-2, 11-3, and 11-4. The as-designed structures were re-analyzed
10 at the noted CSA 500-year loading, and all structures were confirmed to be loaded
11 to less than their design capabilities, thus indicating this section of the LITL is
12 designed in a manner to exceed 500-year CSA return period loads.

13
14 The utilization of the LITL structures for glaze ice loads is shown in the following two
15 charts. The horizontal axis represents the LITL structure number – 3,233 structures
16 from Muskrat Falls to Soldiers Pond; the vertical axis shows the structural utilization
17 of each structure. Structural utilization greater than 100% indicates the structure is
18 being loaded beyond its design capability, and less than 100% indicates it is capable
19 of withstanding the imposed load (or more). The first chart is for the 150-year glaze
20 zones and the second is for the 500-year Zone 11.

21
22 The as-designed analysis confirms the ability of the LITL to withstand CSA 150-year
23 glaze ice loadings in zones outside the Avalon Peninsula and CSA 500-year glaze ice
24 loadings on the Avalon Peninsula.

²⁰ CSA 150-year loading





Island Interconnected System Supply Issues and Power Outages

Zone	Area	LITL Glaze Ice Design Criteria	CSA 50-yr Structure (2010)	CSA 150-yr Structure (2010)	CSA 500-yr Structure (2010)	Notes
1	Inner Labrador	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
3	Labrador Coast	50 mm	45 mm	54 mm		LITL as-designed capability confirmed to be in excess of CSA 150-year loading
4	Northern Pen. Coast	50 mm	45 mm	54 mm		LITL as-designed capability confirmed to be in excess of CSA 150-year loading
6	Northern Peninsula	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
8a	Central-West NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
8b	Central-West NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
9	Birchy Narrows	75 mm	38 mm	46 mm		LITL criterion > CSA 150-year
10-1	Central-East NF	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
10-2	Eastern NF: Gander Lake to Port Blandford	50 mm	38 mm	46 mm		LITL criterion > CSA 150-year
11-1	Eastern NF: Port Blandford to Sunnyside	75 mm	49 mm		70 mm	LITL criterion > CSA 500-year
11-2	Eastern NF: Sunnyside to Whitbourne	75 mm	56 mm		80 mm	LITL as-designed capability confirmed to be in excess of CSA 500-year loading
11-3	Eastern NF: Whitbourne to Rod and Gun Club	75 mm	60 mm		85 mm	LITL as-designed capability confirmed to be in excess of CSA 500-year loading
11-4	Eastern NF: Rod and Gun Club to Soldier's Pond	75 mm	60 mm		85 mm	LITL as-designed capability confirmed to be in excess of CSA 500-year loading

1 Rime Ice

2 The ability of the LITL structures to withstand rime ice accretion in areas subject to
3 this phenomenon is discussed in this section. As will be seen below, the as-
4 designed LITL structures in these areas will be capable of withstanding 500-year
5 loads as predicted by applicable meteorological models.

6

7 Rime ice accretion has long been recognized as a design consideration for portions
8 of the LITL route, particularly in the Long Range Mountains. Data collection has
9 been undertaken over many years to inform the development of suitable criteria
10 for this area. As CAN/CSA 22.3 No. 60826 does not address rime or in-cloud ice
11 accumulation, Landsvirkjun Power (LVP) was engaged to develop a rime ice
12 accretion model to predict rime ice accumulation in these areas based on historic
13 data recorded from nearby weather stations, and to advise on the selected routing
14 for the transmission line in the Long Range Mountains and also in areas in Labrador
15 where rime icing occurs.

16

17 Test structures and spans were established in the mid 1970's, and two
18 instrumented test spans measuring meteorological and load data were installed in
19 2009 (2009-1 and 2009-2) and one original test span from the 1970's was
20 instrumented in 2010 (2010-1). The data record collected from physical observation
21 of the test towers from 1975 to 1985, and the electronic data from the
22 instrumented test spans were used in an extensive study by LVP using numerical
23 models, namely Weather Observation Model (WOBs) and Weather Research and
24 Forecasting (WRF).

25

26 The WOBs model was used to analyze and determine the 50-year icing levels for
27 both the 2009-1 and 2009-2 sites. The WRF model was used to predict rime ice
28 accretion throughout the Long Range Mountains corridor. From the WRF model

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 24 of 57

1 and the typical result displayed in Figure 6 below, it was obvious that the worst area
2 of exposure and rime ice load was in the area of test span 2009-1.

3
4 In the location of Test Span 2009-1, the 50-year rime ice load was determined to be
5 40 kg/m, or 135 mm of radial rime ice. The 50-year icing levels for 2009-2 were
6 determined to be 9 kg/m, or 52 mm of radial rime, only 22% of the weight per
7 metre indicated for the 2009-1 location.

8
9 As indicated in Table 8 of the report,²¹ reference rime ice loadings were predicted
10 as follows:

Test Span	Elevation	25-year	50-year	150-year
2009-1	600 m	35 kg/m	40 kg/m	47 kg/m
2009-2	530 m	8 kg/m	9 kg/m	11 kg/m

11
12
13 In radial measurements, the corresponding loadings are:

Test Span	Elevation	25-year	50-year	150-year
2009-1	600 m	124 mm	135 mm	147 mm
2009-2	530 m	49 mm	52 mm	60 mm

14
15
16 Given that rime ice is most prominent in exposed areas, or elevations that have a
17 higher cloud exposure, the WRF model results were used to aid in line routing by
18 selecting locations that are not exposed to high levels of rime ice, such as areas that
19 are sheltered by hills, or areas of lower elevation. As shown in Figure 6 below, no
20 area of the line route is near the level of icing experienced by 2009-1, and in fact,
21 the predicted 50-year reference rime accumulation for the route through the Long
22 Range Mountains is consistent with test span 2009-2, or 52 mm. The corresponding

²¹ <http://www.pub.nl.ca/applications/MuskralFalls2011/files/exhibits/Exhibit95.pdf>, page 49.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 25 of 57

1 accumulation at structure and conductor height is 60 mm, with application of the
2 1.15 height adjustment.²²

3

4 Given the remote nature of the area and concerns about access to this area during
5 the winter period, the heavier rime ice load was maintained as a design load.

6 Although Zone 7b experiences rime ice near the levels of test span 2009-2 (9 kg/m,
7 or 52 mm radial rime), the rime ice level of 2009-1 were used for this area, given

8 that it is between 550 m and 600 m elevation. The remainder of the Long Range

9 Mountains used a reduced level of 115 mm radial Rime (31 kg/m), but this value is

10 still significantly higher than the model indicated for the selected line route.

11

12 As further security, given the observation that rime ice will shed off the conductors

13 but not necessarily off the tower, given the lattice tower layout, towers were

14 designed to be completely encased in rime ice, with no voids. Therefore, instead of

15 just using an elevated icing level on the tower, it was assumed that the tower would

16 carry the full icing load over the whole structure.

17

18 The results from the test spans demonstrate the value of routing the line inland and

19 through valleys at lower elevations. Using Figure 56 from Exhibit 95 as a basis,

20 Figure 6 below shows the test span locations, the transmission line study corridors

21 (bounded by red lines), and the final transmission line route (shown as the yellow

22 line within the eastern corridor).

²² Given that the WRF model is capable of identifying the area of highest accretion, the CSA spatial factor is not applicable.

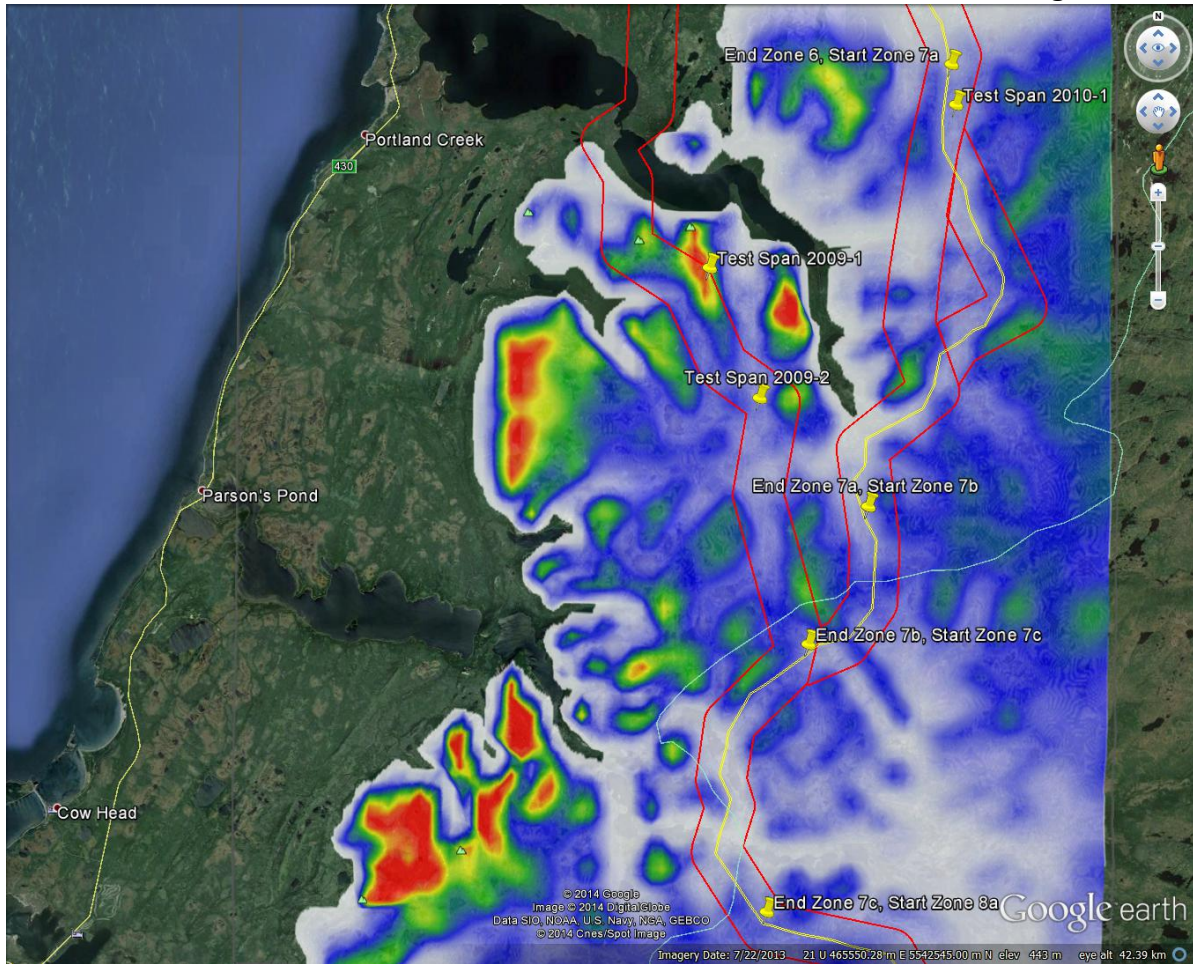


Figure 6 – Rime Ice Accretion in Long Range Mountain Crossing

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Section A.5.6.1 of IEC 60826 makes a similar observation:

The regional and local topography (large and medium scale) modifies the vertical motions of the atmosphere and hence the cloud structure and icing. Coastal mountains along the windward side of the continents act to force moist air upwards, leading to a cooling of the air with condensation of water vapour and droplet growth, eventually with precipitation. The most severe in-cloud icing occurs above the condensation level and the freezing level on freely exposed heights, where mountain valleys force moist air through passes and thus both lift the air and strengthen the wind.

On the leeward side of the mountains the descent of an air mass results in internal heating of the air and evaporation of droplets, eventually with a total dissolution of clouds. A local shelter of hills not more than 50 m higher on the windward side may give a significant reduction in ice loadings. For this reason, routes in high mountains may very well be suited for overhead lines, provided they are sheltered against icing wind directions.

Island Interconnected System Supply Issues and Power Outages

1 The design criteria, along with the 50, 150, and 500-year structure loadings
 2 predicted by the models are presented in the following table:

Zone	Area	LITL Rime Design Criteria	WOBS/WRF 50-year Structure	WOBS/WRF 150-year Structure	WOBS/WRF 500-year Structure
7a	Long Range Mountains	115 mm	60 mm	72 mm	85 mm
7b	Long Range Mountains	135 mm	60 mm	72 mm	85 mm
7c	Long Range Mountains	115 mm	60 mm	72 mm	85 mm

4
 5 To summarize, for the Long Range Mountains, the design loads are between 35%
 6 and 58% greater than those predicted by the meteorological models, with an
 7 estimated return period in excess of 500 years.

8
 9 Two other rime ice zones were identified along the LITL corridor; in coastal
 10 Labrador north of the Strait of Belle Isle, and on the Great Northern Peninsula at
 11 the Highlands of St. John. Analysis by Landsvirkjun also took these areas into
 12 account.

