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

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

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

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

As a result, the statement that "Nalcor has selected a 1:50-year reliability return period" is not reflective of the final climatic loading design criteria for the LITL, the results of a comparison of LITL design loads to CSA reference loads, nor its as-designed capability.

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

The following conclusions are supported in this response:

- 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.
- In addition to the design criteria established for the LITL, 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 as-designed 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 Landsvirkjun Power (LVP), 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 International Electrotechnical Commission (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 rime or glaze 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 capacity in any of these scenarios.

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

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

A.1.2.5 Selection of reliability levels

> Transmission lines can be designed for different reliability levels (or classes) depending on local requirements and the line duties within a supply network.
>
> Designers can choose their reliability levels either by calibration with existing lines that have had a long history of satisfactory performance or by optimisation methods found in technical literature.
>
> In all cases, lines should at least meet the requirements of a reliability level characterized by a return period of loads of 50 years (level 1).

> An increase in reliability above this level could be justified for more important lines of the network as indicated by the following guidelines:
>
> - It is suggested to use a reliability level characterised by return periods of 150 years for lines above 230 kV. The same is suggested for lines below 230 kV which constitute the principal or perhaps the only source of supply to a particular electric load (level 2).
>
> - Finally, it is suggested to use a reliability level characterised by return periods of 500 years for lines, mainly above 230 kV which constitute the principal or perhaps the only source of supply to a particular electric load. Their failure would have serious consequences to the power supply.
>
> The applications of the reliability for overhead lines, including corresponding voltage levels, may be set differently in individual countries depending on the structure of the grid and the consequences of line failures. The impacts on other infrastructure installations such as railroads and motorways should be considered as well.
>
> When establishing national and regional standards or specifications, decisions on the reliability level should be made taking into consideration also the experience with existing lines.

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

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

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

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

a) Reference wind and ice loading as provided in the CSA standard;
b) A study undertaken by Kathleen Jones of the Cold Regions Research and Engineering Laboratory;[1]
c) Hydro's applicable nearly 50-year operating history along the transmission line route;[2] and
d) A study undertaken by Landsvirkjun Power which evaluated rime (or in-cloud) ice loadings, which are a design consideration along the LITL's route, but are not addressed by CAN/CSA 22.3 No. 60826.[3]

Some design aspects warranted special engineering consideration:

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

These approaches were all taken to improve the reliability of the LITL and to mitigate operating risk.

The standard also recognizes a level of variability in performance, and IEC 60826 discusses reliability levels and associated failure probabilities in Table A.2 of the 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.

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

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.

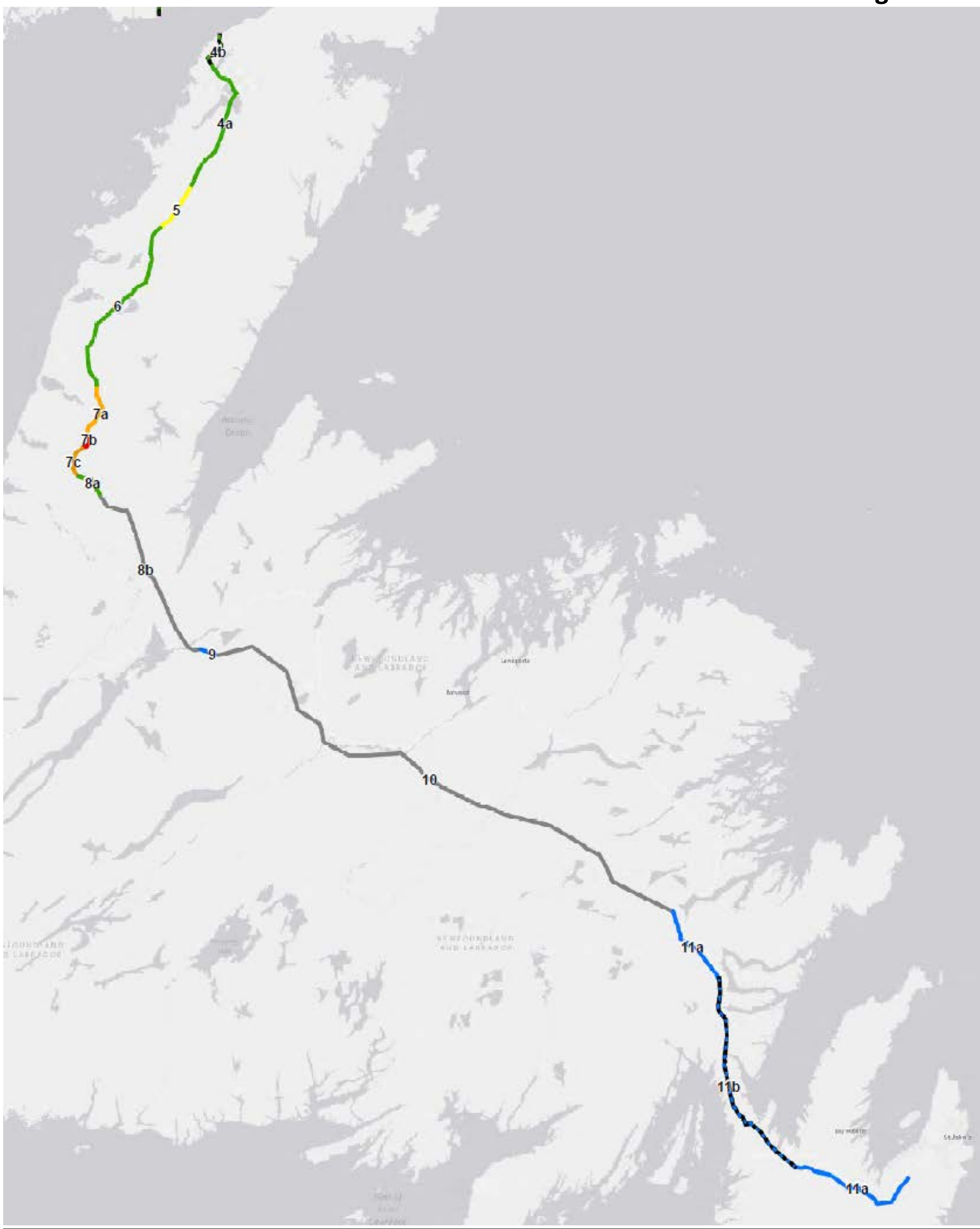
West of Sunnyside, the LITL takes a route that is independent of the 230 kV corridor from Bay d'Espoir. As a result, the two major transmission systems serving the Avalon Peninsula are geographically separated from each other. Given the separation and the independent generation available on each system,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

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

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

Figure 1 – LITL Transmission Route

1 **Figure 2 – LITL Transmission Route and Meteorological Zones - Labrador**



1 **Figure 3 – LITL Route and Meteorological Zones - Newfoundland**

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

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

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

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.

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

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

Evaluation of LITL Against CSA Climatic Loadings

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

Four criteria are considered:

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

Glaze Ice

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

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

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

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

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

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.

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

> "The climatic loadings for each line section are approximately equivalent to the climatic loadings calculated assuming Canadian Standards Association (CSA) 1:500-year return periods."

MHI prepared the following figure[14] to illustrate this:

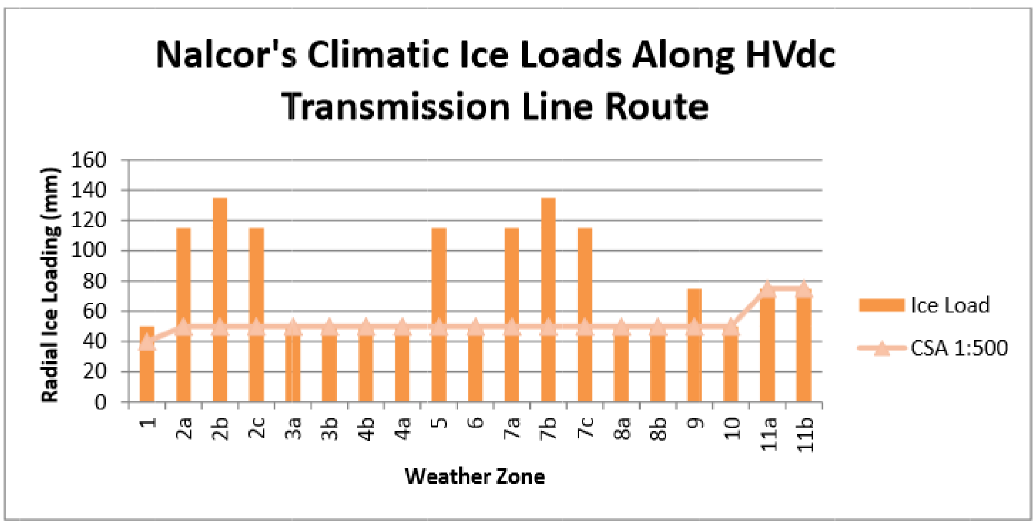


Figure 9: Climatic Ice Loads along the HVdc Transmission Line Route compared to the CSA Standard 1:500-year return period limit

Figure 4 – Climatic Ice Loads from MHI DG3 Report

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

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]

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]

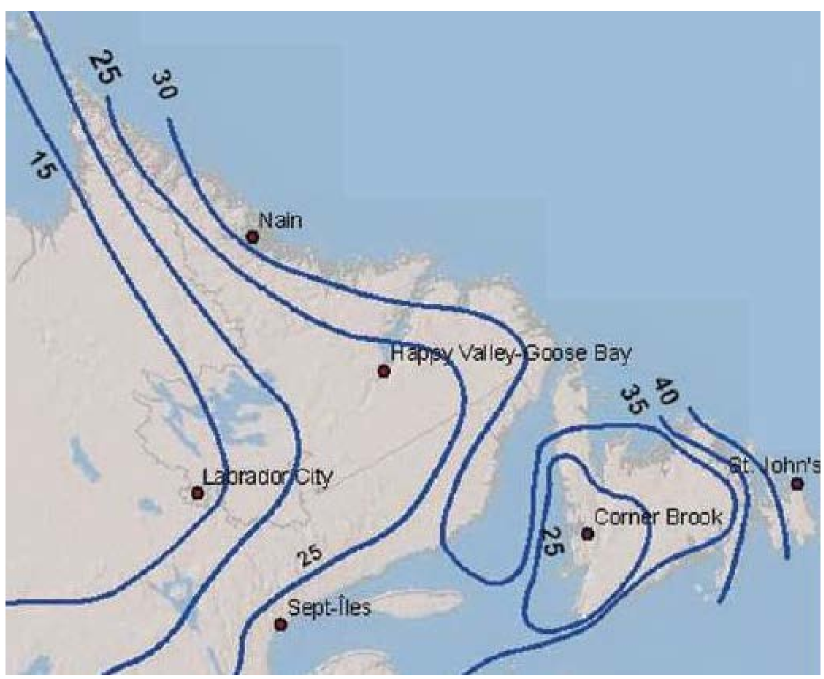


Figure 5 – CSA Glaze Ice Loading Zones for NL

[15] Approximately equivalent.
[16] Contours represent reference ice in mm.

