Nalcor Energy
Newfoundland, Canada

Report

For

Wind Integration Study - Isolated Island

H341742-0000-00-124-0001
Rev. 2
August 7, 2012

Nalcor Energy
Newfoundland, Canada

Report

For

Wind Integration Study - Isolated Island

H341742-0000-00-124-0001
Rev. 2
August 7, 2012

HATCH™

Project Report

August 7, 2012

Nalcor Energy
Wind Integration Study

DISTRIBUTION
Robert Henderson
Joanna Barnard
Tryggvi Olason
Semiu Lawal
Stu Bridgeman
Fiaz Chaudhry
Afzal Majid
Mohamed Kamh

Isolated Island Report

Table of Contents

List of Tables

Executive Summary

Hatch has completed a study to assess how much additional non-dispatchable wind generation can be added, economically and technically, to the Island of Newfoundland's power system. Both the ability of the hydroelectric system to operate efficiently with additional wind generation resources, and issues of system stability and voltage regulation were considered.

The analysis of future system operation was based on an Isolated Island generation expansion plan which includes three new small hydro plants, a refurbishment of the Holyrood steam plant, a combined cycle combustion turbine, two new combustion turbines and the replacement or refurbishment of the existing wind farms at Fermeuse and St. Lawrence.

For an isolated Newfoundland power system, increased wind generation will be used to decrease the use of thermal generation as much as possible without affecting voltage and frequency support, and without unduly increasing spill and causing significantly less efficient dispatch of the hydro generating units.

The results of the modelling study, which focused primarily on macro energy penetration, without detailed consideration of hourly variations required for load balancing or real-time regulation issues to maintain frequency, suggests a maximum wind capacity, including the existing capacity, of 425 MW, which would represent an energy penetration of 14%.

The review of system stability and voltage regulation issues recommended a maximum of 300 MW during the extreme light load conditions for 2035 to prevent violation of stability criteria. Similarly, the wind generation penetration level should not exceed 500 MW during the peak load conditions to avoid transmission line thermal overloads.

A review of current and planned wind energy penetration rates worldwide found that high penetration rates came with significant operational challenges, especially in isolated systems. A penetration rate of 10% is the maximum recommended for the Island of Newfoundland system due to the uncertainty of the technical and economic impacts at the higher penetration rates which are yet to be tested under isolated system circumstances.

It is recommended that the wind penetration to be used in the integration plan be nominally 300 MW. A development plan consisting of approximately 50 MW of new wind every 5 years from 2015 to 2035, and the refurbishment or replacement of exiting capacity as required, would yield a wind energy penetration of about 10%, which is high for an isolated system.

Following further wind measurements at prospective wind generation sites, and before proceeding beyond 100 MW of new wind generation, it is recommended that a further more detailed wind integration study be undertaken to evaluate the hourly chronologic operation of the system with due consideration to wind uncertainty and additional reserves that will be needed to regulate the wind generation resource. This study should also assess the statistics of load variations in combination with the wind variations at specific prospective wind generation sites in order to define appropriate reserve margins.

1. Introduction

Nalcor Energy (Nalcor) requested that Hatch carry out an evaluation of how much additional wind generation can be added to the Island of Newfoundland system, from an economic and technical point of view, assuming no interconnection to neighbouring power systems (Isolated Island Scenario).

To make the final determination, both the ability of the hydroelectric system to operate efficiently with the wind generation resource to reduce use of thermal resources, and issues of system stability and voltage regulation need to be considered. Newfoundland and Labrador Hydro (Hydro) has undertaken the required modelling to assess system stability and voltage regulation; Hatch determined the ability of the system to absorb wind generation and decrease use of thermal resources, without an undue increase in spill.

Hatch also provided an independent review of the stability and voltage regulation analysis done by Hydro to determine whether it is appropriate and reasonably assesses the technical limits of the system to reliably accept this variable and non-dispatchable generation source.

All of the existing hydraulic generation resources on the Island were considered in this study. The hydro plants on Bay d'Espoir, Cat Arm, Hinds Lake, Paradise River, Exploits River, Star Lake, as well as Deer Lake Power were represented in detail, while the Newfoundland Power hydro plants were modelled in a simplified manner.

The 2010 Isolated Island Scenario generation expansion plan under consideration has 25 MW of new wind generation in 2014 and 50 MW of replacement or refurbished wind in 2028 to address the existing wind farms when they reach the end of their operating lives. The plan also includes three small hydro plants, refurbishment of Holyrood, a combined cycle combustion turbine (CCCT), and two new combustion turbines (CTs).

This study is required to determine if it is economically and technically feasible to include additional wind generation plants in this development scenario. This was undertaken by assessing a number of 25-MW or 50-MW increments of wind generation for each of the study years, in succession. After the first study year was assessed (2014), the results were reviewed with Nalcor, and a decision was made with regard to the most likely wind development prior to the next study year (2020). For the next study year, the various 50-MW increments were then assessed relative to the new "existing" wind base. This procedure was repeated for each successive study year. The economic evaluation was done separately, by Nalcor, and re-assessed the decisions made in each study year, related to new wind development. Consequently, the time series of new wind developments used herein differ slightly from that determined in the economic evaluation.