13
 14 For southeastern Labrador, WOBs model analysis was used to determine the rime
 15 ice and wind speeds, with a central area (2b) most affected by heavy rime ice
 16 (design established at 135 mm) and extended areas (2a & 2c) affected by lower
 17 rime ice loads (design established at 115 mm). These zones are significantly lower
 18 in elevation at less than 450 m than the Long Range Mountains (LRM) crossing.
 19 Therefore, a particular icing event was calculated to produce a significantly lower
 20 rime ice load; however persistence, or the reduced frequency of rime ice shedding
 21 off of the conductor given the colder temperatures, means that an overall design
 22 rime ice load similar to the LRM crossing was considered prudent. The WRF model
 23 was also used in this area as a route selection aid; however, the key was to avoid
 24 the areas of higher elevation and significant exposure.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 28 of 57

1 The Highlands of St. John were also analyzed in the same way. Areas of
2 environmental sensitivity and local topography meant that only two routes were
3 available for selection, with the first in a valley east of the Highlands of St. John, and
4 the second on a ridge just east of the valley. The valley was quickly selected due to
5 the significant load reduction because of sheltering effects. The Highlands of St.
6 John reach an elevation of 600 m; however, the valley where the line route was
7 selected reaches a maximum elevation of 500 m. This significant sheltering effect
8 and the research in the icing already determined for the LRM led to selection of a
9 rime ice load of 115 mm.

10

11 In both southeastern Labrador and the Highlands of St. John, rime ice loadings are
12 expected to be consistent with those predicted by the models for Long Range
13 Mountain site 2009-2.

14

15 In each of the rime ice cases, design criteria are significantly greater than the 500-
16 year loadings predicted by the rime ice accretion models. Given the remoteness of
17 these locations, this was considered to be an appropriate design decision.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 29 of 57

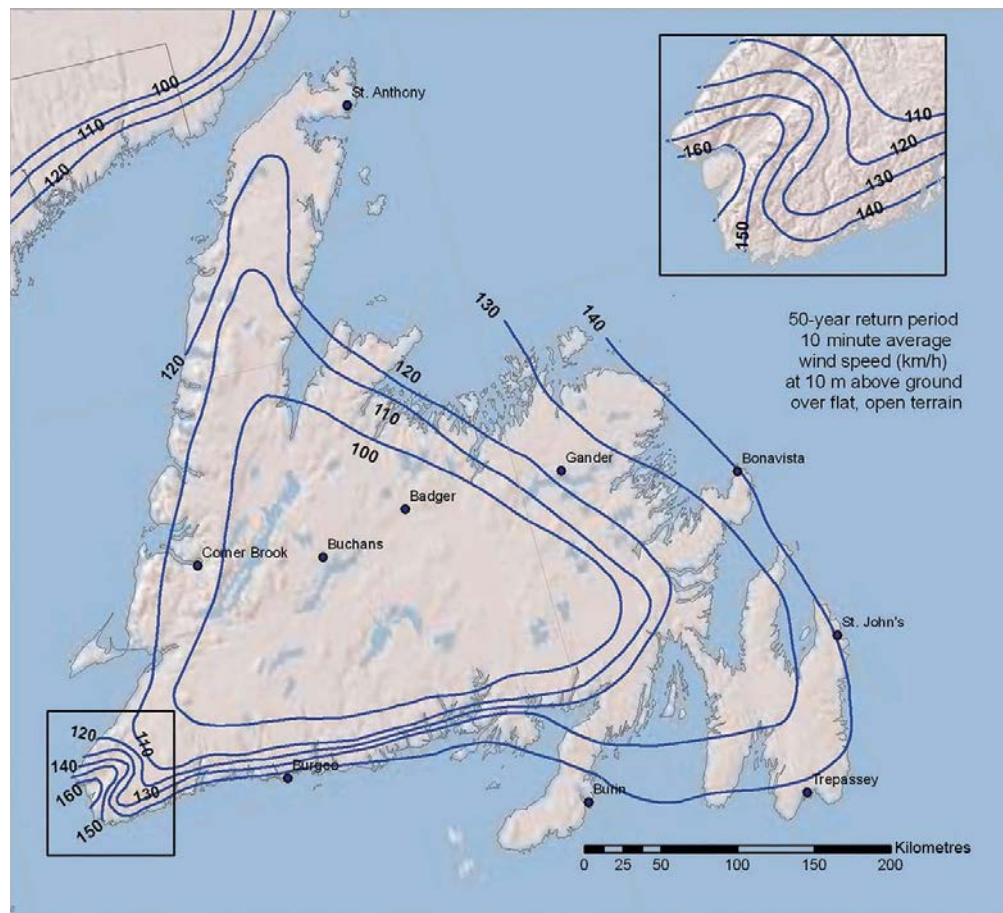
Zone	Area	LITL Rime Design Criteria	WOBS/WRF 50-year Structure	WOBS/WRF 150-year Structure	WOBS/WRF 500-year Structure	Notes
2a	Alpine Labrador	115 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
2b	Alpine Labrador	135 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
2c	Alpine Labrador	115 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
5	Highlands of St. John	115 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
7a	Long Range Mountains	115 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
7b	Long Range Mountains	135 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model
7c	Long Range Mountains	115 mm	60 mm	72 mm	85 mm	LITL criterion > 500-year model

1 Wind

2 As will be seen below, the as-designed LITL structures will be capable of
 3 withstanding wind loads on the Avalon Peninsula consistent with 500-year return
 4 period CSA loadings and with at least 150-year return period CSA wind loadings for
 5 the remainder of the route. The structures will be capable of withstanding greater
 6 than 500-year return period CSA wind loadings in rime ice areas.

7
 8 The CAN/CSA C22.3 No. 60826 standard was also considered as a basis for wind
 9 loading. Figure 7 presents reference wind speeds for Newfoundland, and Figure 8
 10 presents reference wind speeds for Labrador.

11



12

Figure 7 – Figure CA.1 from CAN/CSA C22.3 No. 60826

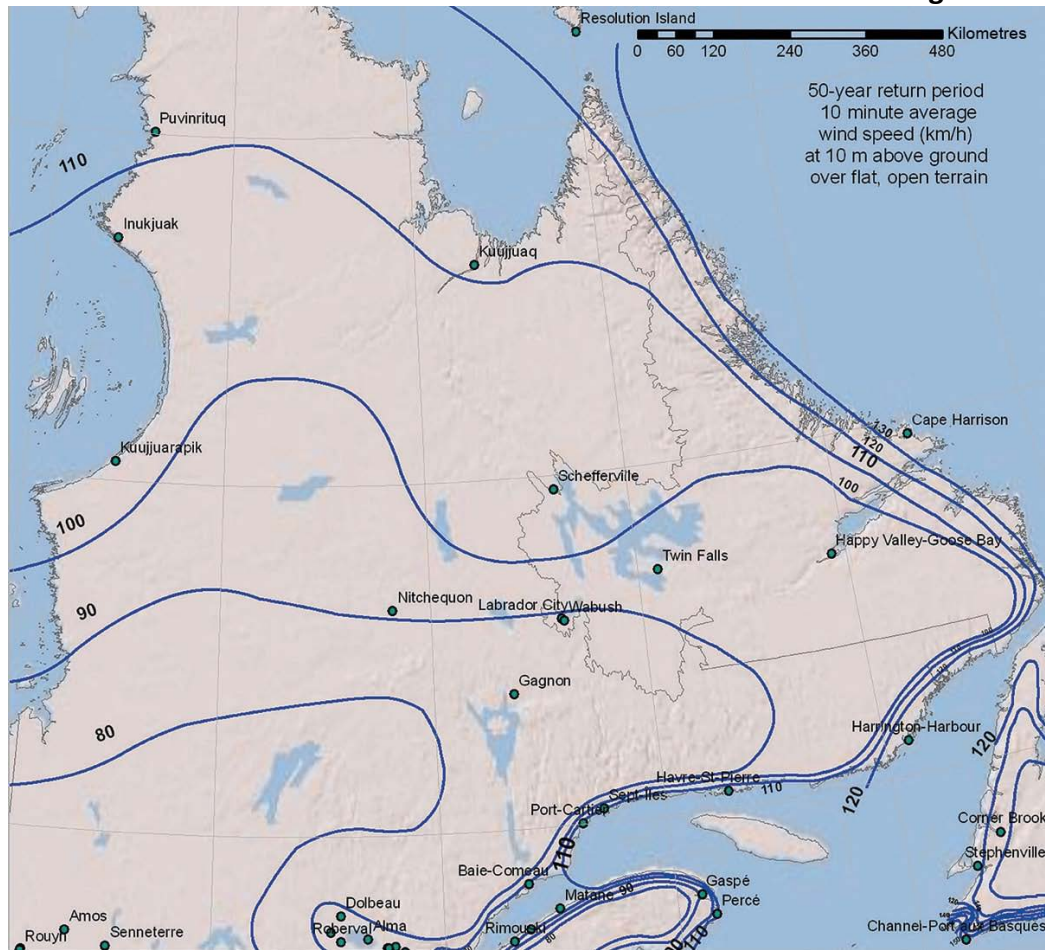


Figure 8 – Figure CA.3 from CAN/CSA C22.3 No. 60826

- 1
- 2
- 3
- 4
- 5
- 6
- 7

Higher resolution versions of these maps are provided in Appendix B of this response.

Reference wind speeds are 10-minute average wind speeds (not gusts), measured at 10 m above ground, and are provided for flat, open terrain.

Island Interconnected System Supply Issues and Power Outages

1 The 50-year reference loadings²³ for each zone are as follows:

2

Zone	Area	CSA 50-yr Reference
1	Inner Labrador	100 km/hr
2a	Alpine Labrador	100 km/hr
2b	Alpine Labrador	100 km/hr
2c	Alpine Labrador	110 km/hr
3	Labrador Coast	120 km/hr
4	Northern Pen. Coast	120 km/hr
5	Highlands St. John	110 km/hr
6	Northern Peninsula	110 km/hr
7a	Long Range Mountains	110 km/hr
7b	Long Range Mountains	110 km/hr
7c	Long Range Mountains	110 km/hr
8a	Central-West NF	110 km/hr
8b	Central-West NF	100 km/hr
9	Birchy Narrows	100 km/hr
10-1	Central-East NF	100 km/hr
10-2	Eastern NF	110 km/hr
11-1,2,3	Western Avalon	125 km/hr
11-4	Eastern Avalon	130 km/hr

3

4 Terrain and obstacles at ground level are important factors in determining the
 5 effects of wind. This is discussed in the CSA standard and the underlying IEC
 6 standard – IEC 60826 2003:

7

8 Wind speed and turbulence depends on the terrain roughness. With
 9 increasing terrain roughness, turbulence increases and wind speed decreases
 10 near ground level. Four types of terrain categories, with increasing
 11 roughness values, are considered in this standard as indicated in Table 4.

²³ The structure wind loadings are the same as the reference loadings with no adjustments required.

Island Interconnected System Supply Issues and Power Outages

Table 4 – Classification of terrain categories

Terrain category	Roughness characteristics	K_R
A	Large stretch of water upwind, flat coastal areas	1,08
B	Open country with very few obstacles, for example airports or cultivated fields with few trees or buildings	1,00
C	Terrain with numerous small obstacles of low height (hedges, trees and buildings)	0,85
D	Suburban areas or terrain with many tall trees	0,67

1
2
3
4
5
6
7
8
9
10
11
12
13

The reference wind speeds in the CSA standard correspond to Terrain Category B conditions. The vast majority of the LITL route is through forested or hilly terrain rather than through open country as might be expected at an airport. Design calculations consider these effects, and therefore Terrain Category C was selected for all glaze ice zones. As a conservative assumption, line designers maintained Terrain Category B in the rime ice zones, even though topography suggests Category C.²⁴

Based on Table CA.2²⁵ of CAN/CSA 22.3 No. 60826, the adjustment factors to modify the 50-year reference for wind to 150-year and 500-year return periods are 1.10 and 1.20 respectively.²⁶ The LITL wind design criteria, along with the 50, 150, and 500-year wind speeds are presented in the following table.

²⁴ The K_R factor in the IEC table is multiplied by the reference wind speed, so structures in Terrain Category C see lower effective wind speeds than those in Category B.