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

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

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

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.

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

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

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.

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

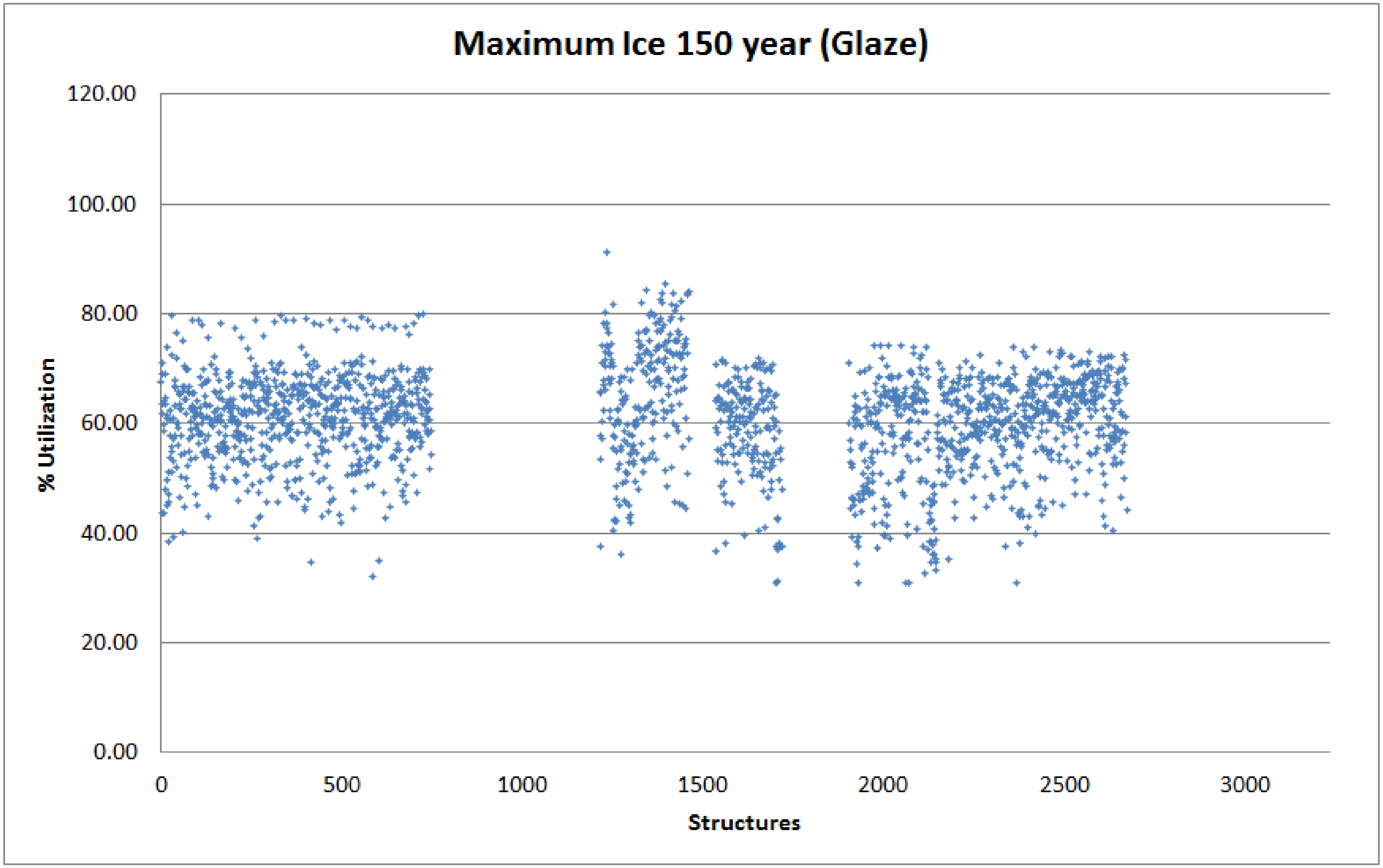
In Zones 3 and 4, the structures would be required to withstand a design loading of 54 mm rather than 50 mm to achieve the desired 150-year design return period. The as-designed structures in Zones 3 and 4 were re-analyzed at 54 mm[20] radial glaze ice loads, and all structures were confirmed to be loaded to less than their design capabilities, thus indicating that they are designed in a manner to withstand glaze ice loads in excess of CSA 150-year loadings.

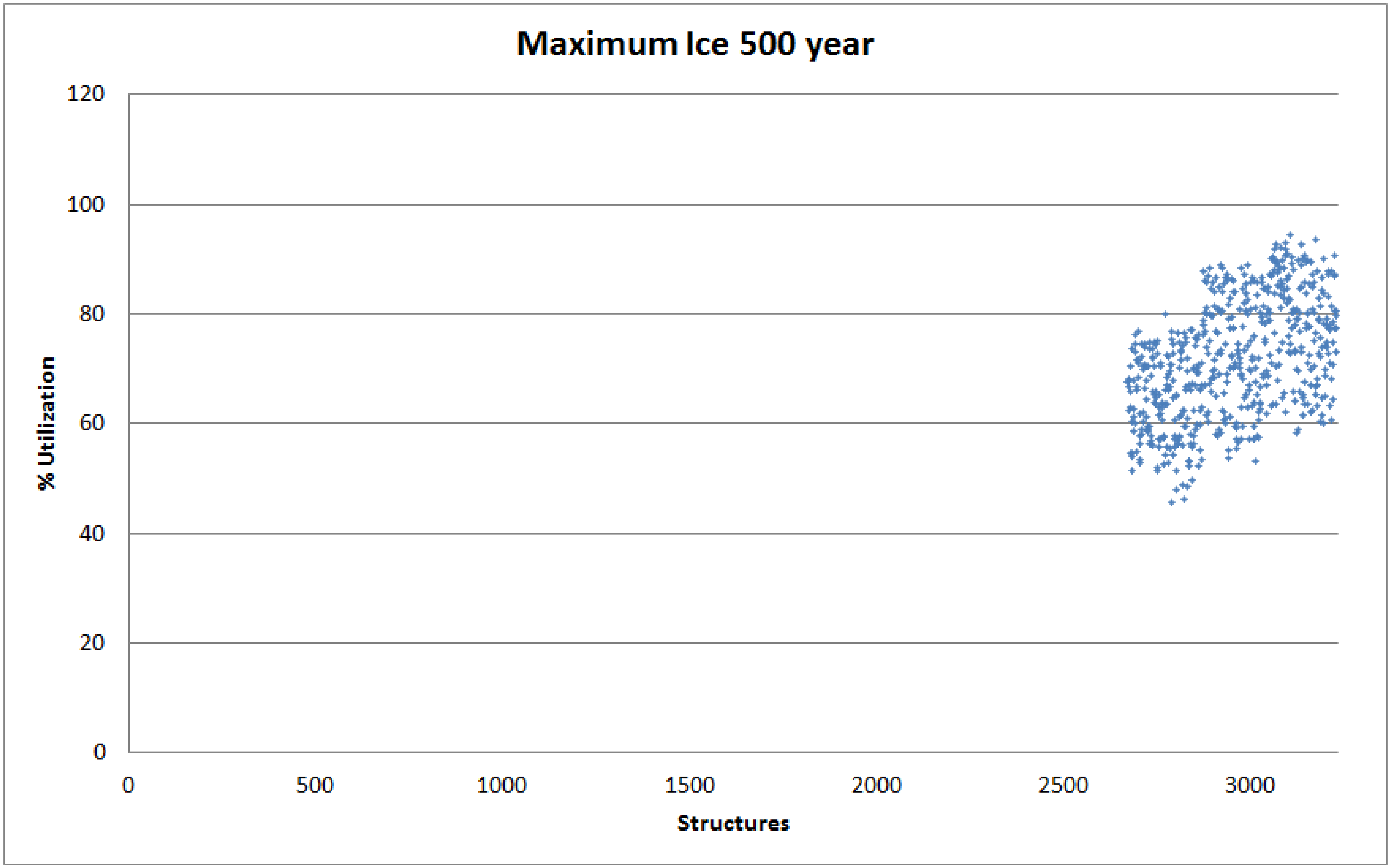
Further analysis was also undertaken to verify the as-designed structural capacity of the LITL in Zones 11-2, 11-3, and 11-4. The as-designed structures were re-analyzed at the noted CSA 500-year loading, and all structures were confirmed to be loaded to less than their design capabilities, thus indicating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

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

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

[20] CSA 150-year loading


Maximum Ice 150 year (Glaze)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Utilization
0
500
1000
1500
2000
2500
3000
Structures


Maximum Ice 500 year
120
100
80
60
40
20
0
% Utilization
0
500
1000
1500
2000
2500
3000
Structures

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

Rime Ice

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

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

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

The WOBs model was used to analyze and determine the 50-year icing levels for both the 2009-1 and 2009-2 sites. The WRF model was used to predict rime ice accretion throughout the Long Range Mountains corridor. From the WRF model and the typical result displayed in Figure 6 below, it was obvious that the worst area of exposure and rime ice load was in the area of test span 2009-1.

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

As indicated in Table 8 of the report, [21] reference rime ice loadings were predicted 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

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

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

[21] http://www.pub.nl.ca/applications/MuskratFalls2011/files/exhibits/Exhibit95.pdf, page 49.

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

Given the remote nature of the area and concerns about access to this area during the winter period, the heavier rime ice load was maintained as a design load. Although Zone 7b experiences rime ice near the levels of test span 2009-2 (9 kg/m, or 52 mm radial rime), the rime ice level of 2009-1 were used for this area, given that it is between 550 m and 600 m elevation. The remainder of the Long Range Mountains used a reduced level of 115 mm radial Rime (31 kg/m), but this value is still significantly higher than the model indicated for the selected line route.

As further security, given the observation that rime ice will shed off the conductors but not necessarily off the tower, given the lattice tower layout, towers were designed to be completely encased in rime ice, with no voids. Therefore, instead of just using an elevated icing level on the tower, it was assumed that the tower would carry the full icing load over the whole structure.

The results from the test spans demonstrate the value of routing the line inland and through valleys at lower elevations. Using Figure 56 from Exhibit 95 as a basis, Figure 6 below shows the test span locations, the transmission line study corridors (bounded by red lines), and the final transmission line route (shown as the yellow 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.