Vista Decision Support System (*Vista* DSS™) was deployed for studying the impact of additional wind generation. *Vista* has been implemented and tested for the existing Island system and used in a number of studies for various additional generation resources, both hydroelectric and wind. For the study herein, the focus was to capture hydrologic variability by modeling 61 years of hydrology using a larger time step, for four levels of expected load, represented by 4 years in the planning horizon – 2014, 2020, 2025, and 2035.

2. System Representation

2.1 Existing System

Currently, the Island Interconnected system, including wind generation, has a net generating capacity of approximately 2000 MW. Of this, Hydro's own generation consists of

- approximately 1100 MW of hydroelectric, including generation on the Exploits River owned by the Government of Newfoundland and Labrador
- approximately 630 MW of thermal (heavy oil, gas and diesel).

The existing wind generation capacity is 54 MW, consisting of two non-utility generation (NUGs) at St. Lawrence (27 MW with 104 GWh annual average energy) and Fermeuse (27 MW with 84 GWh annual average energy).

The balance is primarily hydroelectric from customer generation.

All generation resources on the Island were represented in this study. These include

- Bay d'Espoir System – Granite Canal, Upper Salmon, Bay d'Espoir
- Hinds Lake and customer owned generation at Deer Lake
- Cat Arm
- Paradise River
- Exploits River – Star Lake, Grand Falls, Bishops Falls, and Buchans
- Newfoundland Power's numerous small plants were represented in a simplified manner.

2.2 Generation Expansion

New generation over the planning period (Hydro's 2010 expansion plan) includes the following three new small hydro plants:

- Island Pond (hydro), 36 MW, in service 2015
- Portland Creek (hydro), 23 MW, in service 2018
- Round Pond (hydro), 18 MW, in service 2020.

Information regarding the three new hydro projects was available from feasibility reports, AGRA (1988), Agra-ShawMont (1997) and SNC-Lavalin (2008). Data from these reports were used to represent the projects in *Vista*.

Also included in the expansion plan are

- 25 MW of planned new wind generation in 2014
- new wind generation in 2020, 2025 and 2035, as determined in this study
- 50 MW of replacement or refurbished wind generation in 2028 to address the existing wind farms when they reach the end of their operating lives

- future new wind generation was assumed to have an average expected hourly wind pattern which was provided by Nalcor. All new wind farms were assumed to have a 40% capacity factor. For the purposes of the *Vista* simulations required for this study, it is assumed that it is not significant where the new wind farms are located. Specific location issues are assumed to have technical solutions and cost allowances will be included in the economic assessment. It has been assumed that contracts for new wind generation would allow curtailment if it is required for system stability
- new Combined Cycle Combustion Turbine (CCCT), 170 MW, in service 2022, no minimum output
- new Combustion Turbine (CT), 50 MW, in service 2024, no minimum output
- new CT, 50 MW, in service 2027, no minimum output
- refurbishment of Holyrood. It is assumed that whatever upgrades and repairs required to keep Holyrood functioning at its current capacity are performed so that Holyrood continues to be able to supply 470 MW. It is assumed that there is an ongoing minimum generation requirement of 70 MW at each Holyrood unit, while operating. In addition, there are seasonal minimum operating requirements for voltage regulation and system peaking.

2.3 Island Loads

The 2010 island load forecast for 2014 through 2041, recently used for the Muskrat Falls Integration study, was used for the wind integration simulations. The peak power demand (MW) and annual energy demand (GWh) is listed in Table 2-1. It is the system loads which will determine when additional wind generation can be integrated into the system; the timing herein is approximate only.

Table 2-1 Load Forecast

	Peak Demand (MW)	Annual Energy Demand (GWh)
2014	1654	8513
2020	1761	9008
2025	1853	9511
2035	2019	10369

2.4 Physical and Operational Constraints

Both physical and operational constraints are used to define allowable operations within the *Vista* DSS™ model. Physical constraints are more stringent and are not to be violated by the model. Operational constraints must lie within the physical constraints; penalties are applied to these constraints to give the model guidance on when the constraints can be violated. The constraints include the minimum and maximum water levels for the reservoirs.

The voltage and stability analysis done by Hydro and reviewed by Hatch as discussed in Section 4.4, indicates that minimum conventional generation limits are needed. These were incorporated into the analysis and the wind generation additions were modelled such that their production was rejected or clipped in order to conform to minimum hydroelectric and thermal generation limits.

2.5 Inflows

The 61-year inflow sequence provided by Nalcor has been adopted for the current study. This daily inflow sequence spans the years 1950 to 2010.

2.6 Maintenance Schedules

A generic annual outage schedule provided by Nalcor is used for each study year.

2.7 Thermal Representation

The costs included in the model are set such that use of thermal is minimized. The minimum numbers of thermal and hydro units required in each month through the years of the simulation, for voltage and frequency stabilization as well as for Avalon transmission and system peak support, were provided by Nalcor and included in the model set-up.

3. Study Methodology

Vista DSS™ has been implemented and tested for the existing Island system. A number of studies have been conducted for various additional generation resources, both hydroelectric and wind generation. *Vista* DSS™ uses detailed mathematical equations describing hydro generation unit characteristics (power and efficiency as functions of flow and head), spill, tailwater level and reservoir operations to determine unit generation requirements in any time step. *Vista* can also represent thermal and wind generation, as well as load and market opportunities. The objective of the model is to meet the system load demand in the most economic manner, i.e., operate the entire system in a manner that maximizes system hydroelectric generation to meet system load demand, minimize spill and avoid violation of operational licenses or constraints. For this wind integration study, it was important to capture the hydrologic variability and for that purpose all the available 61 historic inflows were used. The LT *Vista* module was employed for this study as discussed in more detail below.