²⁵ Table CA.2 provides conversion factors for both ice and wind. The ice factors were referenced previously.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 34 of 57

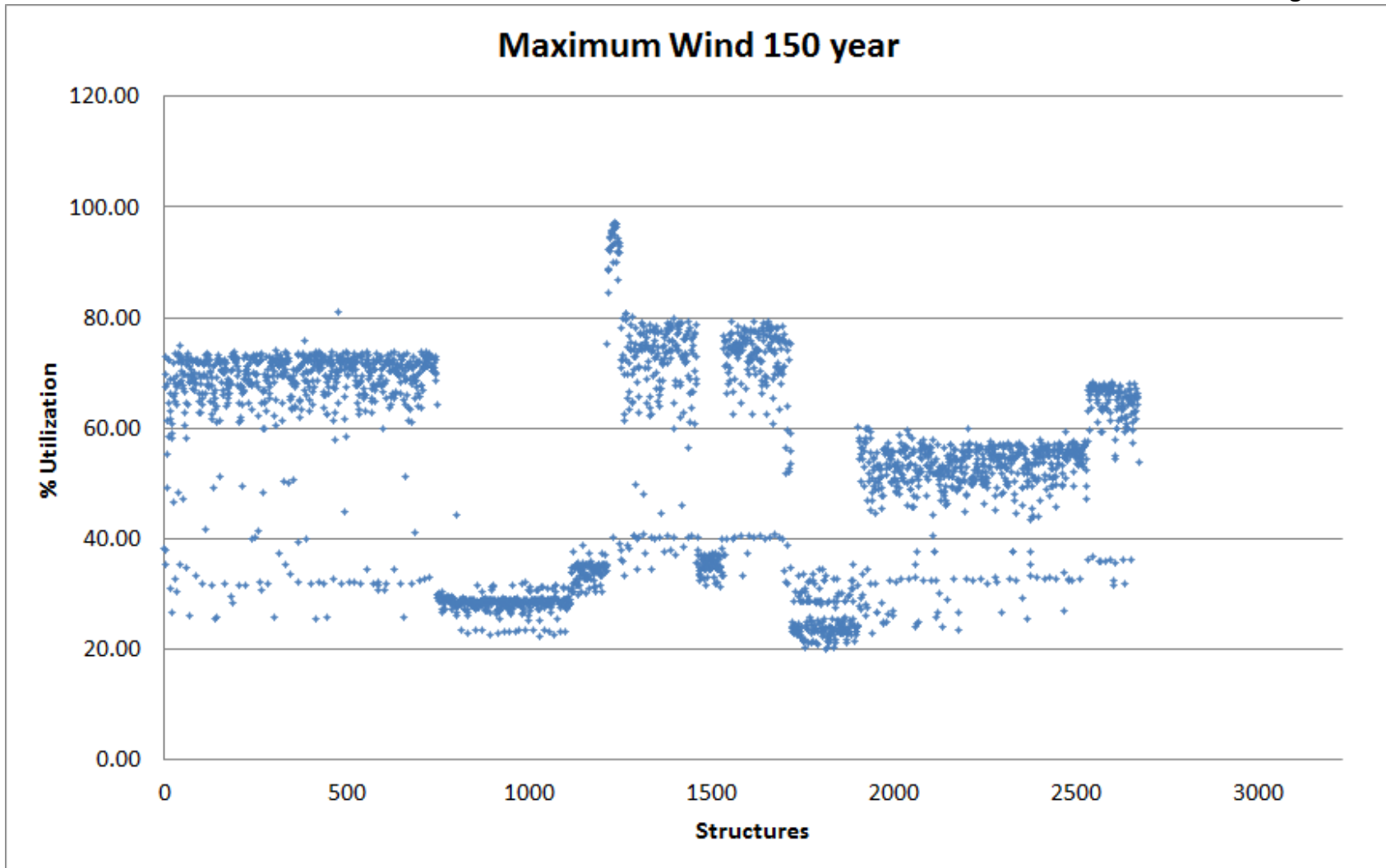
Zone	Area	LITL Design Criteria	CSA 50-year Reference	CSA 150-year	CSA 500-year	Notes
1	Inner Labrador	105 km/hr	100 km/hr	110 km/hr		See discussion below
2a	Alpine Labrador	135 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
2b	Alpine Labrador	135 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
2c	Alpine Labrador	135 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
3	Labrador Coast	120 km/hr	120 km/hr	132 km/hr		See discussion below
4	Northern Pen. Coast	120 km/hr	120 km/hr	132 km/hr		See discussion below
5	Highlands St. John	150 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
6	Northern Peninsula	120 km/hr	110 km/hr	121 km/hr		See discussion below
7a	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
7b	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
7c	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
8a	Central-West NF	120 km/hr	110 km/hr	121 km/hr		See discussion below
8b	Central-West NF	105 km/hr	100 km/hr	110 km/hr		See discussion below
9	Birchy Narrows	130 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
10-1	Central-East NF	105 km/hr	100 km/hr	110 km/hr		See discussion below
10-2	Eastern NF	105 km/hr	110 km/hr	121 km/hr		See discussion below
11-1	Eastern NF	130 km/hr	125 km/hr		150 km/hr	See discussion below
11-2,3	Avalon Peninsula	130 km/hr	125 km/hr		150 km/hr	See discussion below
11-4	Eastern Avalon	130 km/hr	130 km/hr		156 km/hr	See discussion below

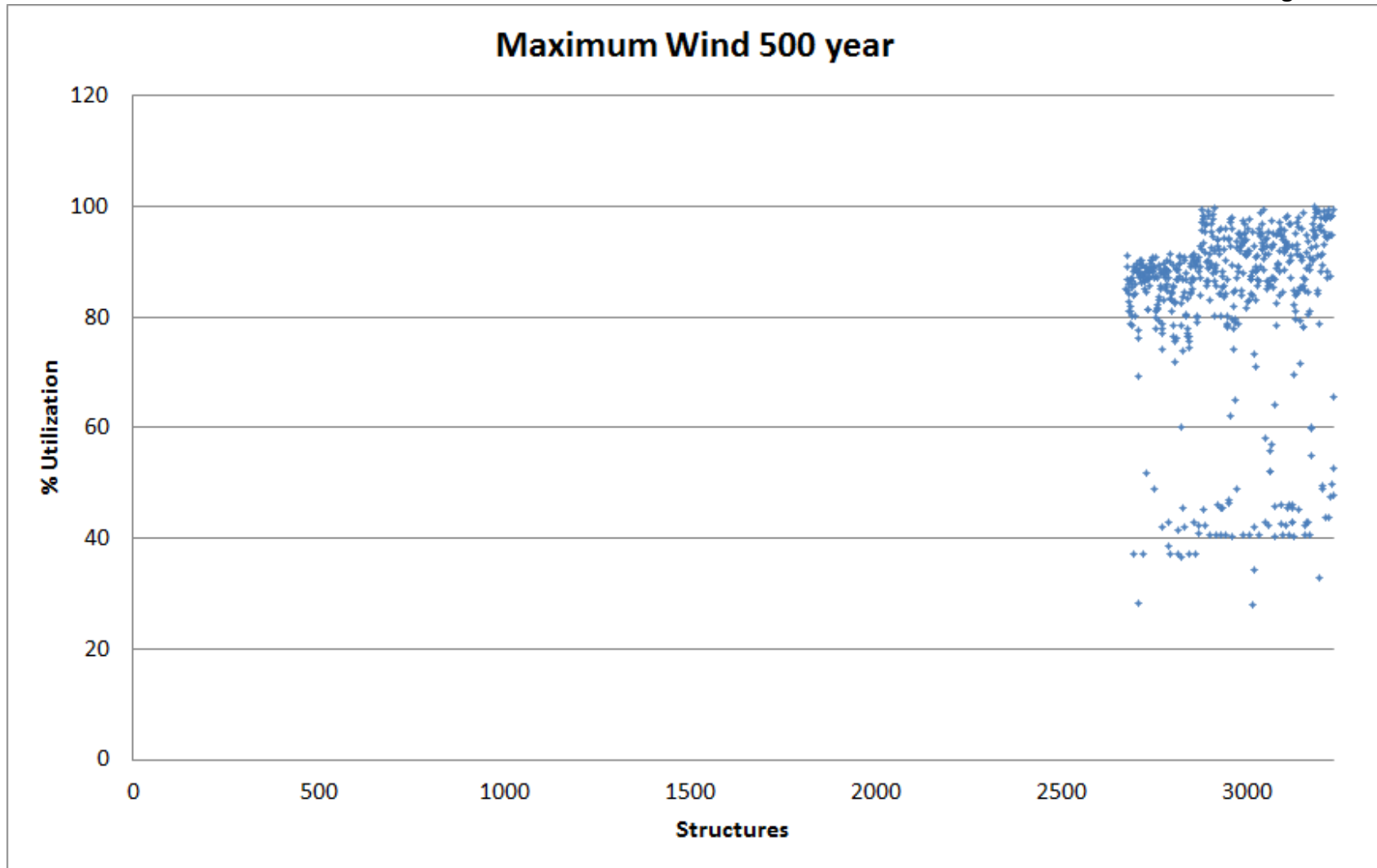
NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 35 of 57

1 The LITL design criteria exceed the CSA 500-year wind criteria in rime ice zones and
2 Zone 9, and are approximately the same as 150-year criteria in several zones. In
3 order to confirm the LITL's ability to withstand greater wind loading, the as-
4 designed structures were subjected to CSA 150-year winds in zones 1, 3, 4, 6, 8, and
5 10. 500-year winds were applied to Zone 11. The results are shown on the charts
6 on the following pages.





Island Interconnected System Supply Issues and Power Outages

Zone	Area	LITL Design Criteria	CSA 50-year Reference	CSA 150-year	CSA 500-year	Notes
1	Inner Labrador	105 km/hr	100 km/hr	110 km/hr		LITL capability confirmed in excess of CSA 150-year loading
2a	Alpine Labrador	135 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
2b	Alpine Labrador	135 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
2c	Alpine Labrador	135 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
3	Labrador Coast	120 km/hr	120 km/hr	132 km/hr		LITL capability confirmed in excess of CSA 150-year loading
4	Northern Pen. Coast	120 km/hr	120 km/hr	132 km/hr		LITL capability confirmed in excess of CSA 150-year loading
5	Highlands St. John	150 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
6	Northern Peninsula	120 km/hr	110 km/hr	121 km/hr		LITL capability confirmed in excess of CSA 150-year loading
7a	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
7b	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
7c	Long Range Mountains	180 km/hr	110 km/hr	121 km/hr	132 km/hr	LITL Criterion > CSA 500-year
8a	Central-West NF	120 km/hr	110 km/hr	121 km/hr		LITL capability confirmed in excess of CSA 150-year loading
8b	Central-West NF	105 km/hr	100 km/hr	110 km/hr		LITL capability confirmed in excess of CSA 150-year loading
9	Birchy Narrows	130 km/hr	100 km/hr	110 km/hr	120 km/hr	LITL Criterion > CSA 500-year
10-1	Central-East NF	105 km/hr	100 km/hr	110 km/hr		LITL capability confirmed in excess of CSA 150-year loading
10-2	Eastern NF	105 km/hr	110 km/hr	121 km/hr		LITL capability confirmed in excess of CSA 150-year loading
11-1	Eastern NF	130 km/hr	125 km/hr		150 km/hr	LITL capability confirmed in excess of CSA 500-year loading
11-2,3	Avalon Peninsula	130 km/hr	125 km/hr		150 km/hr	LITL capability confirmed in excess of CSA 500-year loading
11-4	Eastern Avalon	130 km/hr	130 km/hr		156 km/hr	LITL capability confirmed in excess of CSA 500-year loading

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 39 of 57

1 The as-designed analysis confirmed that no structure in zones off the Avalon
2 Peninsula exceeds its design capacity when subjected to CSA 150-year wind loads
3 and that no structure in Zone 11 on the Avalon Peninsula exceeds its design
4 capacity when subjected to CSA 500-year wind loads.

5
6 As previously indicated, the design criteria in rime ice zones are greater than CSA
7 500-year return period winds.

8

9 Combined Wind and Ice Loading

10 Combined wind and ice loading is recognized as a design factor, and combined
11 design criteria were established for the LITL as outlined in Table 1. These have been
12 developed from operational experience and also from an assessment of measured
13 wind conditions during icing events, including wind speed measurements taken in
14 the Long Range Mountains.

15

16 Neither CAN/CSA 22.3 No. 60826 nor the underlying IEC standard have an
17 established methodology for addressing combined wind and ice loading design
18 criteria. A proposed approach is presented in the IEC standard, as quoted below:

19

20 **6.4.1 Combined probabilities – Principle proposed**

21

22

23

24

25

26

27

28

29

30

31

The action of wind on ice-covered conductors involves at least three variables: wind speed that occurs in presence with icing, ice weight and ice shape (effect of drag coefficient). This action results in both transversal and vertical loads.

Ideally, statistics of wind speed during ice presence on conductors should be used to generate the combined loadings of ice and wind corresponding to the selected reliability level. Since detailed data and observations on ice weight, ice shape and coincident wind, are not commonly available, it is proposed to combine these variables in such a way that the resulting load combinations will have the same return periods T as those adopted for each reliability level.

Island Interconnected System Supply Issues and Power Outages

1 It is noteworthy that this section of the standard has remained outstanding in both
 2 the 2006 and 2010 editions of the standard, and has not been established as a
 3 design requirement.

4
 5 Given the importance of the LITL, the as-designed structures were tested against
 6 conditions developed using the proposed methodology in the standard in order to
 7 confirm the capability of the line to combined wind and ice conditions.

8
 9 The proposed principle considers two combined loading scenarios for the line:

- 10 a) An extreme wind event combined with average maximum (high probability)
- 11 icing conditions, and
- 12 b) A maximum ice event (at maximum design return period) combined with
- 13 average maximum (high probability) wind conditions.