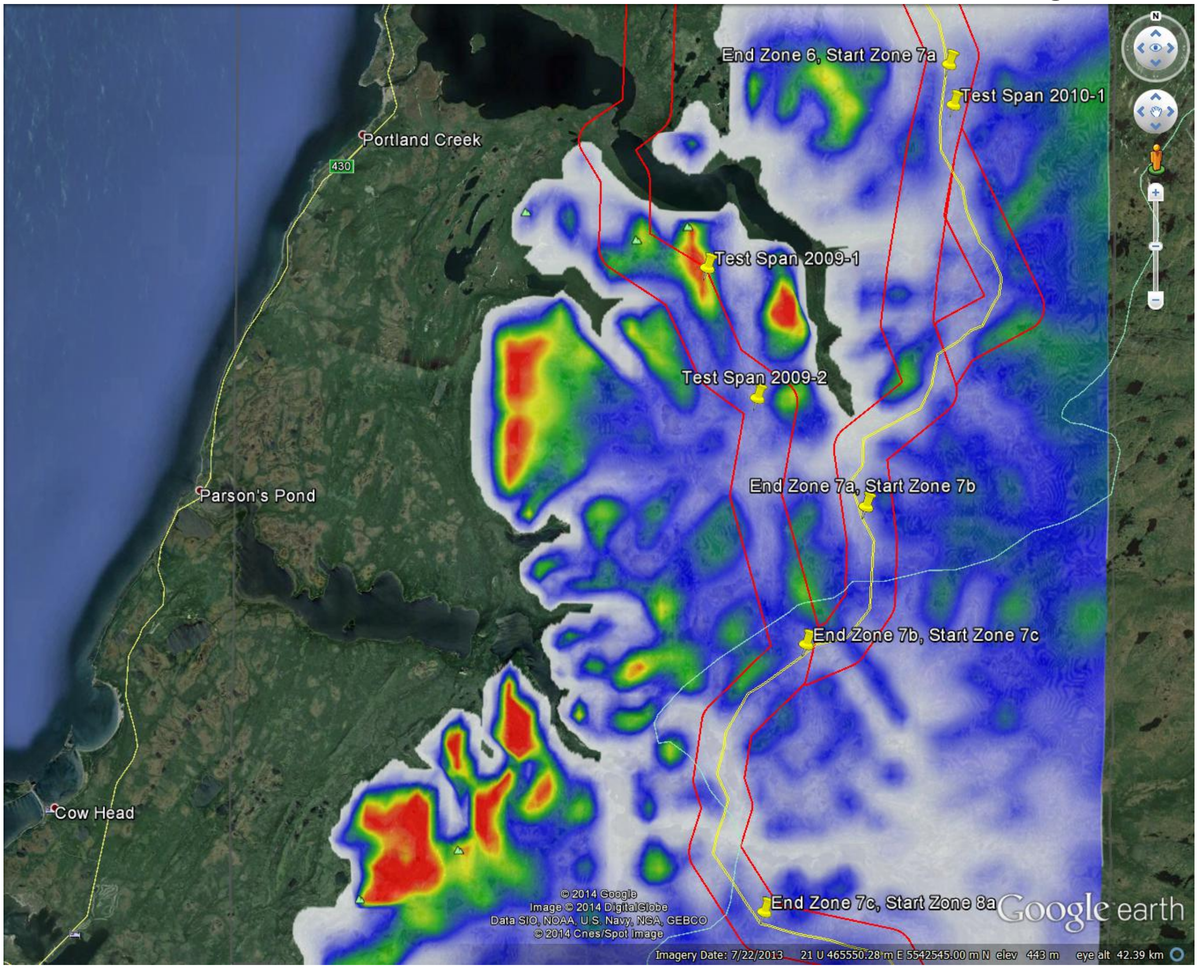


Figure 6 – Rime Ice Accretion in Long Range Mountain Crossing

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.

The design criteria, along with the 50, 150, and 500-year structure loadings 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

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

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

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

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

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

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

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

Wind

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

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

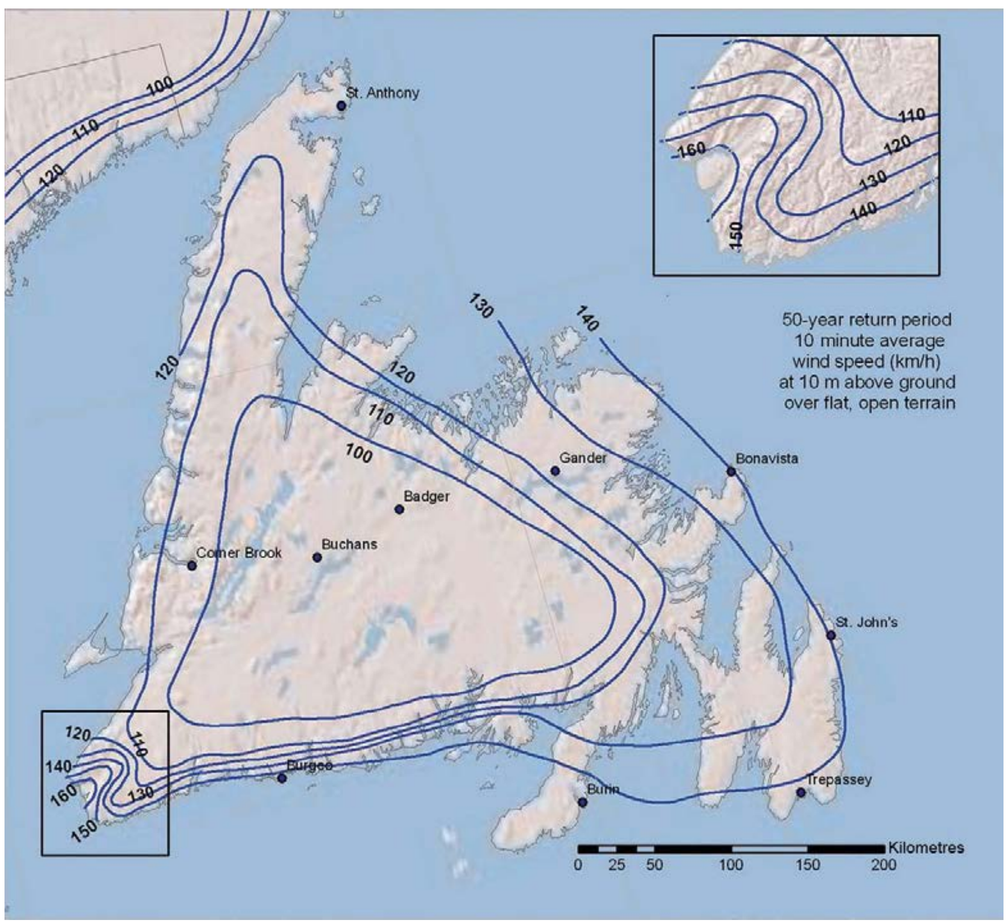


Figure 7 – Figure CA.1 from CAN/CSA C22.3 No. 60826

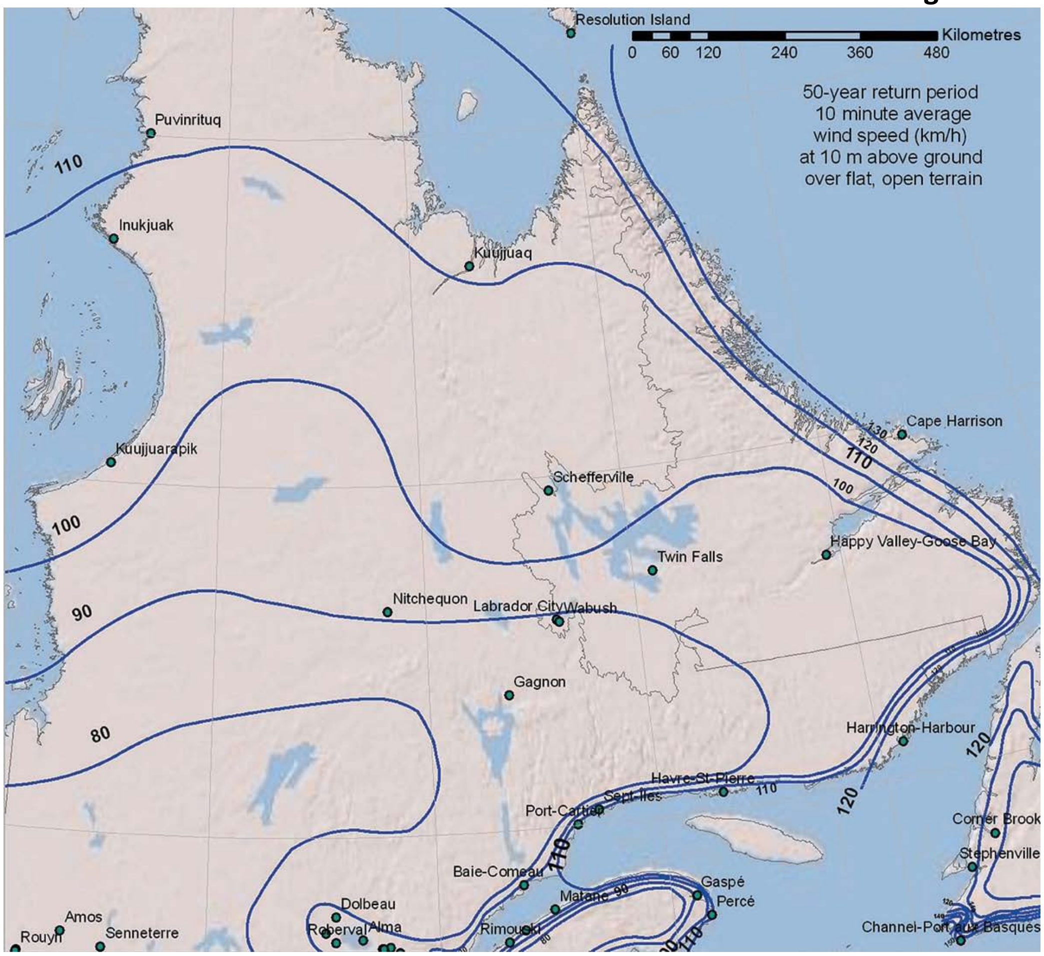


Figure 8 – Figure CA.3 from CAN/CSA C22.3 No. 60826

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.

The 50-year reference loadings[23] for each zone are as follows:

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

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

> Wind speed and turbulence depends on the terrain roughness. With increasing terrain roughness, turbulence increases and wind speed decreases near ground level. Four types of terrain categories, with increasing 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.