3.1 LT *Vista* Analysis

The analyses focused on four specific load cases (forecast) in the planning horizon – 2014, 2020, 2025, and 2035. For each year several analysis were carried out as follows:

- Base Case (changes for each year considered, as defined in Section 2.2 Generation Expansion above).
- Base Case + 25 MW of new wind generation (2014 only).
- Base Case + 50 MW of new wind generation.
- Base Case + 100 MW of new wind generation.
- Base Case + 150 MW of new wind generation.
- Base Case + 200 MW of new wind generation.

Each LT *Vista* analysis employed a 5-day time step, with appropriate sub-periods to define weekday, as well as weekend peaks and off-peaks. The 5-day time step was used rather than a week, to facilitate a continuous simulation of each of the focus years using the 61 years of hydrology.

More specifically, for each of the focus years and each of the wind capacity cases, the methodology was as follows:

- LT *Vista* analysis started on January 1st, using the first (1950) of the 61 years of hydrology and optimized generation until December 31st, in 5-day time steps.
- No end condition was specified for reservoir, but a value of water in storage was used instead. The value of water in storage was based on Holyrood generation costs and reservoir specific water to MW conversion factors.

- The December 31st water levels were then used as start levels for the second analysis, which used 1951 hydrology, then 1952, etc., until all hydrologic sequences were analyzed.

The above analysis captures the impact of wind generation on operations for the range of hydrologic conditions that have occurred in the period 1950 to 2010. Of particular interest are the thermal and hydro generation and spill statistics, in relation to the base case.

The *Vista* analysis included a provision to 'clip' wind for system stability reasons, if conventional generation (hydro and thermal) was at risk of dipping below established minimums.

The LT *Vista* module, when applied for a specified focus year (say 2020), and for a specified hydrology (say 1950), optimizes operations over that year with foreknowledge of the loads, hydrology and wind for that year. It does not have foreknowledge of subsequent hydrologic values, so cannot operate the large storage reservoirs with excessive multiple year foreknowledge. The drawdown in a specific year is determined in part by the value of water in storage at the end of the year, which is a signal to the optimization process to conserve water due to an unknown future. Consequently, the drawdown, spill and thermal energy use is fairly realistic for each hydrologic sequence despite some foreknowledge. The bias that does exist is common between the base case and the comparison (wind penetration) case, so the incremental effects of the wind penetration should be representative.

Holyrood units currently cannot be started and stopped on a daily cycle basis. They are required to be kept operating at minimum output levels during the off-peak hours in order to be ready to meet system demands during the daily peak hours. A separate sensitivity analysis was completed whereby the minimum production for Holyrood was reduced to reflect the potential replacement of the plant (post-2030) so that the units are no longer restricted. The lifting of this restriction may result in more economic integration of wind generation.

3.2 Spill Energy Equivalent

The mechanism used to measure the "Spill Energy Equivalent" associated with increasing wind generation supply was to monitor the actual spill occurring in the different analysis and converting the spill to an energy equivalent using the energy/water conversion factors. The conversions used to approximate the value of spill in terms of MWh are shown in Table 3-1 below.

Table 3-1 Energy Conversion Factors

Plant	Conversion Factor (MWh/kCM)
Granite	0.09515
Island Pond	0.0553
Upper Salmon	0.1304
Round Pond	0.0268
Bay d'Espoir	0.4340
Cat Arm	0.9013
Hinds Lake	0.5398
Deer Lake	0.1727
Paradise River	0.0910
Star Lake	0.2980
Buchans	0.0332
Sandy Brook	0.0737
Grand Falls	0.0698
Bishops Falls	0.0230
NP	0.0136
Portland Creek	0.9778

3.3 Independent Review of Voltage Regulation and System Stability Analysis Results

Hatch carried out an independent review of the study undertaken by Newfoundland and Labrador Hydro (June 2012), on voltage regulation and system stability analysis. The objective of the review was to validate the study results obtained from these analyses and to assess the reasonableness of the general conclusions reached in order to establish technical limits of the Island's power system to reliably accept the non-dispatchable generation source.

The study focused on evaluating the maximum wind power penetration level that would cause the steady-state and dynamic responses of the island power system to remain in compliance with the applicable technical criteria for voltage regulation and transient stability. The study horizon was the years 2020 and 2035. For each of the 2 years, extreme light and peak loading conditions were considered.

In order to develop confidence on the study results presented in the draft study report, Hatch requested Nalcor to provide PSS/E base cases and dynamic models used for conducting the study. Hatch replicated a few distinct simulation scenarios that were reported to be the most limiting in the study report, as follows:

- Peak Load Conditions during the years 2020 and 2035:
  - Steady-state contingency analysis pertaining to the loss of the 230 kV TL248 line (Massey Drive to Deer Lake).

- Extreme Light Load Conditions during the years 2020 and 2035:
  - Loss of the largest generating unit at Bay d'Espoir
  - Sudden load increase of 15 MW at the Voisey's Bay Nickel Terminal Station Bus (Long Harbour).