14 Reference wind speeds are reduced to represent typical maximum wind speeds
 15 during icing conditions and also the relative rarity of maximum wind speeds during
 16 icing events. The meteorological conditions used²⁷ are:

17
 18 Case a) – Extreme Wind + Ice

- 19 150-year zones, 0.72 x reference wind speed
- 20 500-year zones, 0.85 x reference wind speed
- 21 Icing 0.40 x reference ice loading

22
 23 Case b) – Maximum Ice + Wind

- 24 Icing 150 or 500-year ice loading, as applicable
- 25 Wind 0.40 x reference wind speed

²⁷ From IEC 60826, Clause 6.4.2 and 6.4.4.1.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 41 of 57

- 1 Applying these factors results in IEC Extreme Wind + Ice and IEC Maximum Ice +
- 2 Wind combined wind-ice conditions for each zone. These combined loadings are
- 3 presented in the following table:

Zone	Type	LCP Combined Wind/Ice		IEC Extreme Wind + Ice		IEC Maximum Ice + Wind	
		Ice	Wind	Ice	Wind	Ice	Wind
1	Glaze	25 mm	60 km/hr	15 mm	72 km/hr	46 mm	45 km/hr
2a	Rime	60 mm	95 km/hr	24 mm	72 km/hr	72 mm	45 km/hr
2b	Rime	70 mm	95 km/hr	24 mm	72 km/hr	72 mm	45 km/hr
2c	Rime	60 mm	95 km/hr	24 mm	79 km/hr	72 mm	50 km/hr
3	Glaze	25 mm	60 km/hr	18 mm	86 km/hr	54 mm	48 km/hr
4	Glaze	25 mm	60 km/hr	18 mm	86 km/hr	54 mm	54 km/hr
5	Rime	60 mm	105 km/hr	24 mm	86 km/hr	72 mm	54 km/hr
6	Glaze	25 mm	60 km/hr	15 mm	86 km/hr	46 mm	54 km/hr
7a	Rime	60 mm	125 km/hr	24 mm	79 km/hr	72 mm	50 km/hr
7b	Rime	70 mm	125 km/hr	24 mm	79 km/hr	72 mm	50 km/hr
7c	Rime	60 mm	125 km/hr	24 mm	79 km/hr	72 mm	50 km/hr
8a	Glaze	25 mm	60 km/hr	15 mm	76 km/hr	46 mm	47 km/hr
8b	Glaze	25 mm	60 km/hr	15 mm	72 km/hr	46 mm	45 km/hr
9	Glaze	45 mm	60 km/hr	15 mm	72 km/hr	46 mm	45 km/hr
10-1	Glaze	25 mm	60 km/hr	15 mm	72 km/hr	46 mm	45 km/hr
10-2	Glaze	25 mm	60 km/hr	15 mm	79 km/hr	46 mm	50 km/hr
11-1	Glaze	45 mm	60 km/hr	20 mm	86 km/hr	70 mm	48 km/hr
11-2	Glaze	45 mm	60 km/hr	22 mm	86 km/hr	80 mm	48 km/hr
11-3	Glaze	45 mm	60 km/hr	24 mm	90 km/hr	85 mm	50 km/hr
11-4	Glaze	45 mm	60 km/hr	24 mm	94 km/hr	85 mm	52 km/hr

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 43 of 57

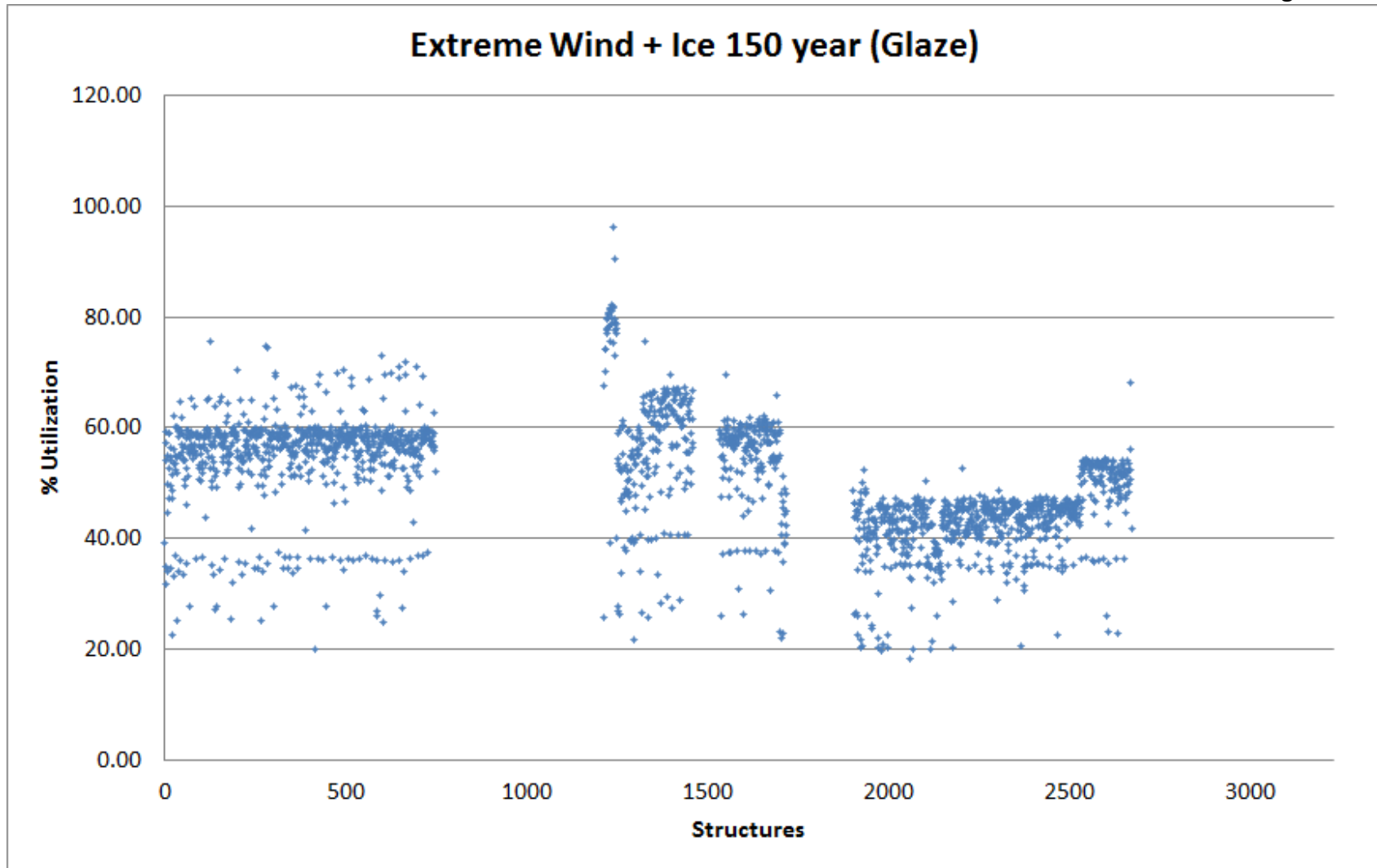
1 The as-designed structures were then subjected to the combined wind/ice
2 conditions as presented above. In all three cases, no exceedances of the structural
3 capacity of any structure on the line occurred.

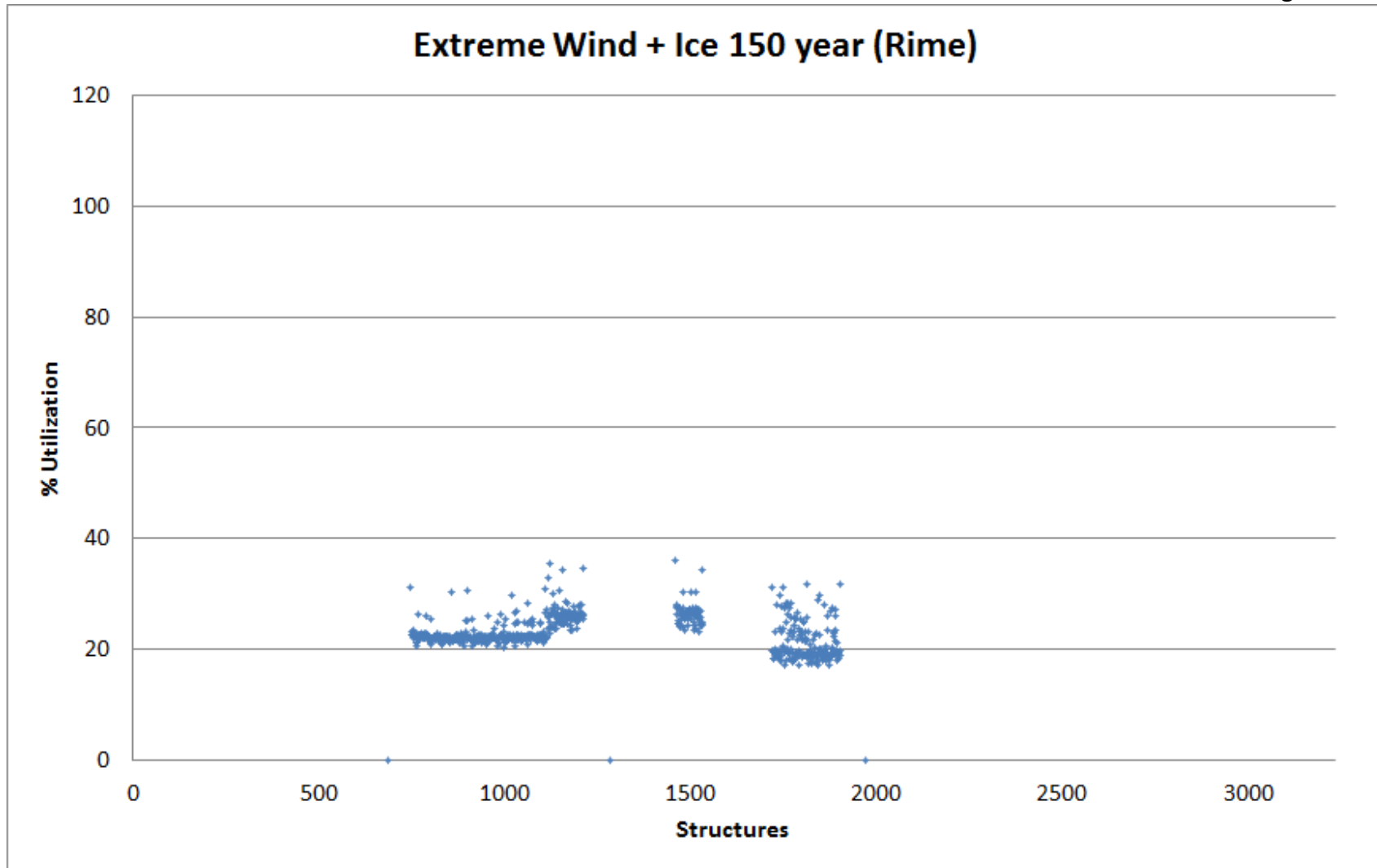
4

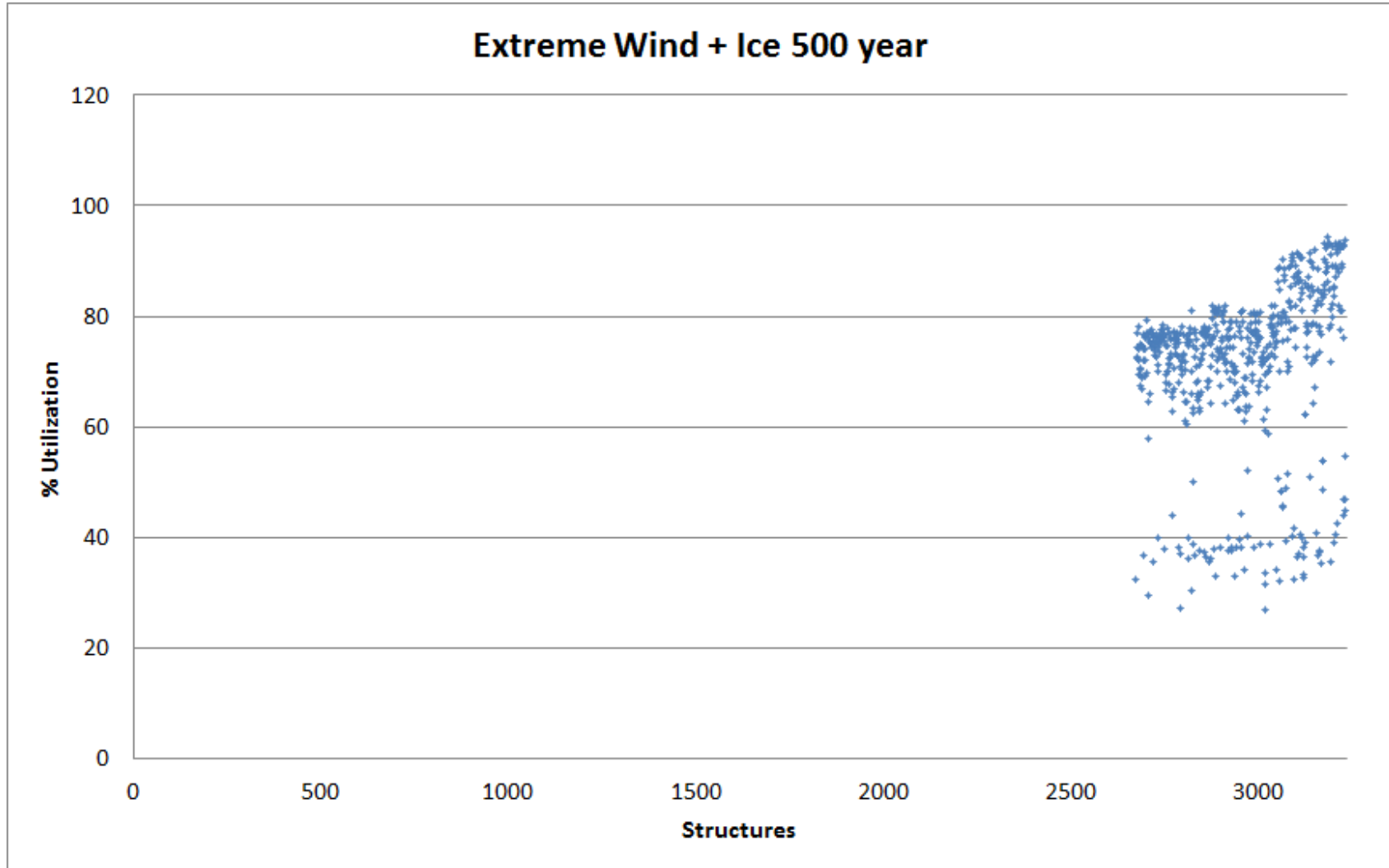
5 Structural utilization for the IEC combined ice/wind cases are shown on the
6 following pages.