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

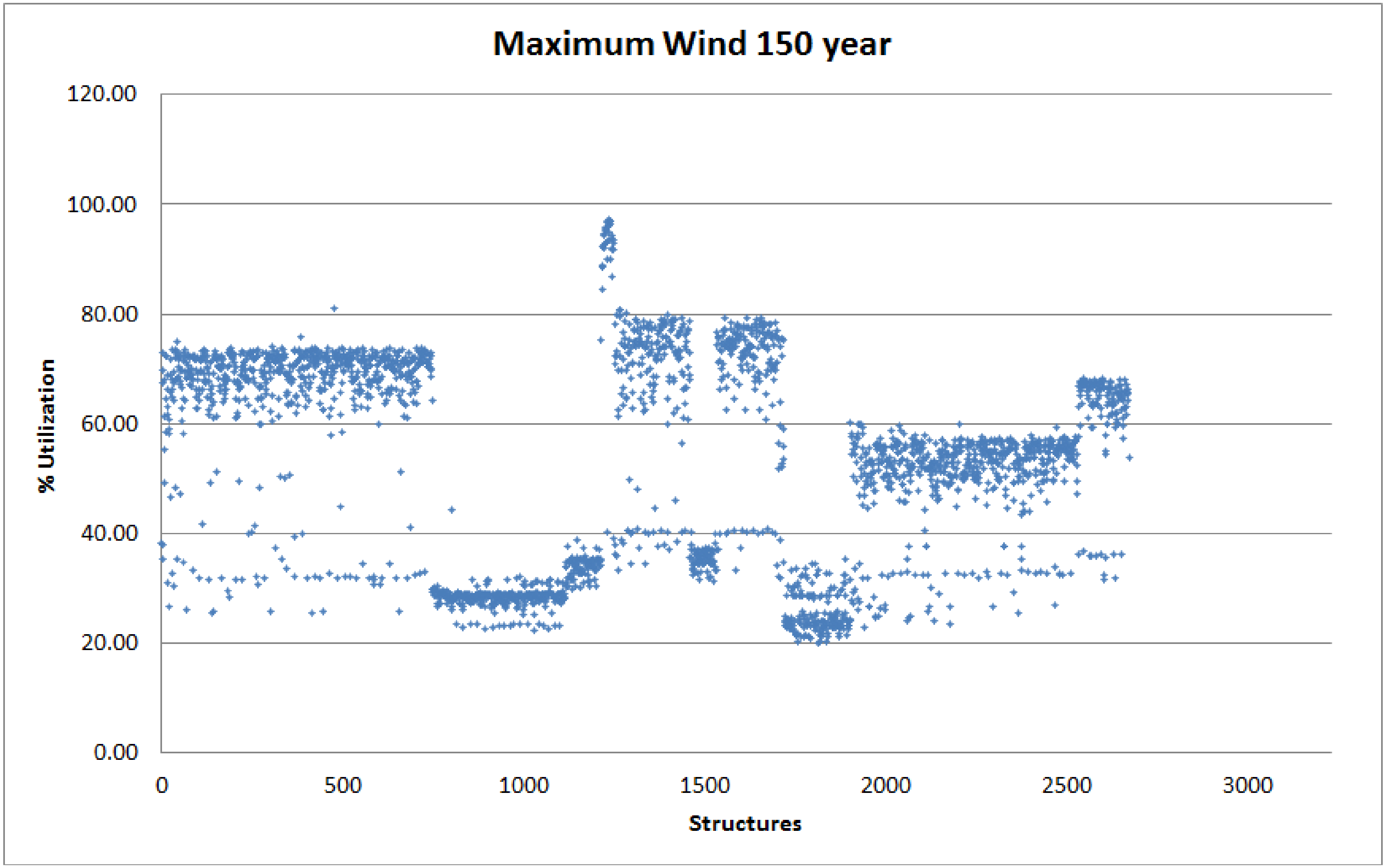
The reference wind speeds in the CSA standard correspond to Terrain Category B conditions. The vast majority of the LITL route is through forested or hilly terrain rather than through open country as might be expected at an airport. Design calculations consider these effects, and therefore Terrain Category 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]

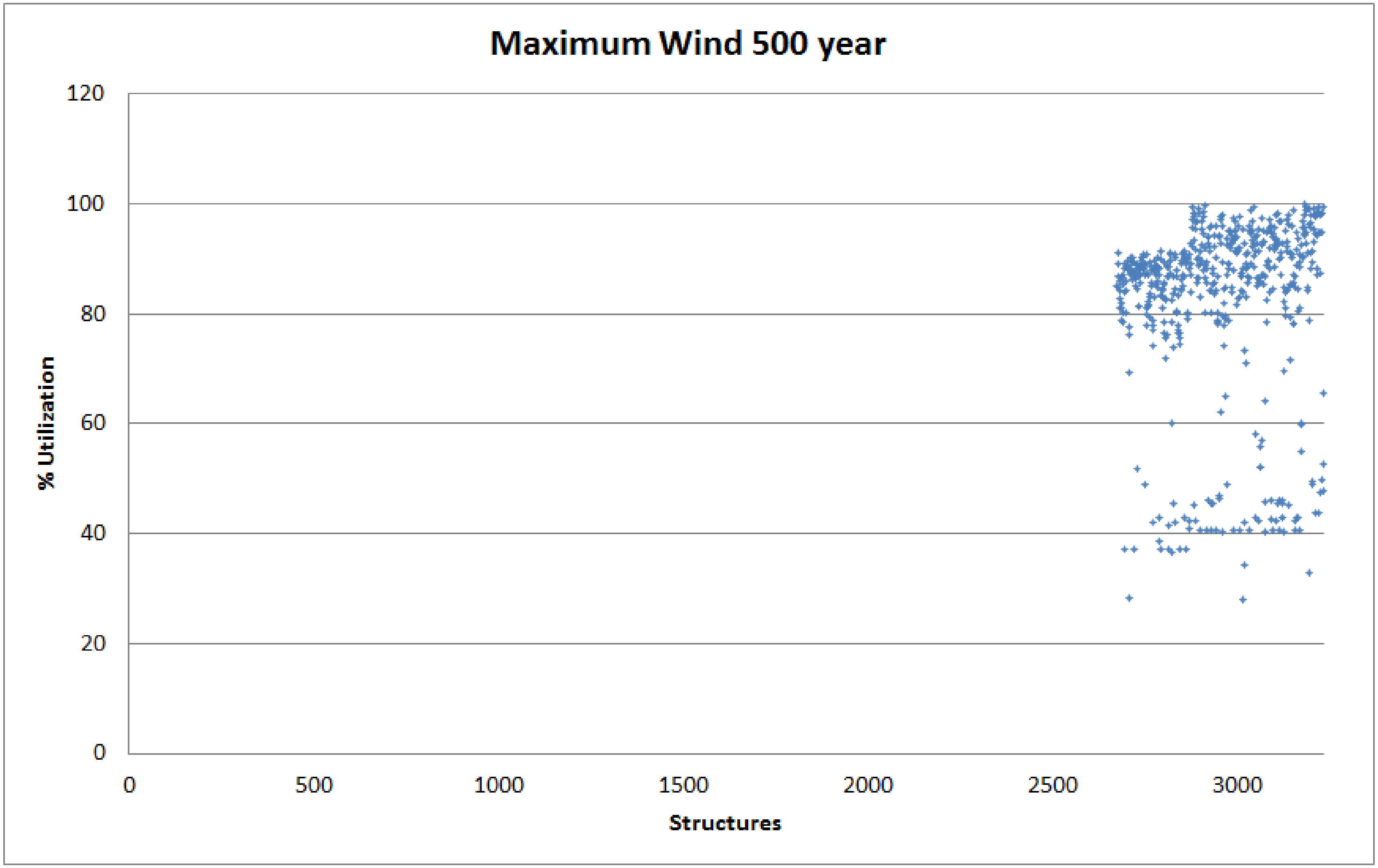
Based on Table CA.2[25] of CAN/CSA 22.3 No. 60826, the adjustment factors to modify the 50-year reference for wind to 150-year and 500-year return periods are 1.10 and 1.20 respectively.[26] The LITL wind design criteria, along with the 50, 150, and 500-year wind speeds are presented in the following 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.

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

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


Maximum Wind 150 year
% Utilization
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
3000
Structures


Maximum Wind 500 year
120
100
80
60
40
20
0
% Utilization
0
500
1000
1500
2000
2500
3000
Structures

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

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

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

Combined Wind and Ice Loading

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

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

> **6.4.1 Combined probabilities – Principle proposed**
>
> 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.

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

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

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

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

Reference wind speeds are reduced to represent typical maximum wind speeds during icing conditions and also the relative rarity of maximum wind speeds during icing events. The meteorological conditions used[27] are:

Case a) – Extreme Wind + Ice

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

Case b) – Maximum Ice + Wind

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

[27] From IEC 60826, Clause 6.4.2 and 6.4.4.1.

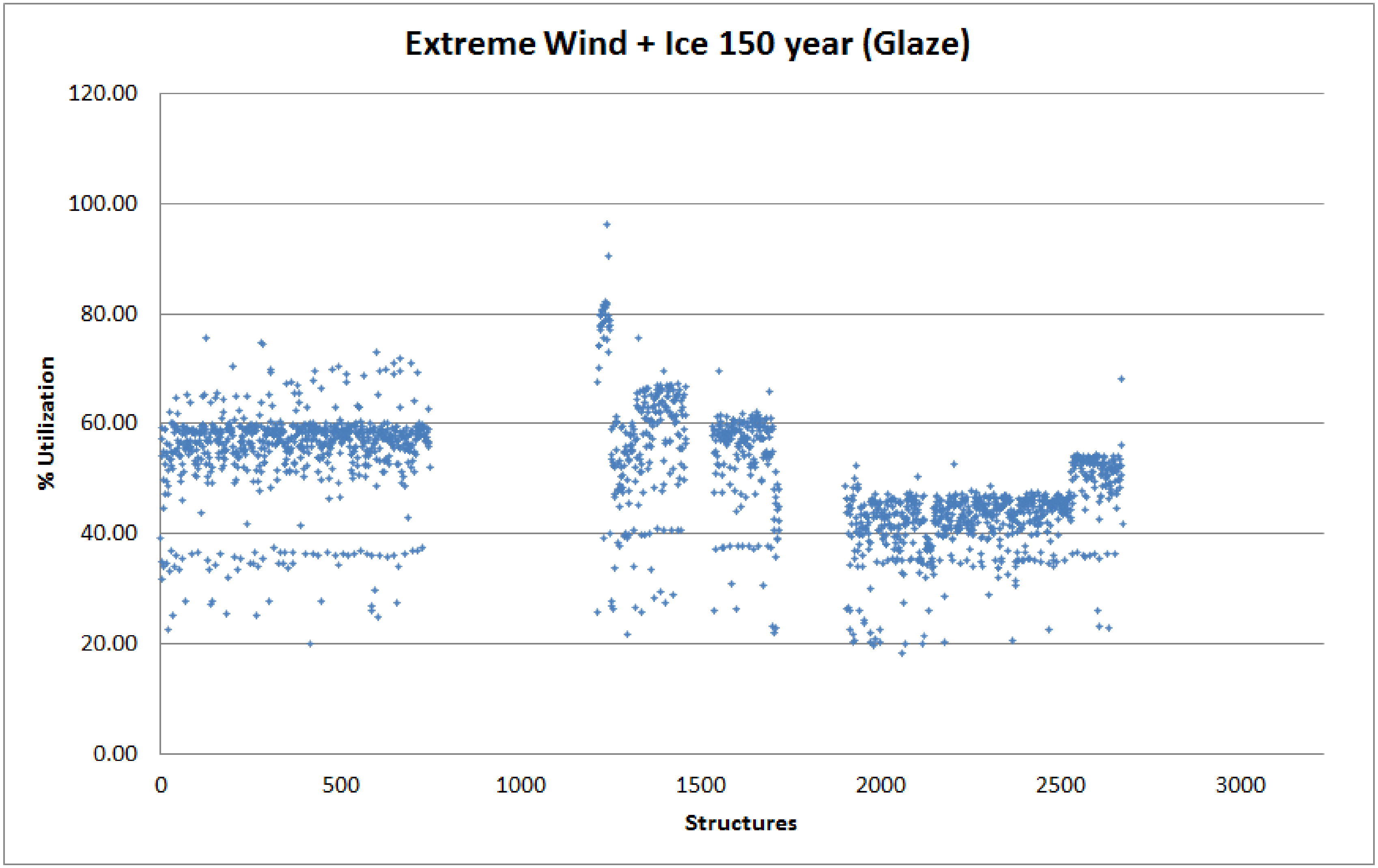
Applying these factors results in IEC Extreme Wind + Ice and IEC Maximum Ice + Wind combined wind-ice conditions for each zone. These combined loadings are presented in the following table:

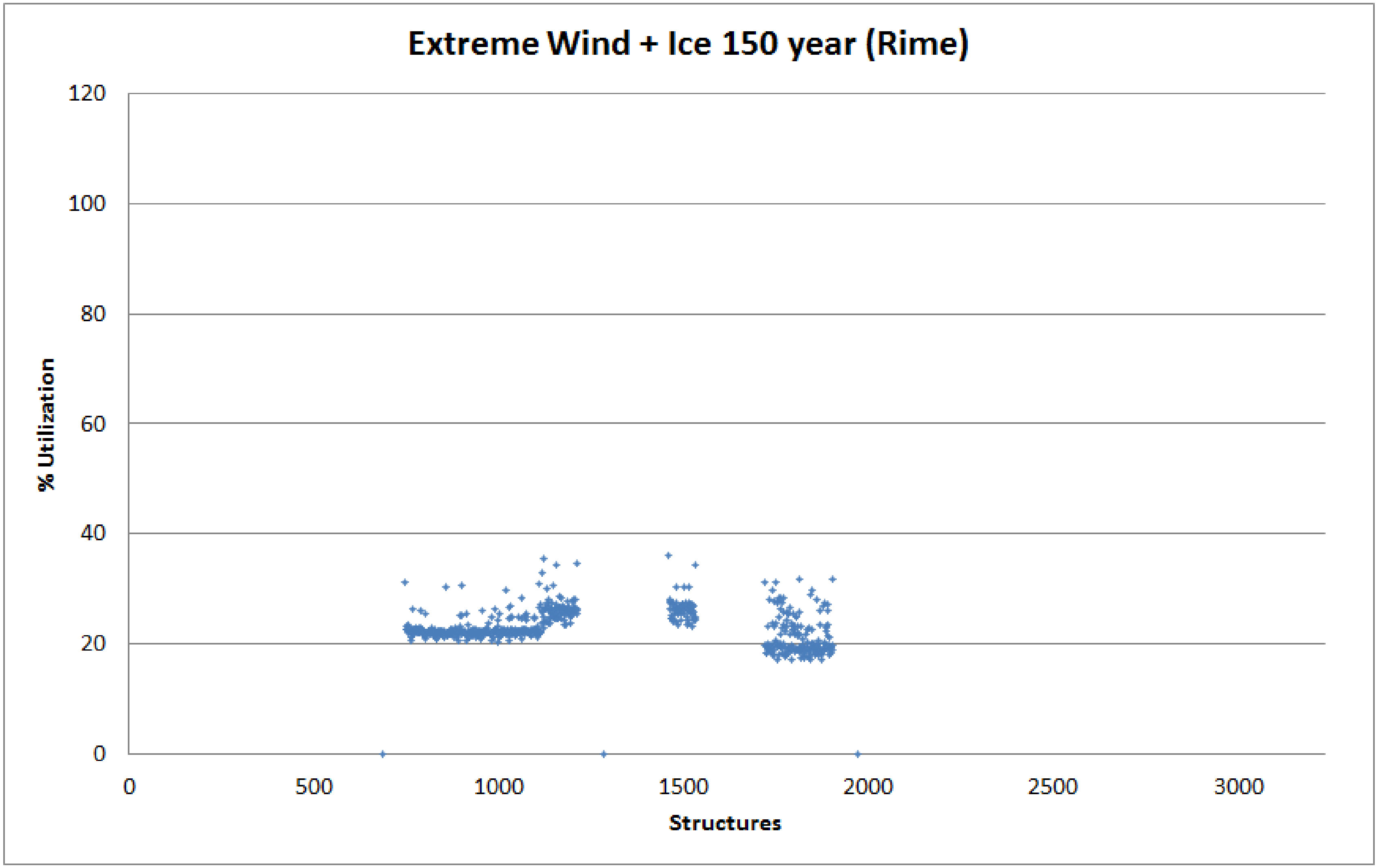
Zone	Type	LCP Combined Wind/Ice		IEC Extreme Wind + Ice		IEC Maximum Ice + Wind	
		Ice	Wind	Ice	Wind	Ice	Wind
1	Glaze	25 mm	60 km/hr	15 mm	72 km/hr	46 mm	45 km/hr
2a	Rime	60 mm	95 km/hr	24 mm	72 km/hr	72 mm	45 km/hr
2b	Rime	70 mm	95 km/hr	24 mm	72 km/hr	72 mm	45 km/hr
2c	Rime	60 mm	95 km/hr	24 mm	79 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

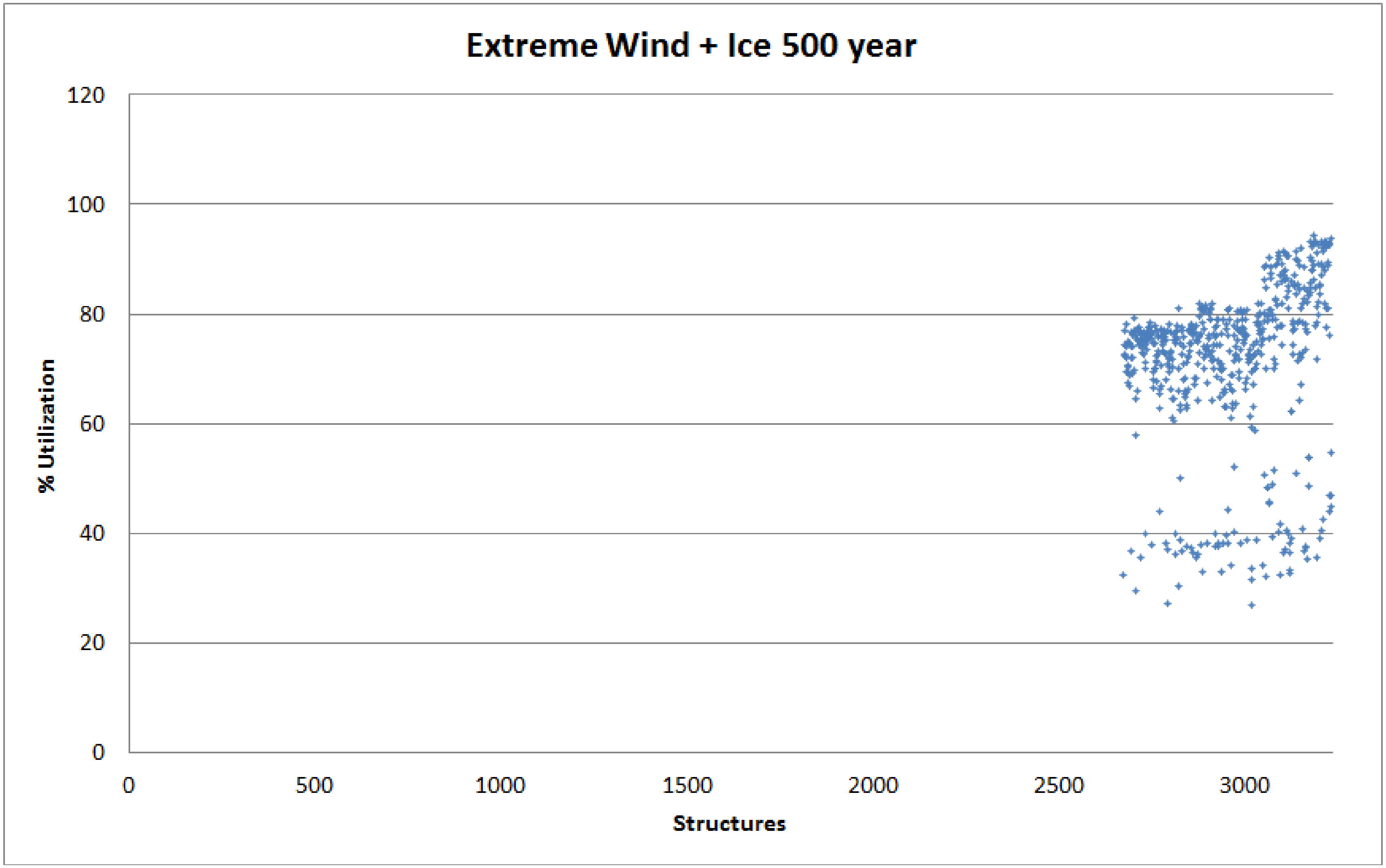
The as-designed structures were then subjected to the combined wind/ice conditions as presented above. In all three cases, no exceedances of the structural capacity of any structure on the line occurred.

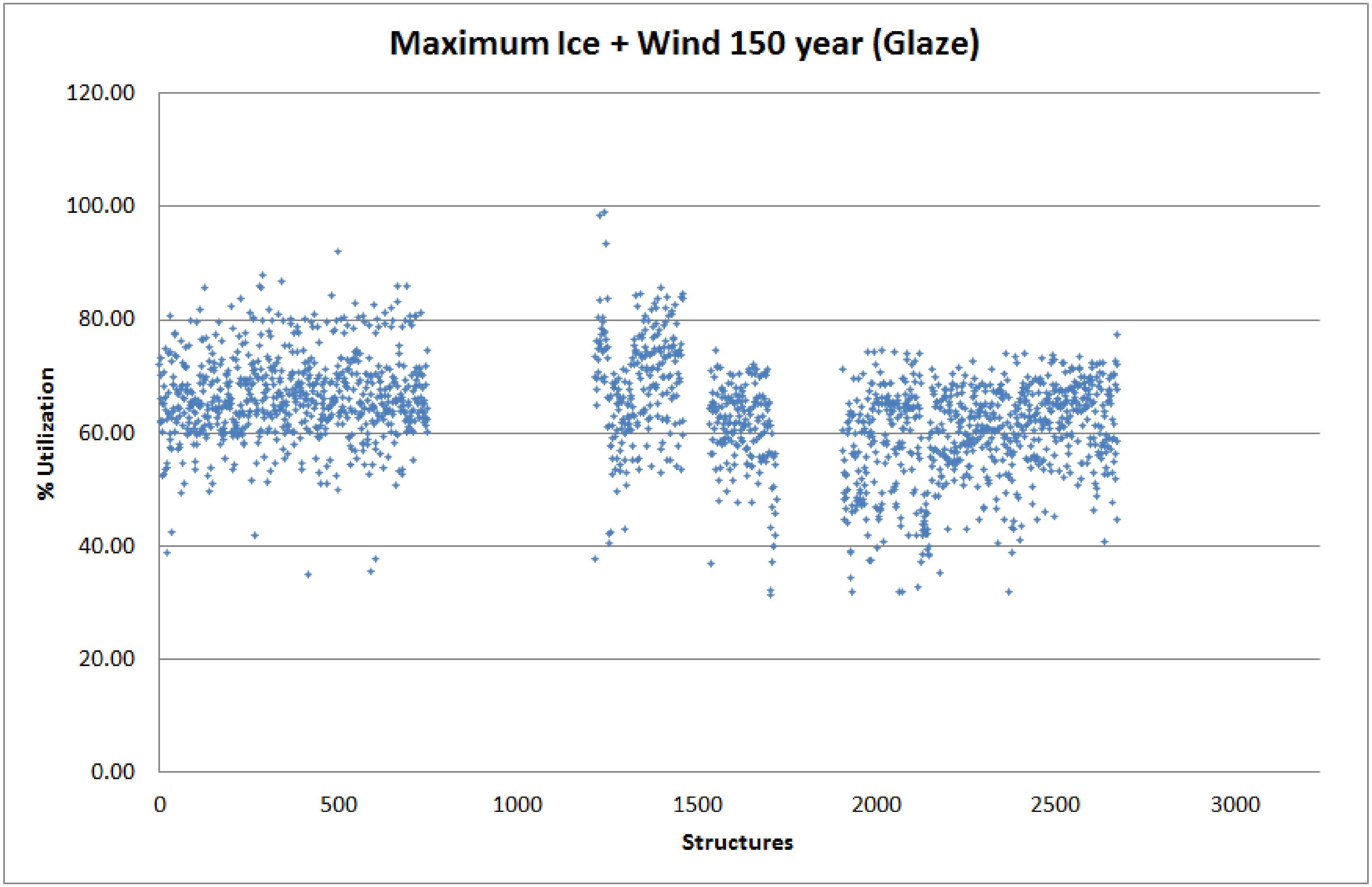
Structural utilization for the IEC combined ice/wind cases are shown on the following pages.