Comments were provided on a preliminary report and then the revised report was also reviewed.

3.4 Literature Review

A brief literature review was conducted to establish the current and planned levels of wind energy generation (penetration) for other systems, both interconnected and isolated system cases.

The literature review was supplemented with detailed information available for wind penetration studies undertaken directly by Hatch.

4. Results and Conclusions

4.1 Effectiveness of Additional Wind Generation

The impact of adding 25 to 200 MW of new wind generation on the efficiency of operations of the Newfoundland power system in the selected load years 2014, 2020, 2025 and 2035 was analyzed, using the methodology outlined in Section 3. For each of the focus years and installed wind capacities considered, system operations for 61 years of historic inflows were simulated. For each case, hydro and thermal generation and spill (converted to energy equivalent) were recorded.

Results are summarized in Tables 4-1 to 4-4, in terms of average wind, hydro and thermal energy, as well as the efficiency of wind generation at displacing thermal generation. This wind efficiency measure is defined as

$$\textit{Wind Efficiency} = \frac{\textbf{Incremental Thermal Reduction}}{\textbf{Available Wind Energy}} * \mathbf{100}$$

If wind generation is fully effective at displacing thermal energy, then the Wind Efficiency would be 100%, that is, each increment of 50-MW of new wind generation would displace 175 GWh/y of thermal energy (assuming a capacity factor of 40%).

In 2014, the first 25-MW increment of wind generation is 84% effective at displacing thermal energy; that is, 88 GWh of new wind energy, results in the reduction of thermal generation of 74 GWh on average, for the 61 hydrologic simulations (wind efficiency of 74/88 = 84%). As seen in Table 4-1, the successive increments of 50 MW have displacement efficiencies of 80%, 67%, 45% and 36%. The table also lists the average displacement efficiency for the total new wind generation. For example in 2014, after the addition of 200 MW of wind generation (second last row) the average displacement efficiency of the entire new plant is 58%. Following consultation with Nalcor, subsequent simulations assumed that 25 MW of new wind generation would be developed prior to 2020.

In 2020, the first 50-MW increment of wind generation (beyond the 25 MW developed after 2014) is 77% effective at displacing thermal energy. As seen in Table 4-2, the successive increments have displacement efficiencies of 54%, 44%, 23% and 13%. Following consultation with Nalcor, subsequent simulations assumed that 50 MW of new wind generation would be developed prior to 2025.

By 2025, the load will have grown and the system will be able to absorb additional wind energy. The first 50-MW increment (beyond the 25 MW in 2014 and the 50 MW developed after 2020) of wind generation is 97% effective at displacing thermal energy. As seen in Table 4-3, the successive increments have displacement efficiencies of 88%, 71% and 47%. Following consultation with Nalcor, subsequent simulations assumed that 150 MW of new wind generation would be developed prior to 2035.

By 2035, the load has grown further, and the system will be better able to absorb wind energy. The first 50-MW increment of wind generation (beyond the 225 MW of new wind generation assumed to be developed as per the 2014, 2020 and 2025 analysis prior to 2035) is 97% effective at displacing thermal energy. As seen in Table 4-4, the successive increments have displacement efficiencies of 93%, 93% and 71%. With an additional 150 MW in 2035, or soon after, the total installed wind capacity would be 375 MW plus the existing/replacement 50 MW; or 425 MW. The gross wind energy production will be 1489 GWh/y, compared to the total island annual energy production of 10 369 GWh/y (from all sources); indicating a gross wind energy penetration of 14%, a high penetration for an isolated system.

None of the *Vista* runs used in this analysis showed a need to 'clip' the wind for system stability reasons to prevent conventional generation dipping below established minimums. This may be because of the averaging over the long time step used; additional studies using a shorter time step are recommended as Nalcor approaches the maximum wind energy penetration.

Table 4-1 Wind Impact Summary – 2014

New Wind Capacity	Total Wind Capacity (MW)	Available New Wind Energy (GWh)	Hydro Energy (GWh)				Thermal Energy (GWh)		Total Generation (GWh)	Wind Efficiency at Displacing Thermal (%)
			Gen	Δ	Spill	Δ	Gen	Δ	Gen	Δ
Base	54	-	6578		731		1740		8513	
25	79	88	6564	-14	743	12	1666	-74	8513	84
50	104	175	6546	-17	760	17	1596	-70	8513	80
100	154	350	6489	-57	803	43	1478	-118	8513	67
150	204	526	6393	-97	877	74	1399	-79	8513	45
200	254	701	6280	-112	974	97	1337	-63	8513	36

Table 4-2 Wind Impact Summary – 2020

New Wind Capacity	Total Wind Capacity MW	Available New Wind Energy (GWh)	Hydro Energy (GWh)				Thermal Energy (GWh)		Total Generation (GWh)	Wind Efficiency at Displacing Thermal (%)
			Gen	Δ	Spill	Δ	Gen	Δ	Gen	Δ
Base	79		7101		595		1624		9008	
50	129	175	7060	-41	623	29	1490	-134	9008	77
100	179	350	6979	-81	672	49	1396	-94	9008	54
150	229	526	6881	-98	746	74	1319	-77	9008	44
200	279	701	6746	-135	845	99	1279	-40	9008	23