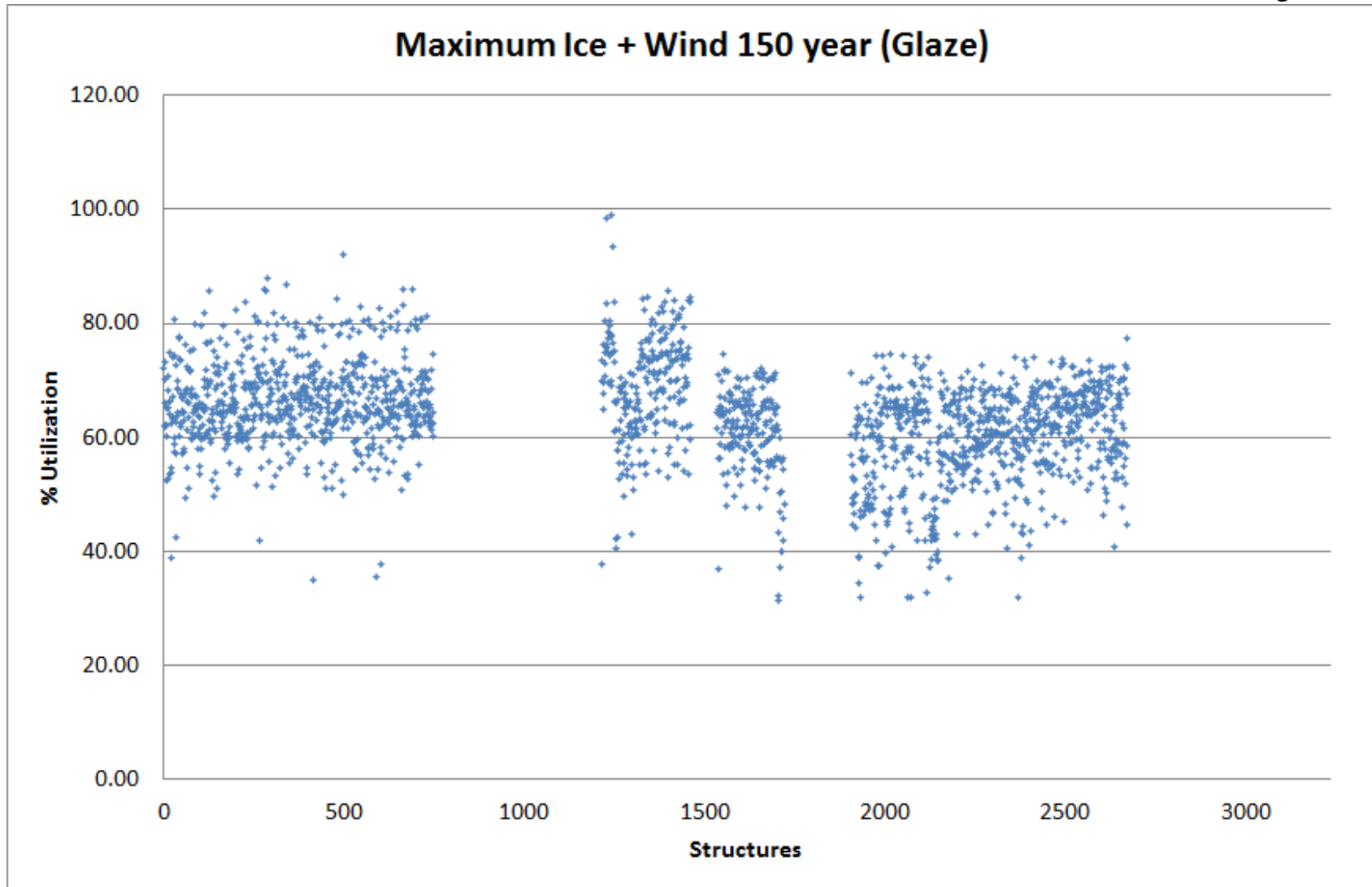
7

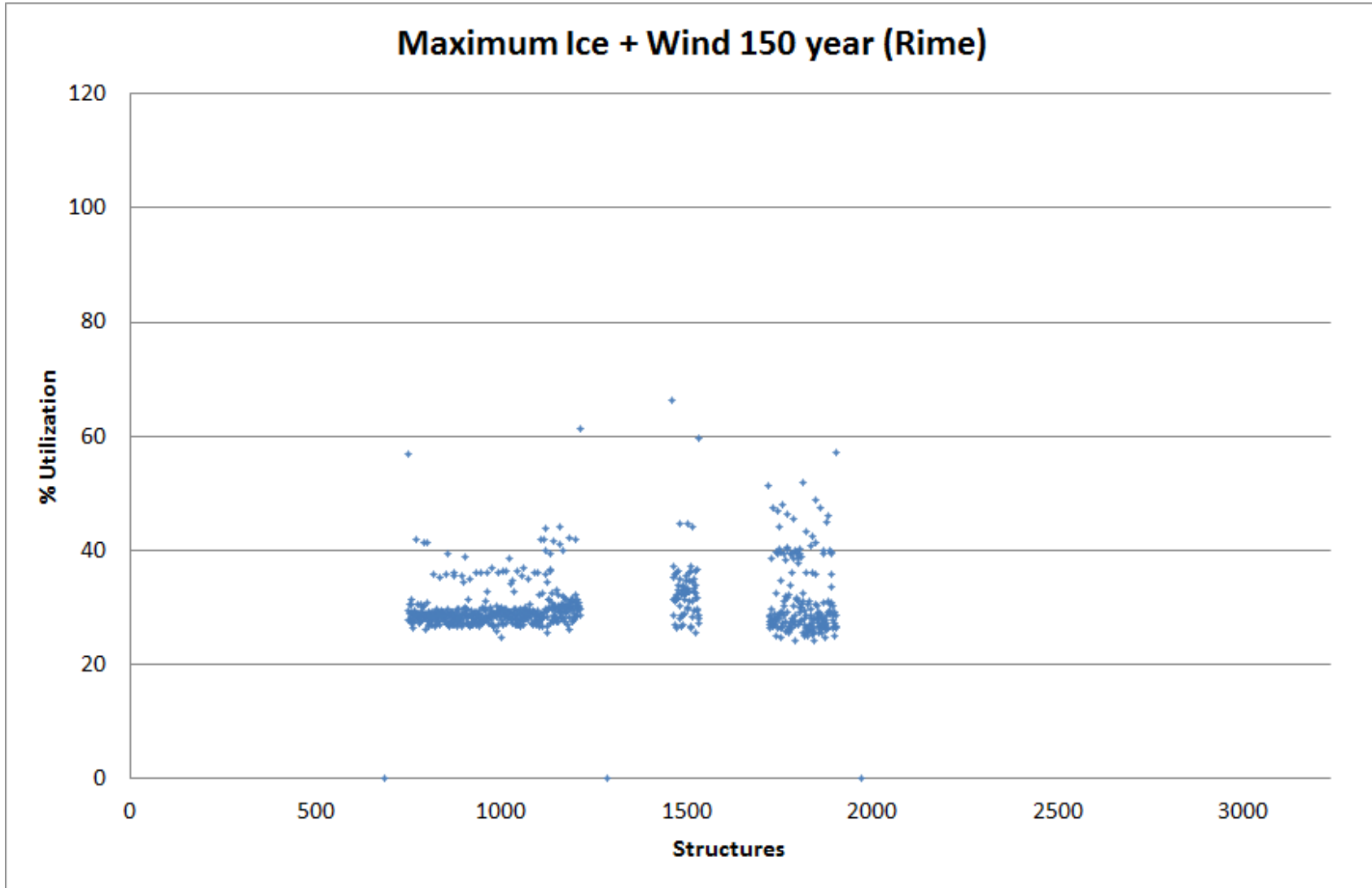
8 No structure was loaded beyond 100% of its structural capacity in any of these
9 scenarios, thus confirming the capacity of all structures to withstand the proposed
10 IEC 60826 combined wind and ice standards for both extreme wind and ice
11 scenarios.

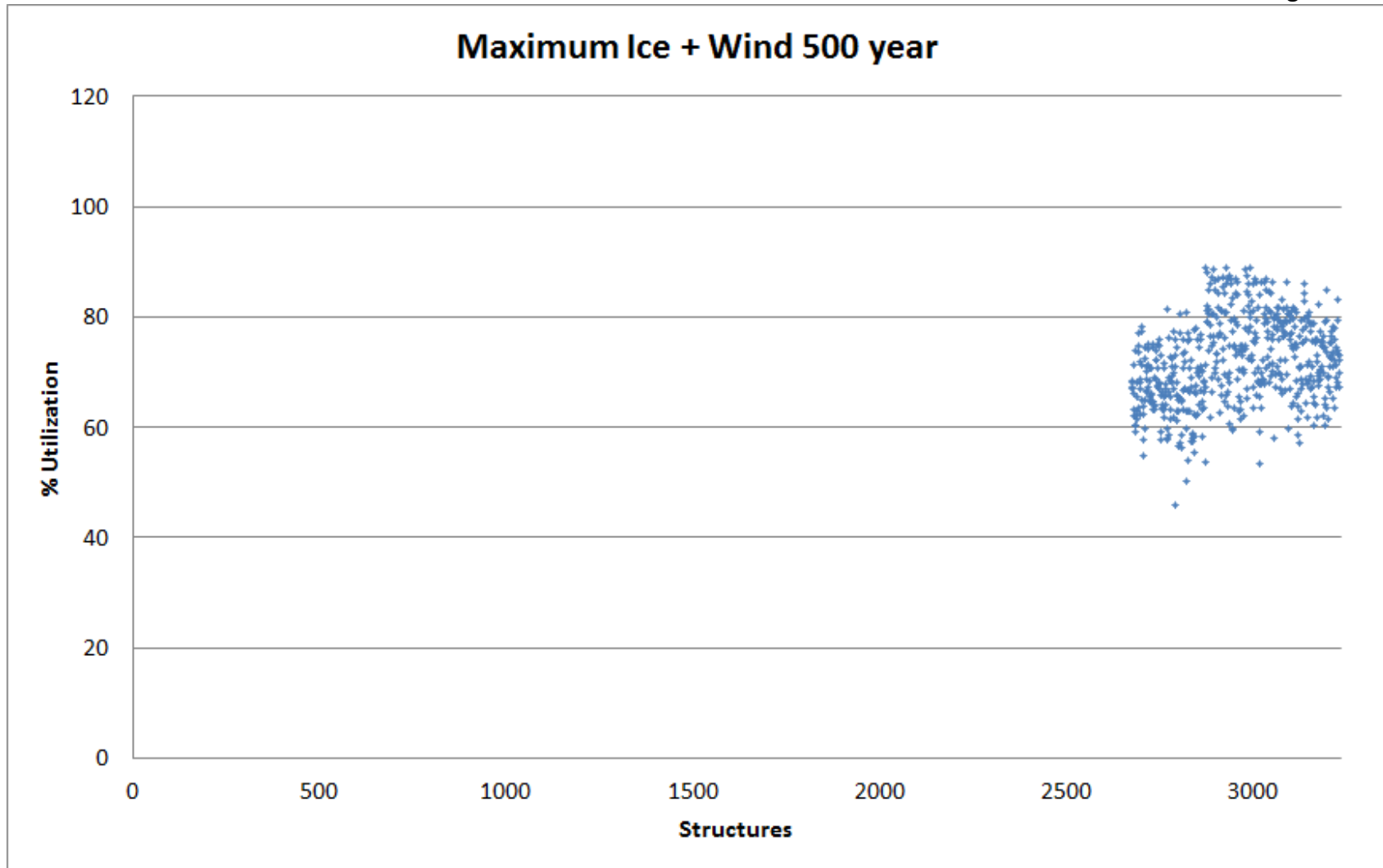












1 Summary and Conclusions:

2 The design criteria for the LITL were developed following the principles outlined in
3 CAN/CSA 22.3 No. 60826. They were developed giving consideration to reference
4 data from the standard, operational experience and identified operational risks, as
5 well as model data for unique conditions (rime ice) not incorporated in the
6 standard.