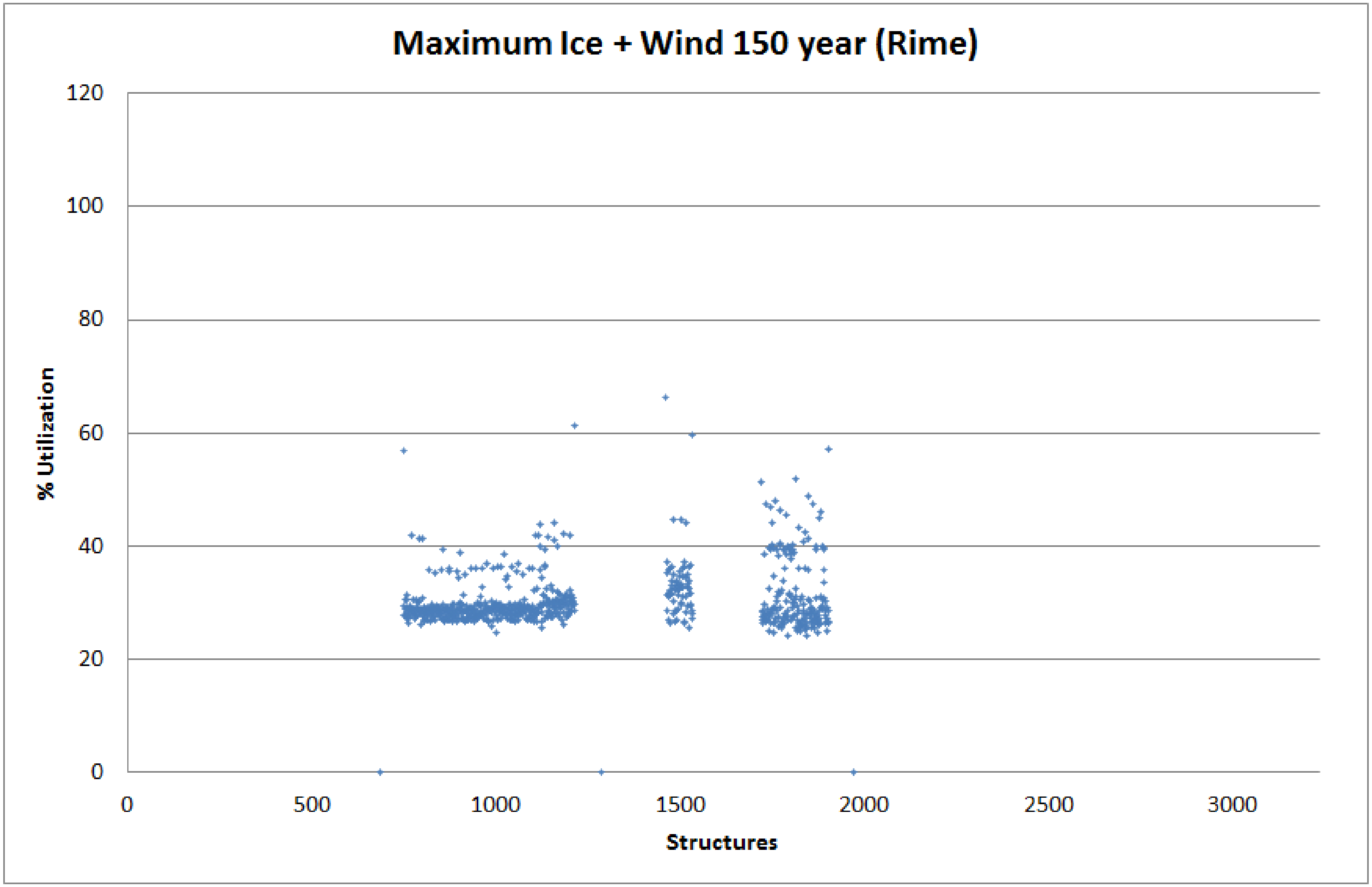
No structure was loaded beyond 100% of its structural capacity in any of these scenarios, thus confirming the capacity of all structures to withstand the proposed IEC 60826 combined wind and ice standards for both extreme wind and ice scenarios.

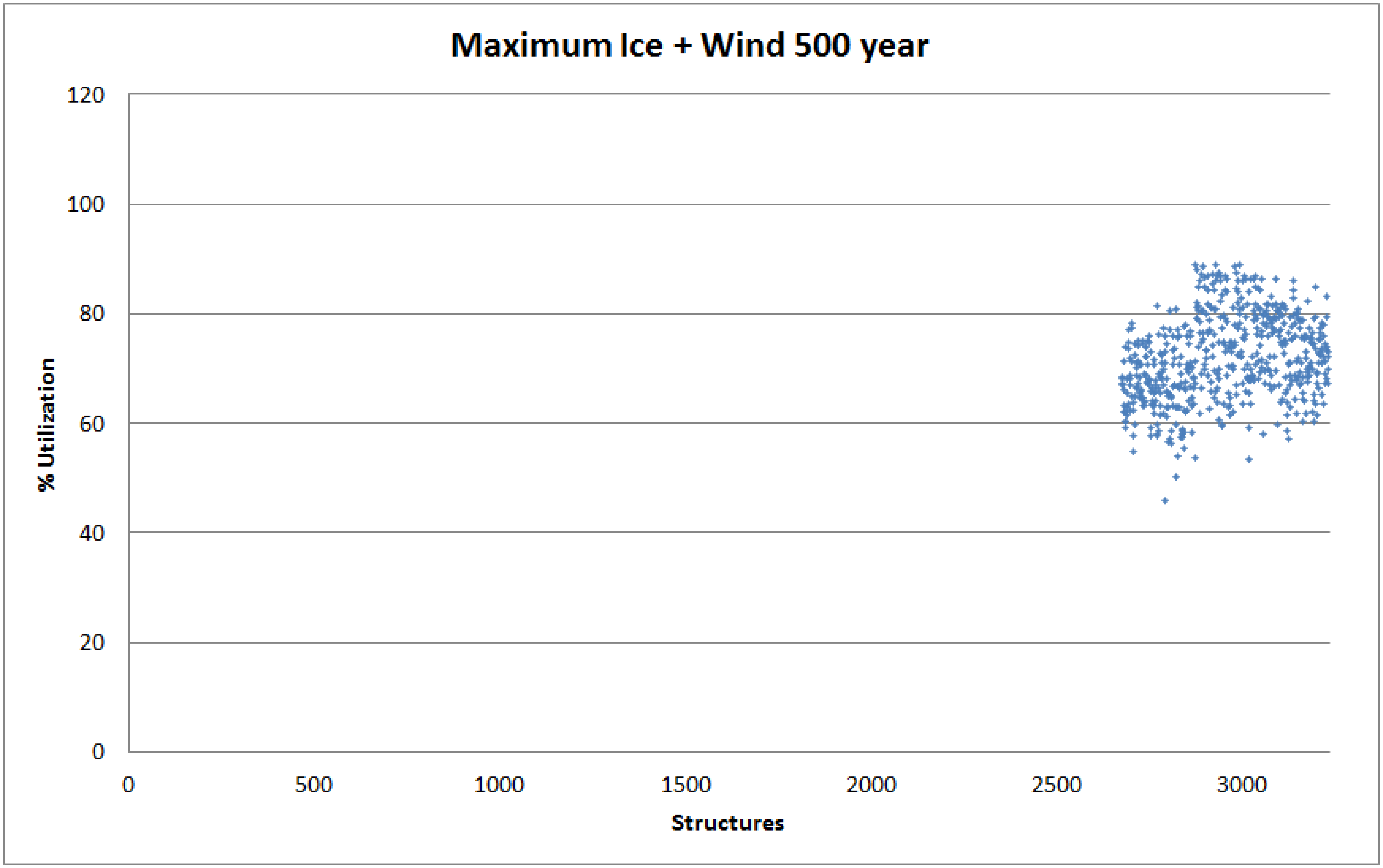

Extreme Wind + Ice 150 year (Glaze)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Utilization
0
500
1000
1500
2000
2500
3000
Structures


Extreme Wind + Ice 150 year (Rime)
120
100
80
60
40
20
0
% Utilization
0
500
1000
1500
2000
2500
3000
Structures


Extreme Wind + Ice 500 year
% Utilization
Structures
0
20
40
60
80
100
120
0
500
1000
1500
2000
2500
3000


Maximum Ice + Wind 150 year (Glaze)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Utilization
0
500
1000
1500
2000
2500
3000
Structures


Maximum Ice + Wind 150 year (Rime)
% Utilization
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
Structures


Maximum Ice + Wind 500 year
120
100
80
60
40
20
0
% Utilization
0
500
1000
1500
2000
2500
3000
Structures

Summary and Conclusions:

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.

In addition to the design criteria established for the LITL, 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 LVP, 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 of these scenarios.