Table 4-3 Wind Impact Summary – 2025

New Wind Capacity	Total Wind Capacity MW	Available New Wind Energy (GWh)	Hydro Energy (GWh)				Thermal Energy (GWh)		Total Generation (GWh)	Wind Efficiency at Displacing Thermal (%)
			Gen	Δ	Spill	Δ	Gen	Δ	Gen	Δ
Base	129		7104		586		1948		9511	
50	179	175	7098	-6	593	7	1779	-170	9511	97
100	229	350	7078	-20	608	15	1624	-155	9511	88
150	279	526	7027	-51	638	30	1499	-125	9511	71
200	329	701	6935	-92	702	64	1417	-83	9511	47

Safety • Quality • Sustainability • Innovation

Table 4-4 Wind Impact Summary – 2035

New Wind Capacity	Total Wind Capacity MW	Available New Wind Energy (GWh)	Hydro Energy (GWh)				Thermal Energy (GWh)		Total Generation (GWh)	Wind Efficiency at Displacing Thermal (%)
			Gen	Δ	Spill	Δ	Gen	Δ	Gen	Δ
Base	275		7075		587		2331		10369	
50	325	175	7069	-6	590	3	2162	-170	10369	97
100	375	350	7057	-13	601	11	1999	-163	10369	93
150	425	526	7044	-13	613	12	1836	-163	10369	93
200	475	701	6994	-50	652	39	1711	-125	10369	71

4.2 Impact of Additional Wind Generation on Reservoir Operations

The simulation results presented in Section 4.1 summarized the impact of additional wind generation on hydro generation and spillage, in energy terms. The hydroelectric generation facilities have to absorb and re-regulate the irregular wind generation and the impact on reservoir levels is quite significant especially for the capacity of new wind generation considered in this study.

To illustrate the effects of wind generation on reservoir operations, the distribution of reservoir levels for two of the largest storage reservoirs, Meelpaeg and Long Pond were assessed, for the base case and comparison case with 200 MW new wind generation, for the 2020, 2025, and 2035 study years.

The results are presented in Appendix A as percentiles processed from the 61-year simulation in each case. The percentiles clearly show how the addition of 200 MW of wind generation increases the 50% water levels as well as the spread of water levels, resulting in the increased spill and loss of hydro generation efficiency, demonstrated in Tables 4-1 to 4-4 above.

The average levels for these two reservoirs increases by over 2 m in 2020, 1.5 m in 2025, and 1.25 m in 2035, for the 200 MW wind penetration cases. This is the primary causative factor for increased spill, lower hydro generation efficiencies, and thus reduced thermal displacement efficiency.

The resultant maximum water levels during flood events will be higher in most years, than the base case with less wind penetration. However, since the levels remain within allowable operating limits, dam safety is not a concern since the handling of probable maximum floods assumes that the reservoirs are at their maximum operating levels at the beginning of the design events.

4.3 Voltage Regulation Issues and System Stability

As indicated in Section 3.4, the first step in Hatch's review of Hydro's work on voltage regulation issues and system stability was to review four PSS/E base cases and the relevant dynamic models pertaining to the study. Hatch independently conducted steady-state load flow and transient stability simulations for the most limiting contingency events, as identified in the report. Hatch critically reviewed the simulation results and conclusions of the draft report with the following focus, whether

- the load flow base cases sufficiently represent the required operating scenarios
- the simulated events are enough to draw reasonable conclusions regarding the maximum allowable wind penetration to avoid voltage and frequency criteria violation
- the conclusions reached are in line with the simulation results depicted in the draft report
- the conclusions are technically reasonable.

Hatch provided Hydro with specific comments on the preliminary draft report and clarified and discussed many aspects of the simulation results with the study team in order to reach a common understanding of the applicable criteria. Subsequently, Hydro provided a revised report for further review. After a careful review of the revised report, it is confirmed that all Hatch concerns and comments on the preliminary draft were properly addressed.

Based on the simulation results presented in the report, it is concluded that the transient stability constraint is found to be the most limiting factor in determining the wind penetration level during the extreme light load conditions. Correspondingly, it is recommended that no more than 225 MW and 300 MW of net wind generation could be dispatched under the extreme light load conditions of 2020 and 2035, respectively. At the same time, 500 MW was found to be the wind penetration limit under peak load conditions of 2020 and beyond in order to avoid any thermal violations subsequent to the loss of the 230 KV line – TL248. This was classified as the worst single element contingency in the study report. These wind generation limits are based on the assumption that sufficient reactive power and voltage support resources will be provided at the point of interconnections of the wind farms to be incorporated into the island power system of Newfoundland.

The report noted that the extreme light loading conditions are anticipated for very short durations of the year, particularly during the night hours of the summer season, when the wind generation profile is usually at its minimum, likely to be at or less than approximately 50% of the installed capacity. Should the installed wind generation capacity be 500 MW, it is anticipated that the available wind generation under light load conditions is less than or equal to 250 MW, which is in close proximity to the wind penetration level limited by the transient stability constraint. At the same time, it is recommended that assumptions related to the minimum wind generation profile under light load conditions be substantiated with the historical wind data for the geographical areas where the potential wind generation projects are expected to be installed.

5. Review of Wind Penetration in Other Areas

5.1 Interconnected Systems

Experience in other jurisdictions was examined to provide guidance on existing and planned levels of wind generation penetration. The documents consulted are listed in Section 8 of this report.