7

8 In addition to the design criteria established for the LITL, the as-designed structures
9 were evaluated against the following loadings:

- 10 a) CSA 150-year ice loadings for the line section off the Avalon Peninsula.
11 b) CSA 500-year ice loadings for the route on the Avalon Peninsula.
12 c) CSA 150-year wind loadings for the line section off the Avalon Peninsula.
13 d) CSA 500-year wind loadings for the line section on the Avalon Peninsula.

14 No structure was loaded beyond 100% of its design structural capacity in any of
15 these scenarios.

16

17 The design criteria for rime ice accretion are beyond 500-year return period loads
18 predicted by rime ice accretion models developed by LVP, and the design criteria
19 for wind are beyond 500-year CSA return period winds in rime zones.

20

21 The as-designed structures were evaluated against proposed combined wind and
22 ice criteria in IEC Standard 60826 in the following conditions:

- 23 a) Extreme wind (72% or 85% of reference wind as applicable for 150-year
24 and 500-year zones respectively) combined with 40% of reference ice
25 load; and
26 b) Maximum ice (150 or 500-year loads as applicable for 150-year and 500-
27 year zones respectively) combined with 40% of reference wind speed.

NP-NLH-004

Island Interconnected System Supply Issues and Power Outages

Page 51 of 57

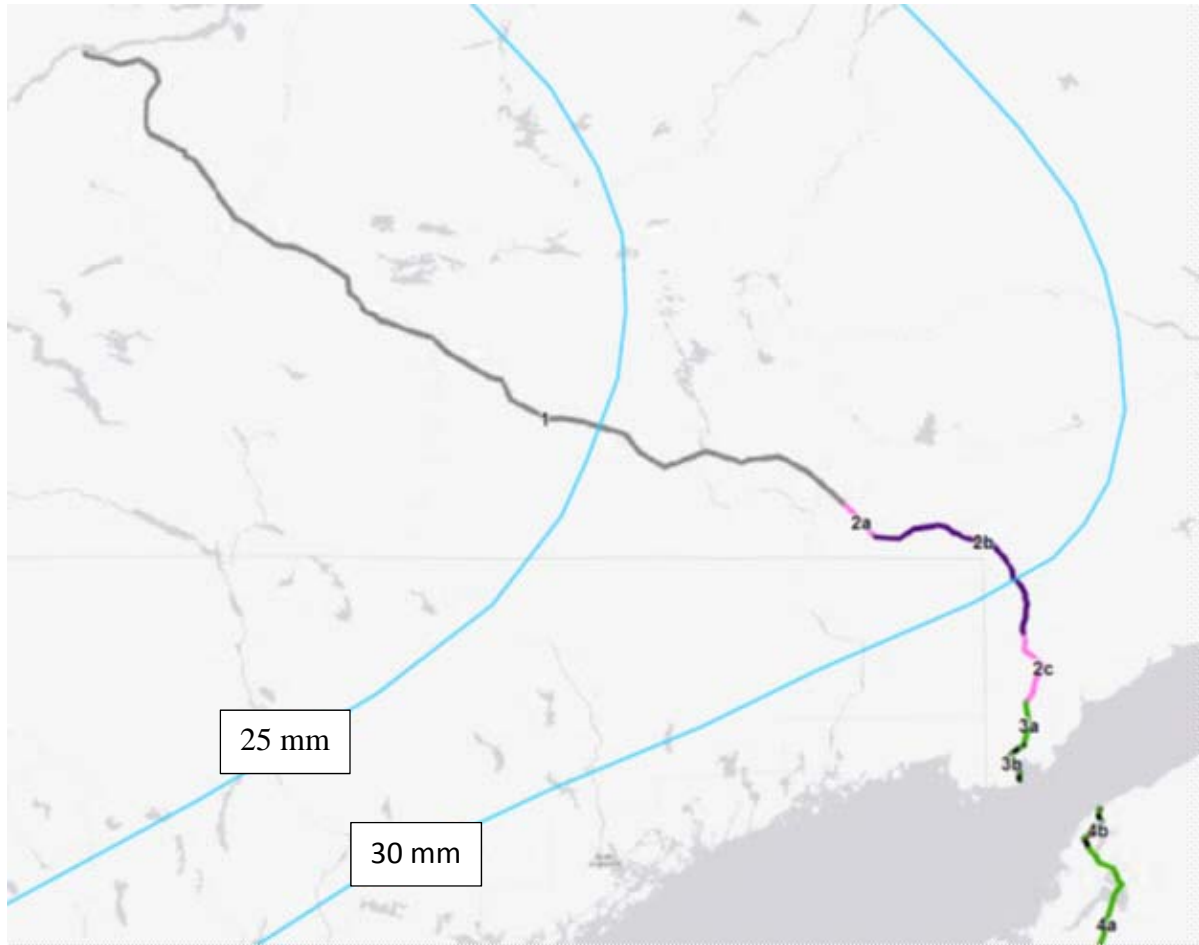
1 No structure was loaded beyond 100% of its as-designed structural capability in any
2 of these scenarios.

3

4 In conclusion, the LITL has been designed in accordance with applicable standards
5 and it meets climatic loading conditions commensurate with its important role in
6 the Island Interconnected System.

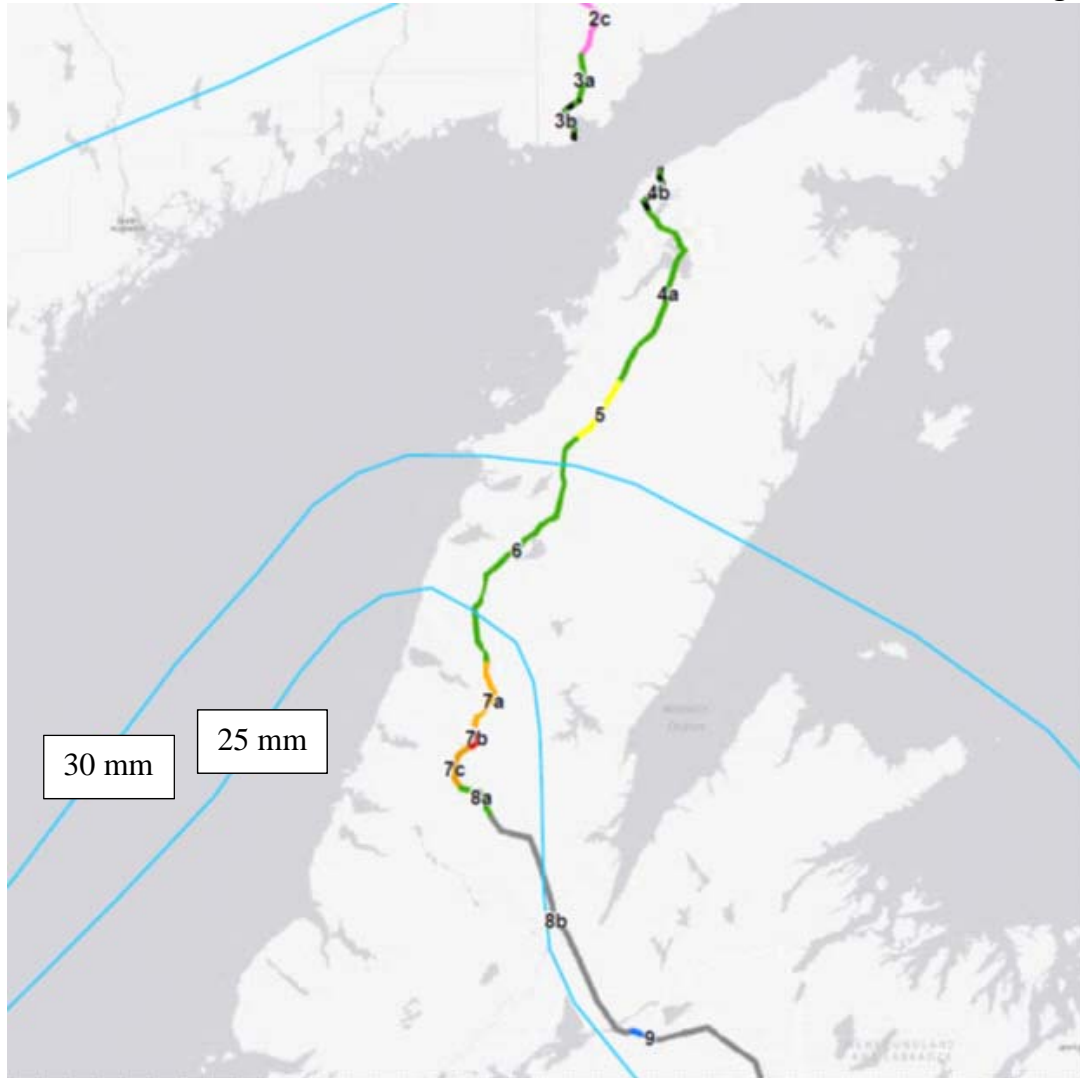
1
2

Appendix A: CSA Ice Load Regions



3
4

Figure A-1: CAN/CSA 22.3 No. 60826-10 Reference Contours – Labrador



1
2
3

Figure A-2: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland West

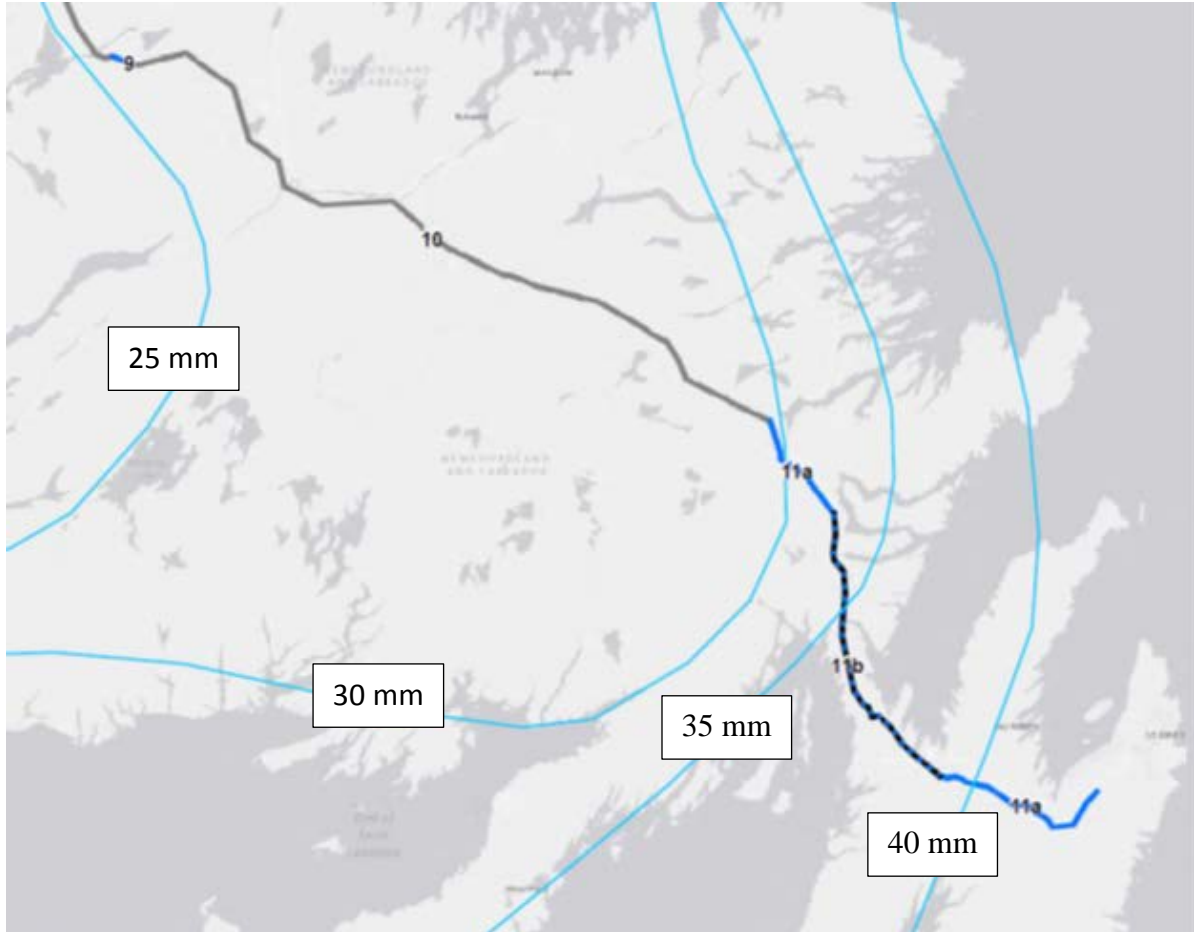
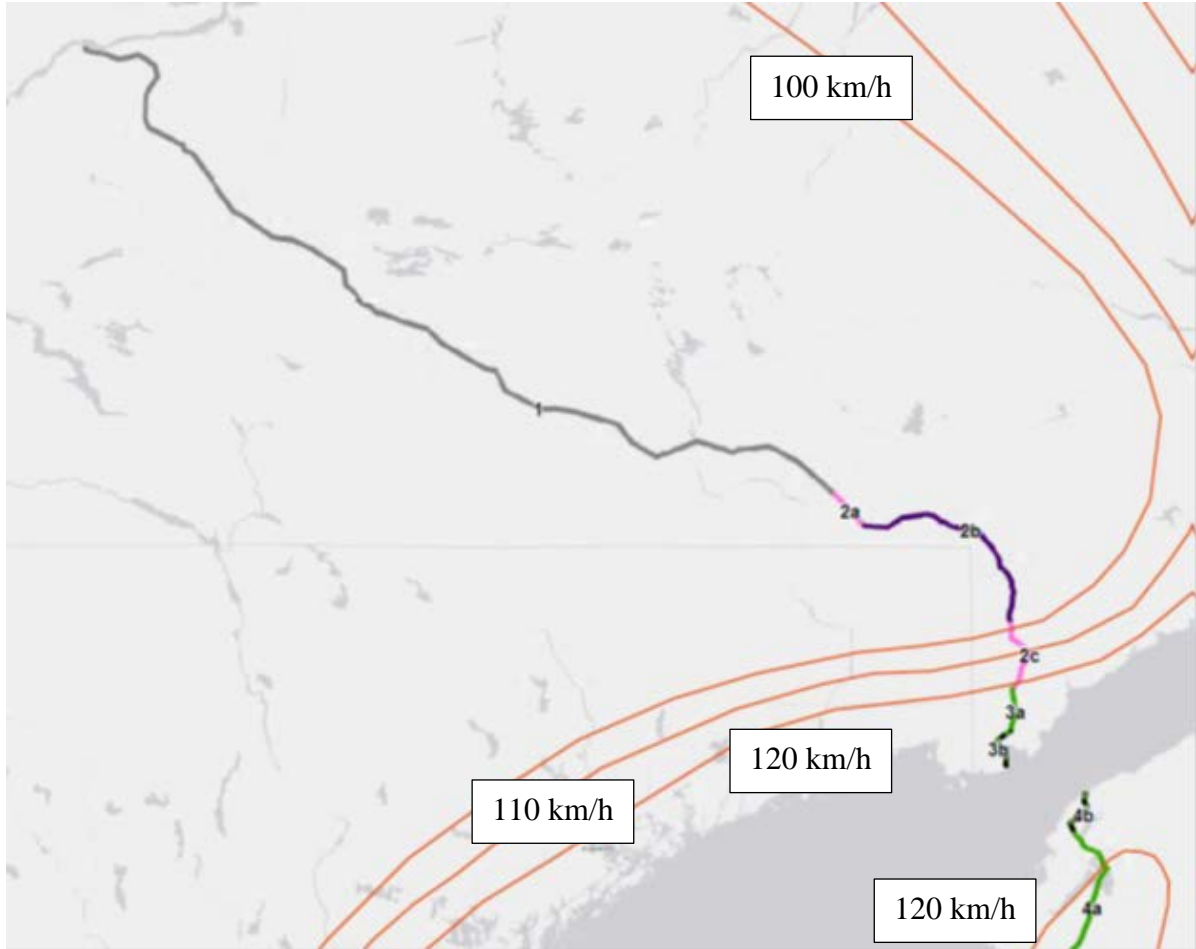