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

Appendix A: CSA Ice Load Regions

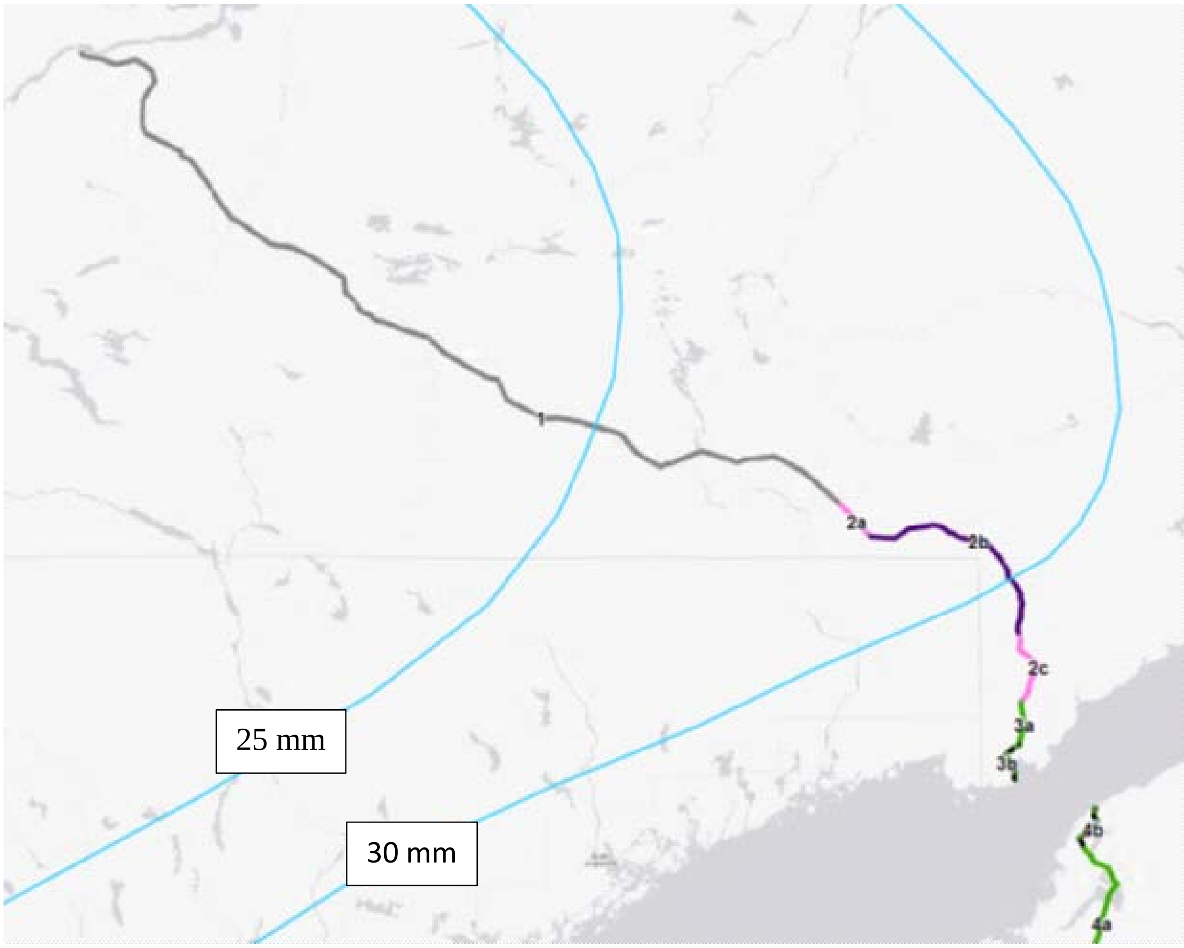


Figure A-1: CAN/CSA 22.3 No. 60826-10 Reference Contours – Labrador

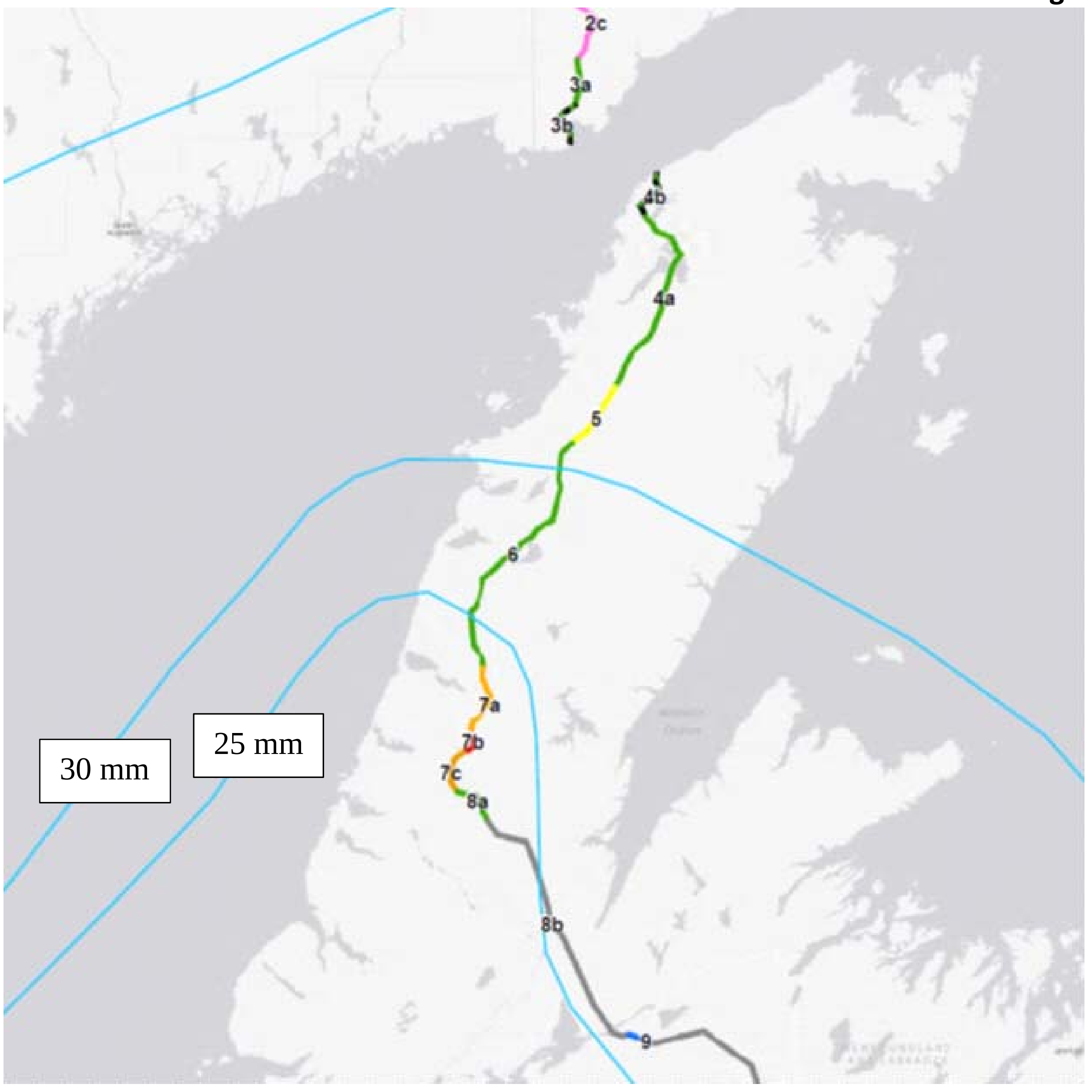


Figure A-2: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland West

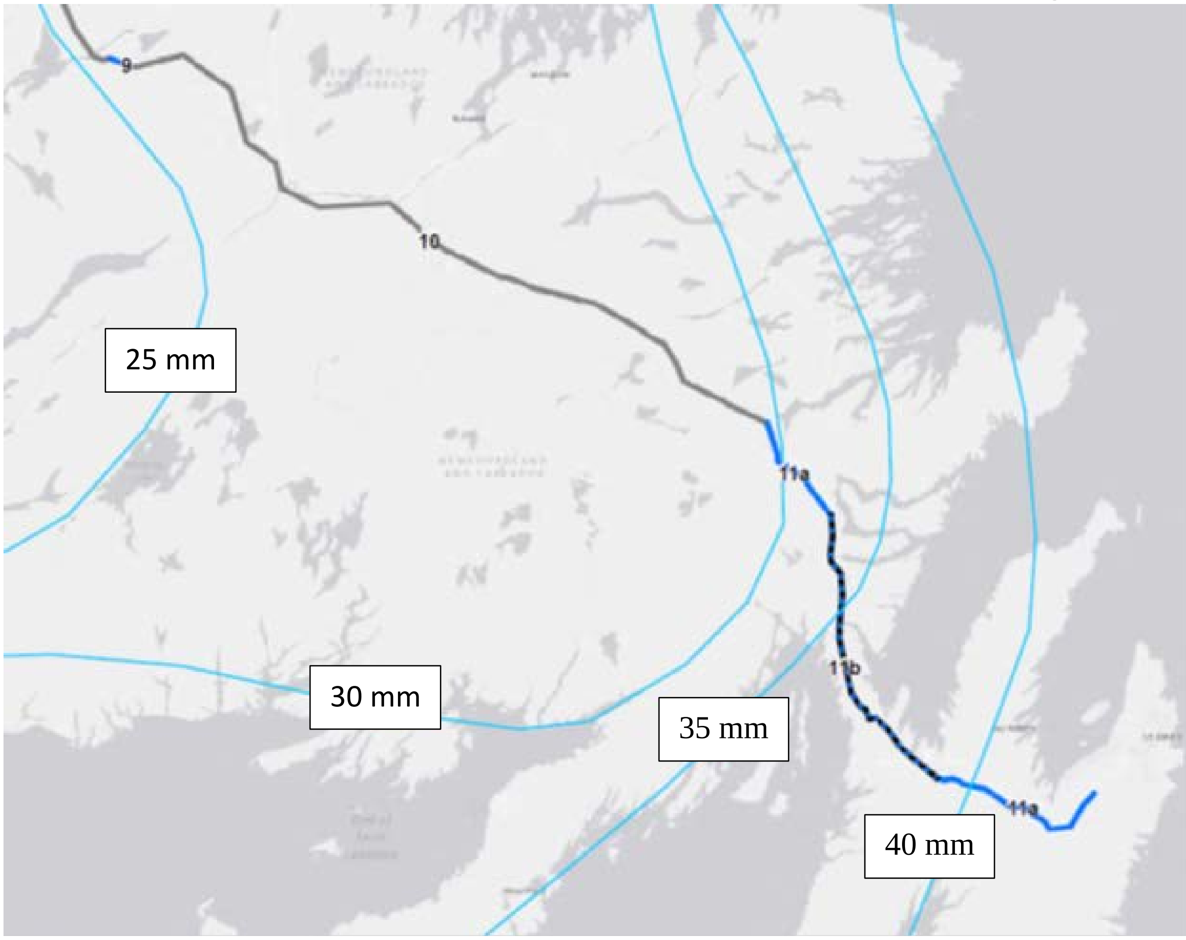


Figure A-3: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland East