Europe

In 2011, the average penetration of wind generation on an energy basis, for Europe, was 5%. The highest penetrations were as follows:

- Denmark 26%
- Portugal 17%
- Spain 15%
- Ireland 14%
- Germany 9%

The Denmark situation is somewhat unique in that it has an unlimited market access to export excess energy and import deficits. If exported energy is excluded, the "domestic" wind energy penetration rate would be substantially less. Thus, excluding Denmark, the current European high wind energy penetration experience is between 9% and 17%.

The targets for 2020 and 2030 for Europe are 14% and 28%, respectively.

Canada

In 2011, wind penetration for Canada was 2.3% and CanWEA predicts rapid increases until at least 2025, when it could reach 20%. The most aggressive wind growth is taking place in Alberta, British Columbia, Ontario and Quebec.

In Alberta, the current plan is to increase the wind capacity from 890 MW in 2011 to 7000 MW in 2015.

In 2006, in Ontario, the energy wind penetration was 2%. The Ontario Wind Integration Study undertaken in that year investigated higher wind penetrations by the year 2020 of between 7% and 13%, and identified significant negative impacts at the higher levels of penetration. The current plan is to increase the wind capacity from 1970 MW in 2011 to 4480 MW in 2015.

In Quebec, the current plan is to increase the wind capacity from 920 MW in 2011 to 2820 MW in 2015. This is viable since there is substantial hydro flexibility and adjacent markets to help balance the load.

In British Columbia, the current plan is to increase the wind capacity from 248 MW in 2011 to 780 MW in 2015. This relatively low penetration is due to a difficult licensing process and the emphasis on developing small hydro.

United States

On an aggregate basis, the energy penetration in 2011 (see references) is estimated to be just under 4%. The top five states as of 2011 are

- South Dakota 22%
- Iowa 19%
- North Dakota 15%
- Minnesota 13%
- Wyoming 10%
- Ten other states have wind energy penetration rates above 4% (Colorado 9%, Kansas 8%, Idaho 8%, Oregon 8%, Oklahoma 7%, Texas 7%, New Mexico 5%, Washington 5%, Maine 5%, and Montana 4%).

In general, the states listed above all have significant interconnections with neighbouring jurisdictions which enables load balancing during times of rapid wind generation changes.

The U.S. Department of Energy's report "20% Wind Energy by 2030" envisages that wind power can meet 20% of all national energy demands by 2030 (see references).

5.2 Isolated Systems

5.2.1 New Zealand

New Zealand is an isolated island system, with significant challenges in maintaining frequency within reasonable limits. As of 2011, there was 614 MW of wind generation, compared to a total system capacity of 9750 MW. This is equivalent to a capacity penetration of 6.3%, and an energy penetration of nearly 5%. The composition of the system in this year also includes hydroelectric (5252 MW), gas (1942 MW), coal (920 MW), geothermal (731 MW), oil (165 MW) and other (127 MW). Due to the generation diversity, and a high proportion of dispatchable generation resources, the plan is to achieve a wind energy penetration of 20% by the year 2020. Significant measures have been put into place to be able to achieve this high penetration, including an aggressive automated load shedding program for water heaters and other non essential loads.

5.2.2 Hawaii

The electric system for the isolated island of Oahu has a daily peak of about 1200 MW and a daily minimum of about 600 MW. Total firm generation capacity on Oahu is 1817 MW, comprising seven thermal generation plants, almost all burning fuel oil.

The Hawaii Clean Energy Initiative (HCEI), which was announced in 2008, includes a mandate for the state of Hawaii to generate 40% of its energy from renewable resources by 2030. The resources include solar, wind, biomass, geothermal, hydropower, and ocean technologies.

The recent Oahu Wind Integration Study (OWIS, 2011) has concluded that the isolated island of Oahu can achieve a wind energy penetration of 20% (25% with photovoltaic energy included), subject to a number of conditions. These include the implementation of a sophisticated wind forecasting system, generation system modifications (to allow lower minimum unit outputs, fast starts, and higher thermal ramp rates), increase of reserve requirements, and the implementation of aggressive load management methods.

5.3 Hatch Experience with Wind Penetration

Hatch has been involved in a number of wind integration studies, which provide some additional context to the situation in Newfoundland. These are discussed below.

5.3.1 Bonneville Power Administration (BPA)

BPA is the regional balancing authority for the Pacific Northwest region of the United States. It manages power balancing for a region with about 40 000 MW of generating capacity. There has been a recent rapid growth of wind generation in the region of nearly 4000 MW and the plan is to extend this to 6000 MW. Although the system is hydroelectric dominated, there are severe operating limitations on the hydro facilities due to fishery requirements and flood control responsibilities. The current penetration on a capacity basis is thus about 10%, and on an energy basis about 6%. They are experiencing significant operational challenges at this level, and believe that they will be at the limit of practical operation at about 15% on a capacity basis (10% on an energy basis). The need to carry a high level of spinning and regulation reserves at a few swing plants has resulted in increased spill and market purchases in order to manage the non-dispatchable wind generation.