Figure A-3: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland East

1
2
3

1
2

Appendix B: CSA Wind Load Regions



3
4

Figure B-1: CAN/CSA 22.3 No. 60826-10 Reference Contours – Labrador

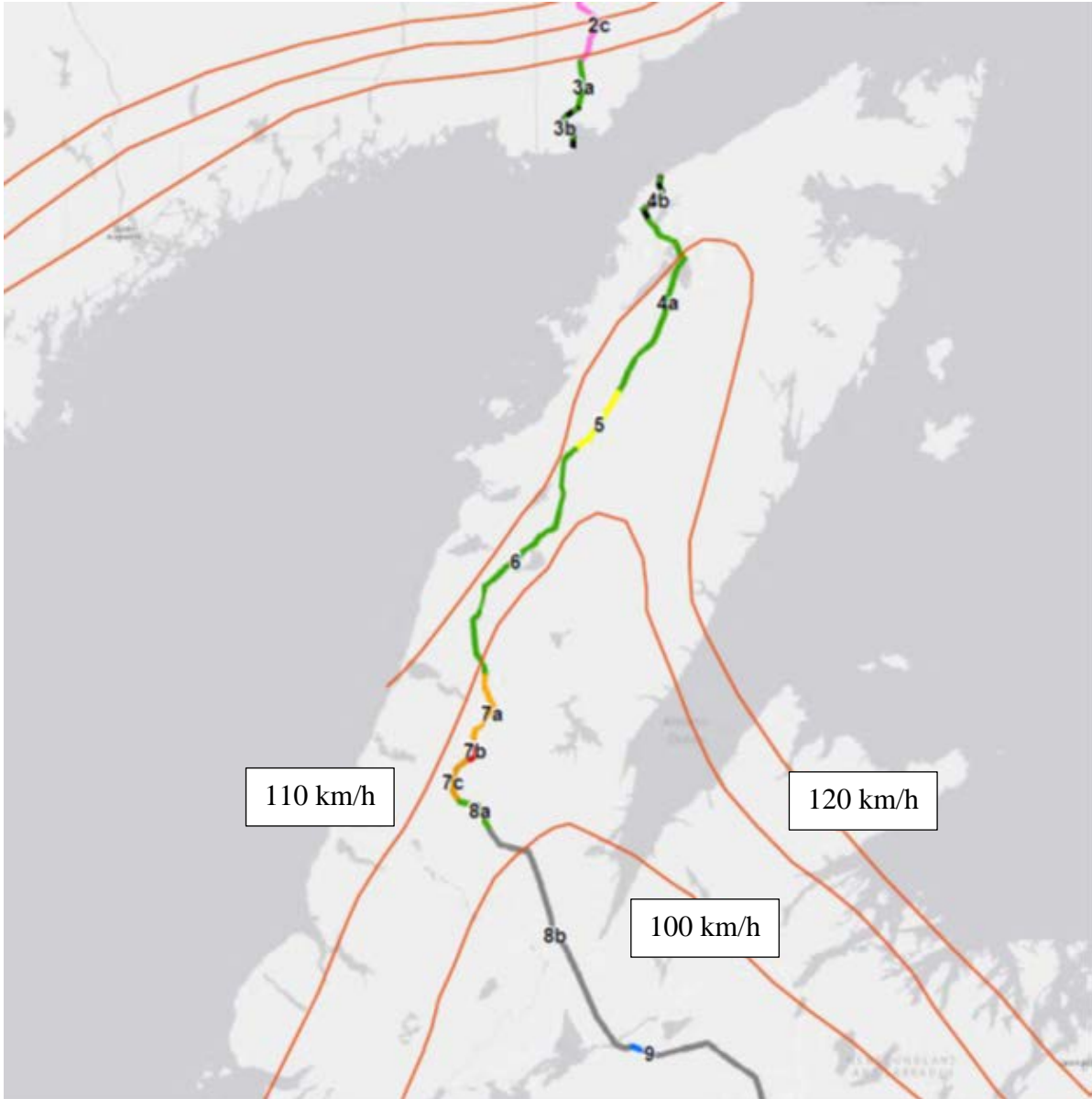
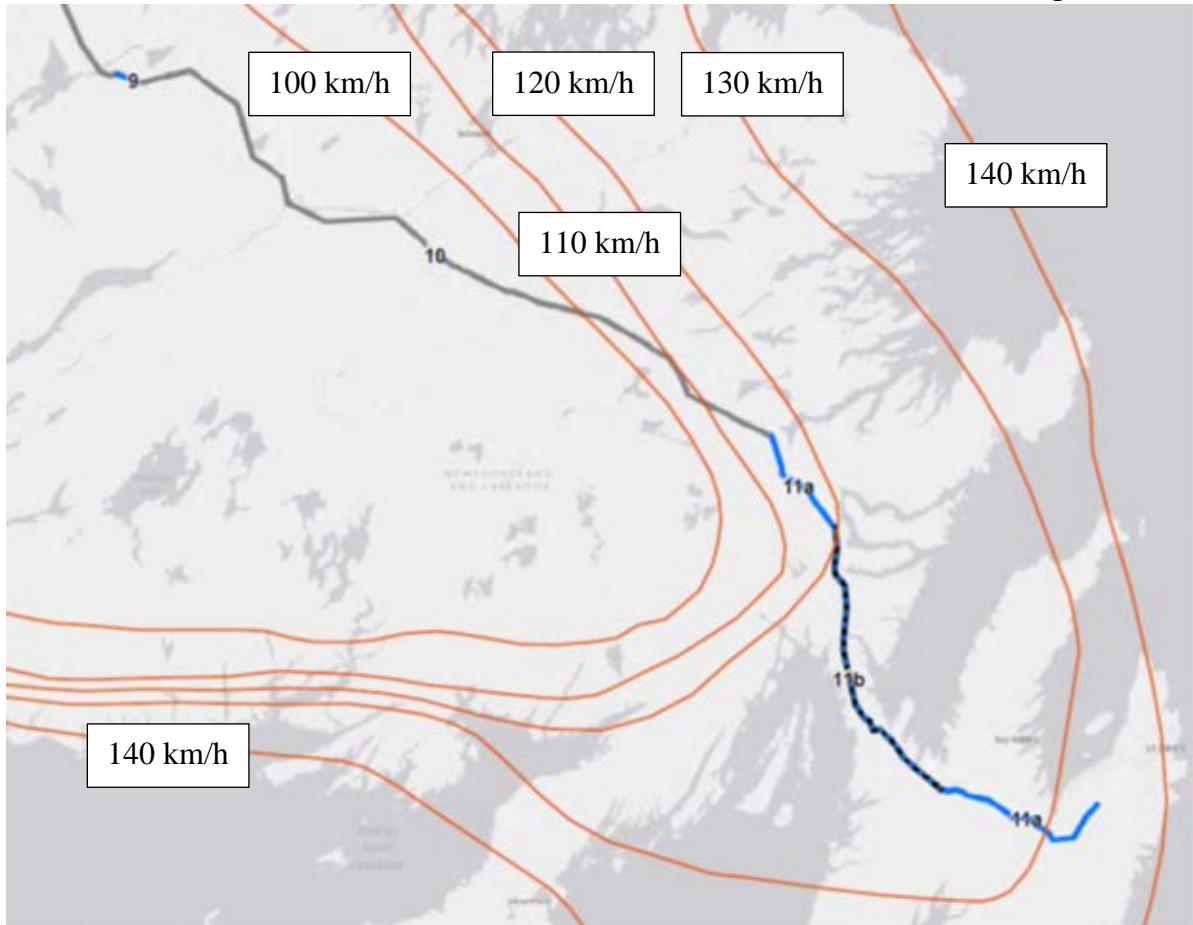


Figure B-2: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland North

1
2
3

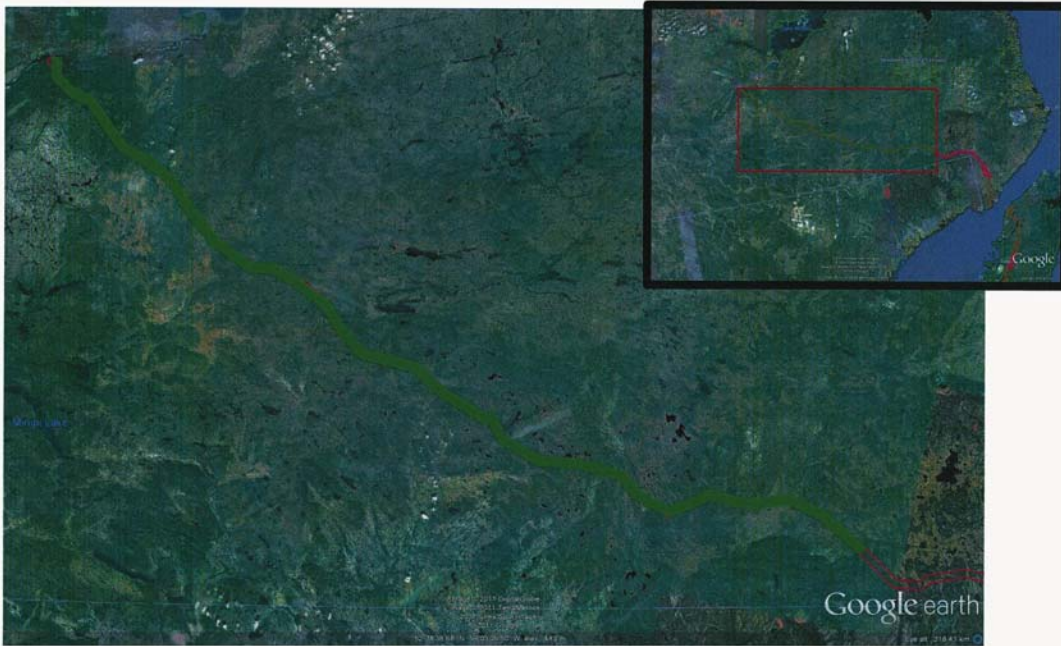


1
2
3

Figure B-3: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland South

APPENDIX A – Ice Loading Region Maps

Appendix A updated with current meteorological loadings. Loadings are highlighted in each zone