Appendix B: CSA Wind Load Regions

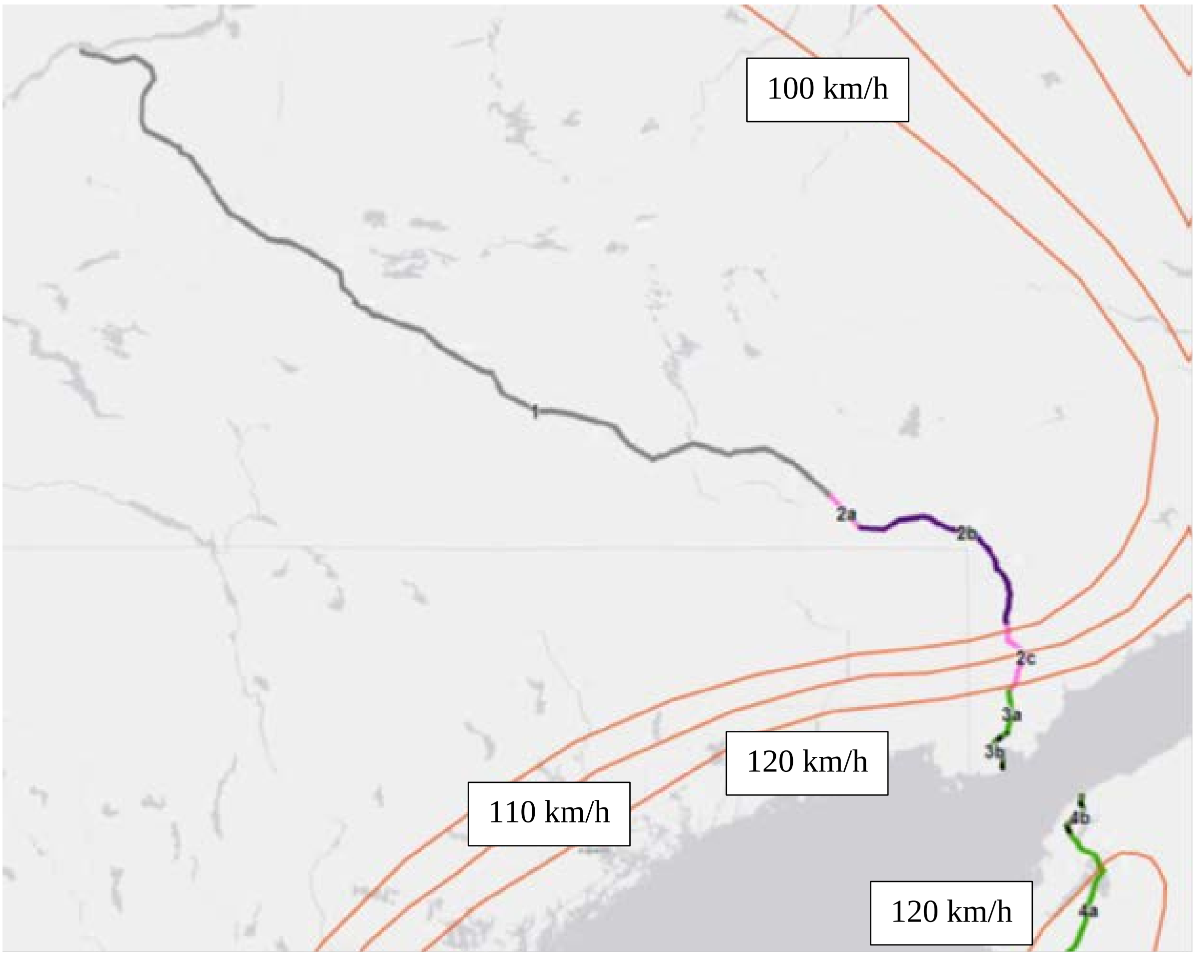


Figure B-1: CAN/CSA 22.3 No. 60826-10 Reference Contours – Labrador

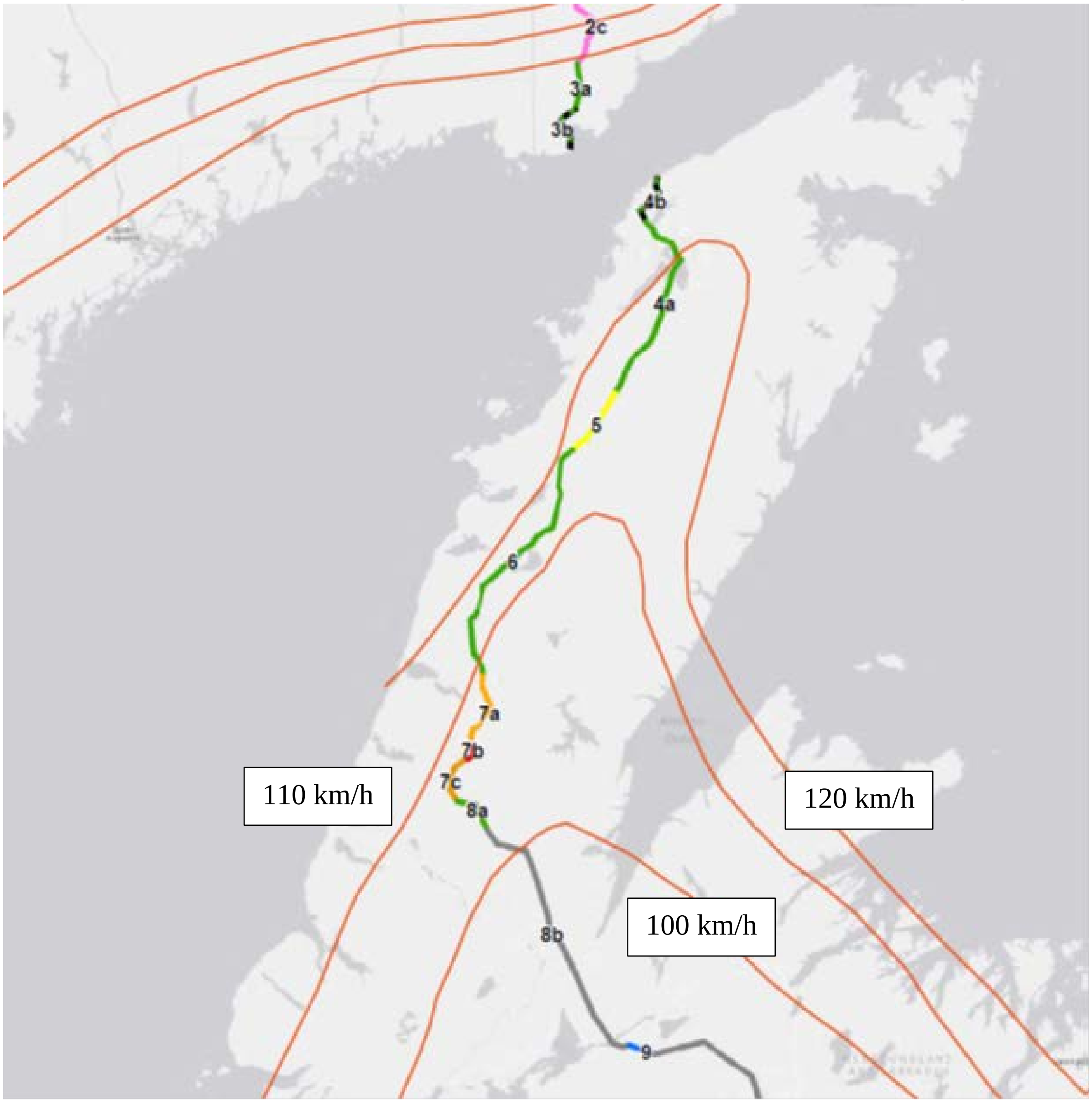


Figure B-2: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland North

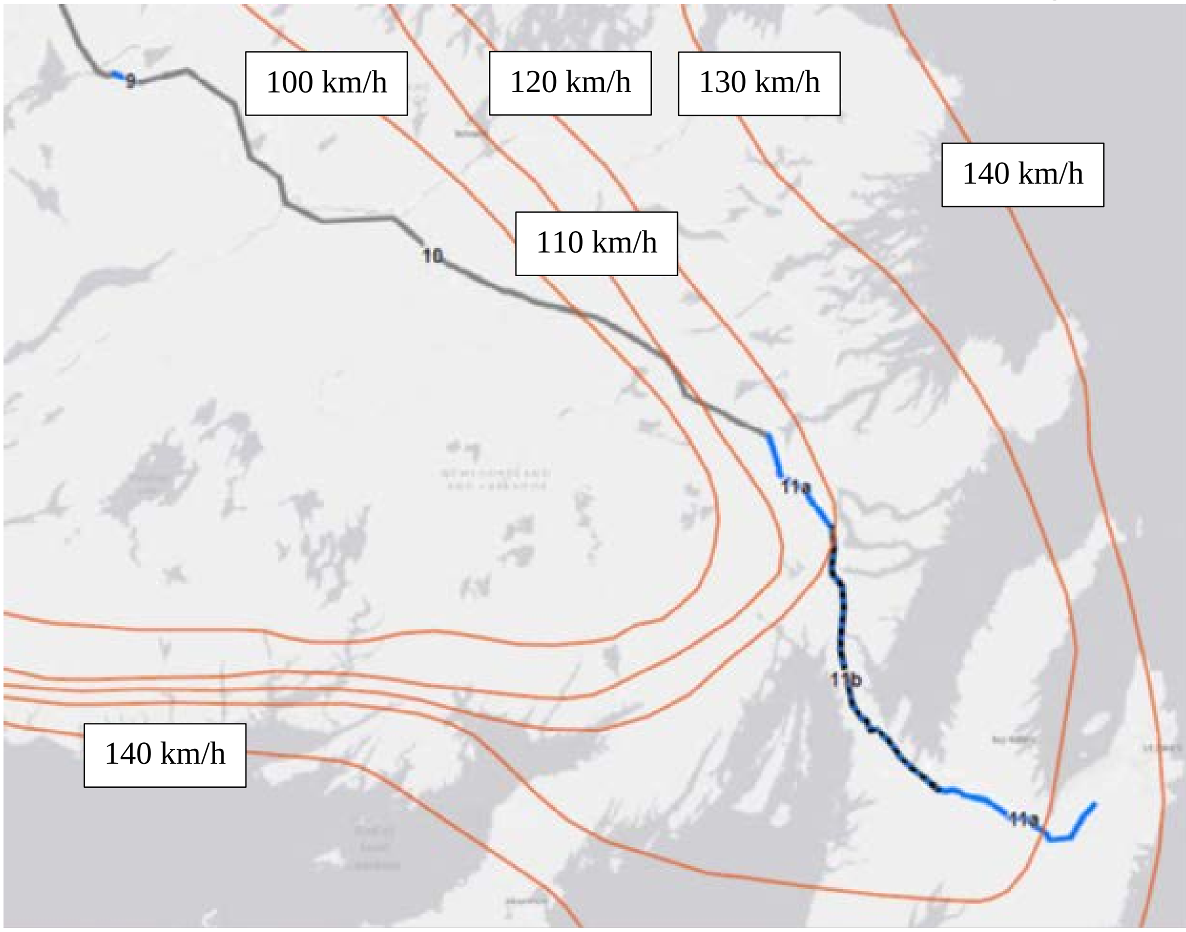


Figure B-3: CAN/CSA 22.3 No. 60826-10 Reference Contours – Newfoundland South