5.3.2 Nova Scotia Power Inc. (NSPI)

NSPI generates electricity for the Province of Nova Scotia, and in 2008 had a total generating capacity of 2330 MW. This capacity was made up of 1893 MW of thermal plant, 377 MW of hydroelectric plant, and 60 MW of wind generators. The wind energy penetration at this time was about 1.5%.

The Nova Scotia Wind Integration Study for the Nova Scotia Department of Energy (Hatch, 2008) considered wind penetration cases for 2020 (with an annual peak load of 2866 MW including demand side management loads) as follows: 581 MW (base case; 20% wind capacity penetration, 13.5% energy penetration), 781 MW (27% capacity penetration; 19% energy penetration), and 981 MW (34% capacity penetration; 24% energy penetration).

The results of the base case with 13.5% wind energy penetration was very positive, while the higher penetration cases demonstrated significant adverse operational problems, especially beyond a penetration of 20%.

5.3.3 Manitoba Hydro (MBH)

MBH owns and operates over 5500 MW of hydroelectric generation facilities, and in 2005 considered the development of up to 1000 MW of wind generation facilities. Detailed chronologic simulations have demonstrated that this 18% capacity penetration is feasible (10% energy penetration), but brings operating challenges and additional integration costs. In practice, as of 2012, the wind capacity in Manitoba is 254 MW, compared to the total system capacity of 5500 MW; a capacity penetration of 2%. The development program is on hold, and the energy penetration is not likely to reach over 5% in the foreseeable future.

5.4 Overview

A wind energy penetration rate of 10% is the maximum recommended for the Island of Newfoundland system due to the uncertainty of the technical and economic impacts at the higher penetration rates which are yet to be proven under isolated system circumstances.

6. Sensitivity Analysis – No Minimum Thermal Generation

There are a minimum number of thermal units required in each month of the years of the simulation for voltage and frequency stabilization as well as for Avalon transmission and System peak load support as discussed in Section 2.

An additional sensitivity analysis was carried out, without the requirement for minimum thermal generation. Up to 600 MW of new wind generation was considered in this case and results are shown in Table 6-1. The 2020 case was used for convenience. This penetration level is higher than the 10% wind energy penetration that is considered to be the limiting value for an isolated system.

In Table 6-1, the third column entitled “Usable Energy” is the maximum possible wind energy that could be assimilated into the system for the specified wind capacity. At high installed wind capacities, the usable energy is less than the available 175 GWh per 50-MW wind generation increment, due to minimum loads relative to wind generation capability, i.e., the wind energy is “clipped”. Note that the effectiveness of the wind in displacing thermal generation is reduced further than the clipping indicated in the “usable energy” column as shown in the last column.

The wind efficiency is much higher in this case as compared to the analysis with minimum thermal generation. The efficiency of displacing thermal generation is over 90% all the way up to 300 MW of new wind generation, and drops to 78% for the next 100 MW increment. This indicates that significantly more wind development could potentially be economically viable without the thermal minimal constraint. However, it will likely be the mid-2030s before Holyrood will be replaced by generating sources capable of operating at no minimum and by that time the system will have already reached the recommended wind penetration level.

Table 6-1 Wind Impact Summary – No Minimum Thermal Generation

New Wind			Existing Wind	Hydro Energy				Thermal Energy		Total Generation	Wind Efficiency at Displacing Thermal
Wind	Wind Energy (GWh)		(GWh)	(GWh)				(GWh)		(GWh)	(%)
Installed Capacity (MW)	Available Energy	Usable Energy[1]	Energy	Gen	Δ	Spill	Δ	Gen	Δ	Gen	
Base			283	7120		576		1605		9008	
50	175.2	175.2	283	7112	-7.7	581	6	1438	-167.4	9008	95.6
100	350.4	350.4	283	7112	-0.2	579	-2	1263	-175.2	9008	100.0
150	525.5	525.5	283	7110	-2	578	-1	1090	-173	9008	98.6
200	700.8	700.8	283	7100	-10	582	5	924	-166	9008	94.5
300	1051.2	1051.2	283	7079	-21	600	17	595	-329	9008	94.0
400	1401.6	1401.6	283	7003	-76	655	55	320	-275	9008	78.4
450	1576.7	1576.5	283	6920	-83	708	54	228	-92	9008	52.4
500	1752.0	1745.8	283	6817	-104	782	74	163	-66	9008	37.4
550	1927.1	1903.2	283	6697	-119	875	92	124	-38	9008	21.9
575	2014.8	1971.9	283	6639	-58	919	44	114	-10	9008	11.9
600	2102.4	2034.2	283	6587	-52	959	40	104	-10	9008	11.6

Note:
1) Usable Energy is the Available Energy less wind clipped

7. Conclusions

Hatch has carried out an evaluation of how much additional wind generation can be added to the Island of Newfoundland system, from an economic and technical point of view, assuming no interconnection to neighbouring power systems. In addition, the technical limitations of additional wind generation due to voltage and stability limitations were reviewed. This was followed by a review of worldwide experience with wind generation to establish a recommended upper limit of wind penetration for the isolated power system in Newfoundland.

Vista modelling was undertaken to determine the level of thermal displacement for increasing installed wind generation capacities in four load forecast years.

In 2014, the first 25-MW increment of wind generation is 84% effective at displacing thermal energy, and the successive increments of 50 MW have displacement efficiencies of 80%, 67%, 45% and 36%. Following consultation with Nalcor, subsequent simulations assumed that 25 MW of new wind generation would be developed prior to 2020.