Zone 1 – Inner Labrador

Average Meteorological Loading Zone

Maximum Ice: 50 mm glaze, Maximum Wind: 105 km/h, Combined Ice and Wind: 25 mm glaze and 60 km/h



Zone 2a – Alpine Labrador

High Alpine Meteorological Loading Zone

Maximum Ice: 115 mm (Rime), Maximum Wind: 135 km/h, Combined Ice and Wind: 60 mm (Rime) and 95 km/h



Zone 2b – Alpine Labrador

Extreme Alpine Meteorological Loading Zone

Maximum Ice: 135 mm (Rime), Maximum Wind: 135 km/h, Combined Ice and Wind: 70 mm (Rime) and 95 km/h



Zone 2c – Alpine Labrador

High Alpine Meteorological Loading Zone (Western Corridor Alternative Only)

Maximum Ice: 115 mm (Rime), Maximum Wind: 135 km/h, Combined Ice and Wind: 60 mm (Rime) and 95 km/h



Zone 5 – Highlands of St. John

High Alpine Meteorological Loading Zone (Western Corridor Alternative Only)

Maximum Ice: 115 mm (Rime), Maximum Wind: 150 km/h, Combined Ice and Wind: 60 mm (Rime) and 105 km/h



Zone 6 –Northern Peninsula

Average Meteorological Loading Zone

Maximum Ice: 50 mm (Glaze), Maximum Wind: 120 km/h, Combined Ice and Wind: 25 mm (Glaze) and 60 km/h



Zone 7a – Long Range Mountains Crossing

High Alpine Meteorological Loading Zone (Eastern Corridor Alternative Only)

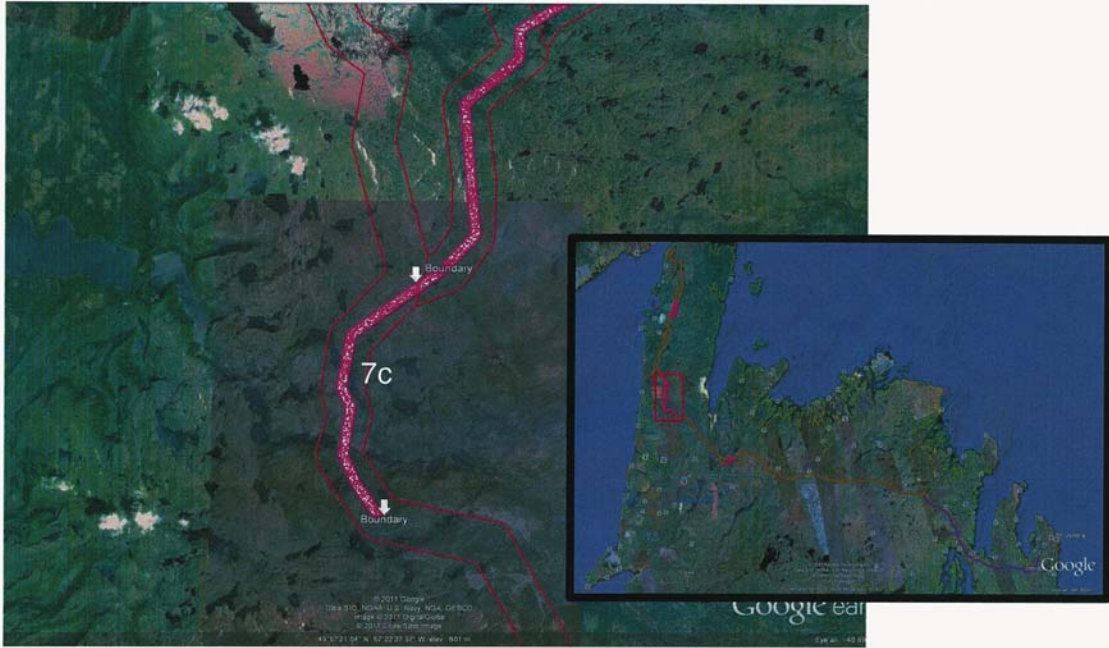
Maximum Ice: 115 mm (Rime), Maximum Wind: 180 km/h, Combined Ice and Wind: 60 mm (Rime) and 125 km/h



Zone 7b – Long Range Mountains Crossing

Extreme Alpine Meteorological Loading Zone (Eastern Corridor Alternative Only)

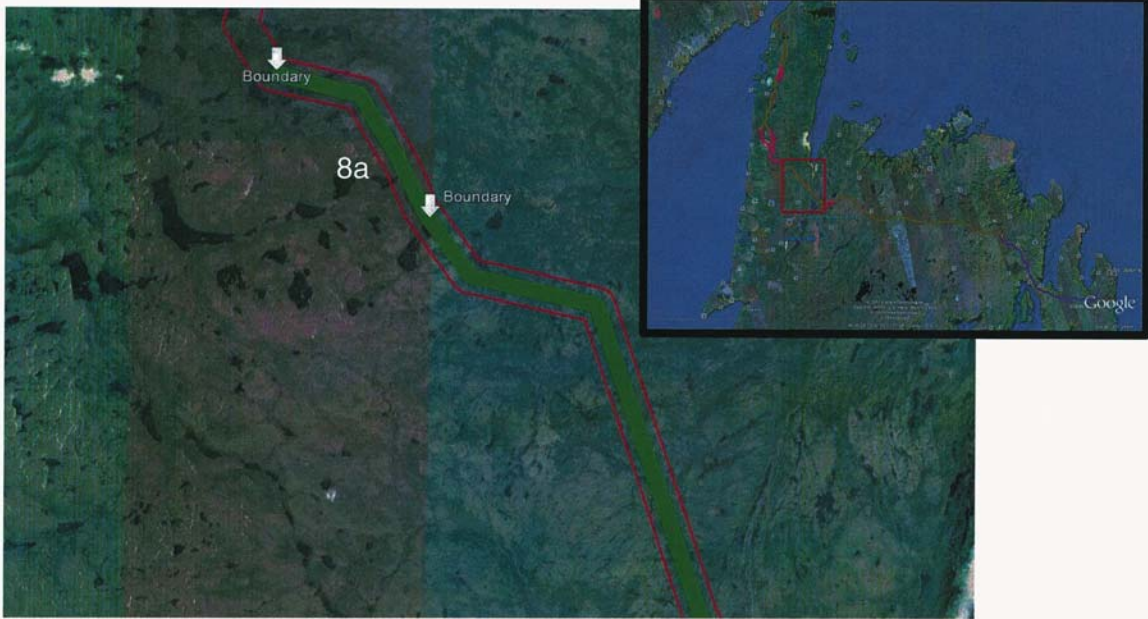
Maximum Ice: 135 mm (Rime), Maximum Wind: 180 km/h, Combined Ice and Wind: 70 mm (Rime) and 125 km/h



Zone 7c – Long Range Mountains Crossing

High Alpine Meteorological Loading Zone

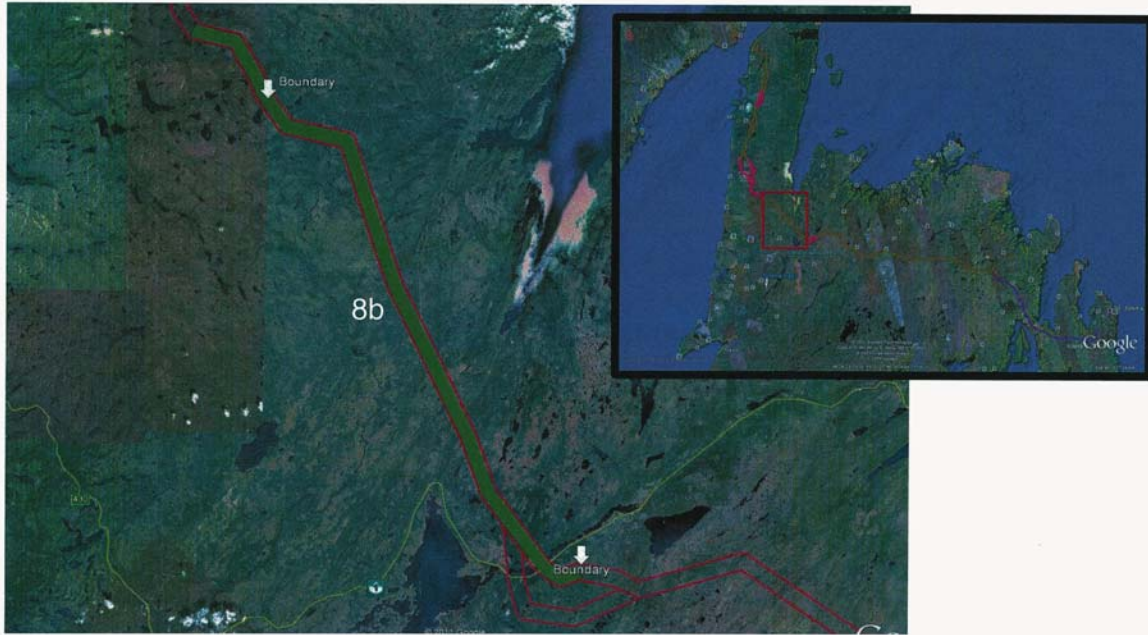
Maximum Ice: 115 mm (Rime), Maximum Wind: 180 km/h, Combined Ice and Wind: 60 mm (Rime) and 125 km/h



Zone 8a – Central-West Newfoundland

Average Meteorological Loading Zone

Maximum Ice: 50 mm (Glaze), Maximum Wind: 120 km/h, Combined Ice and Wind: 25 mm (Glaze) and 60 km/h



Zone 8b – Central-West Newfoundland

Average Meteorological Loading Zone

Maximum Ice: 50 mm (Glaze), Maximum Wind: 105 km/h, Combined Ice and Wind: 25 mm (Glaze) and 60 km/h



Zone 9 – The Birchy Narrows

Alpine Meteorological Loading Zone (Northern Corridor Alternative Only)

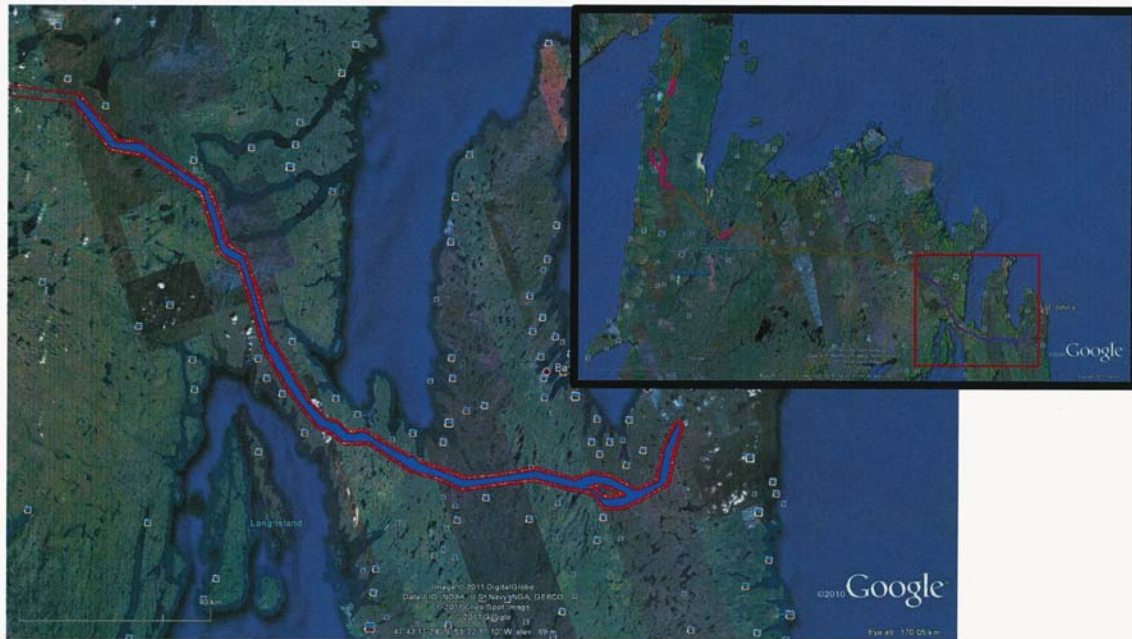
Maximum Ice: 75 mm (Glaze), Maximum Wind: 130 km/h, Combined Ice and Wind: 45 mm (Glaze) and 60 km/h



Zone 10 – Central-East Newfoundland

Average Meteorological Loading Zone

Maximum Ice: 50 mm (Glaze), Maximum Wind: 105 km/h, Combined Ice and Wind: 25 mm (Glaze) and 60 km/h



Zone 11 – Eastern Newfoundland

Eastern Meteorological Loading Zone

Maximum Ice: 75 mm (Glaze), Maximum Wind: 130 km/h, Combined Ice and Wind: 45 mm (Glaze) and 60 km/h