In 2020, the first 50-MW increment of wind generation is 77% effective at displacing thermal energy, and the successive increments have displacement efficiencies of 54%, 44%, 23% and 13%. Following consultation with Nalcor, subsequent simulations assumed that 50 MW of new wind generation would be developed prior to 2025.

By 2025, the load will have grown and the system will be able to absorb additional wind energy. The first 50-MW increment of wind generation is 97% effective at displacing thermal energy, and the successive increments have displacement efficiencies of 88%, 71% and 47%. Following consultation with Nalcor, subsequent simulations assumed that 150 MW of new wind generation would be developed prior to 2035.

By 2035, the load has grown further, and the system will be better able to absorb wind energy. The first 50-MW increment of wind generation is 97% effective at displacing thermal energy, and the successive increments have displacement efficiencies of 93%, 93% and 71%.

With an additional 150 MW in 2035 or soon after, the total installed wind capacity would be 375 MW plus the refurbished/replacement 50 MW; for a total of 425 MW. The gross wind energy production will be 1489 GWh/y, compared to the total island annual energy production of 10,369 GWh/y; indicating a gross wind energy penetration of 14%.

In the *Vista* modelling done for this study, the average operating levels for the Meelpaeg and Long Pond reservoirs increase by over 2 m in 2020, 1.5 m in 2025, and 1.25 m in 2035, for the 200 MW wind penetration cases. This is the primary causative factor for increased spill, lower hydro generation efficiencies, and thus reduced thermal displacement efficiency.

The conclusions reached above are based on study results that focused primarily on macro energy penetration, without detailed consideration of hourly variations required for load balancing, as well as real-time regulation issues to maintain frequency.

Following further wind measurements at prospective wind generation sites, and before proceeding beyond 100 MW of new wind generation, it is recommended that a further more detailed wind integration study be undertaken to evaluate the hourly chronologic operation of the system with due consideration to wind uncertainty and additional reserves that will be needed to regulate the wind generation resource. This study should also assess the statistics of load variations in combination with the wind variations at specific prospective wind generation sites in order to define appropriate reserve margins.

The technical limitations of additional wind generation due to voltage and stability limitations were reviewed. The findings were that wind penetration levels up to 225 MW and 300 MW could be tolerated under light load conditions for 2020 and 2035, respectively. Under peak load conditions 500 MW is the limit in both years analyzed. These limits are based on the assumption that sufficient reactive power and voltage support resources will be provided at the points of interconnections of the wind farms to be incorporated into the island power system of Newfoundland.

Based on current worldwide experience, and planned wind penetration programmes, it would be prudent to assume that the total viable wind penetration in 2035 is less than the 425 MW noted above. It is recommended that the total wind penetration to be used in the integration plan be nominally 300 MW to allow for the noted complexities and their associated costs. Therefore, considering the existing wind farms (54 MW existing/50 MW replacement), the development plan to be advanced could be as follows:

- 2015 50 MW
- 2020 50 MW
- 2025 50 MW
- 2030 50 MW
- 2035 50 MW

This would yield a wind generation penetration in 2035 of 300 MW in capacity yielding a 10% energy penetration, which is consistent with a high penetration in isolated power systems.

8. References

1. "AWEA Annual Report 2011" (American Wind Energy Association, April, 2012) http://awea.org/newsroom/pressreleases/Annual _Report.cfm)
2. "Wind Power in the United States: Technology, Economic and Policy Issues" ,CRS Report for Congress; June 20, 2008 (Congressional Research Service
3. "20% Wind Energy by 2030", U.S. Department of Energy's Report
4. "Oahu Wind Integration Study", May 2, 2011, Hawaii Natural Energy Institute, Hawaii Electric Company, GE Energy, U.S. Department of Energy
5. "Oahu Wind Integration and Transmission Study: Summary Report", November, 2010, NREL/TP-5500-48632, U.S. Department of Energy
6. "Wind Vision 2025", CANWEA, 2008, (http://www.canwea.ca/images/uploads/File/Windvision_summary_e.pdf)
7. "Coordination of Hydroelectric and Wind Generation for Manitoba Hydro", Diana Hurdowar-Castro, Stuart Bridgeman, Bill Girling, Kevin Gawne, and Kelly Hunter, technical paper published in the Proceedings of Hydrovision 2006 Conference, August 2006
8. "Wind Resources Impact Study" March 2009, Bonneville Power Administration (BPA) internal report
9. "Nova Scotia Wind Integration Study", March 2008, Hatch Ltd. report to the Nova Scotia Department of Energy, PRH-327074.03
10. "A Study to Evaluate Wind Integration into the Manitoba Hydro System", May 2005, Hatch Ltd. (Synexus Global) report to Manitoba Hydro
11. "Island Pond/Granite Canal Re-optimization and Cost Update Study", AGRA ShawMont (1997)
12. "Feasibility Study, Round Pond Hydroelectric Development", Lavalin (1988)
13. "Wind Integration Study – Isolated Island: Technical Study of Voltage Regulation and System Stability", Newfoundland and Labrador Hydro, (June 2012)
14. "Feasibility Study for Portland Creek Hydroelectric Project", SNC-Lavalin (2007)

Appendix A
Detailed Plots of
Reservoir Water Level Changes

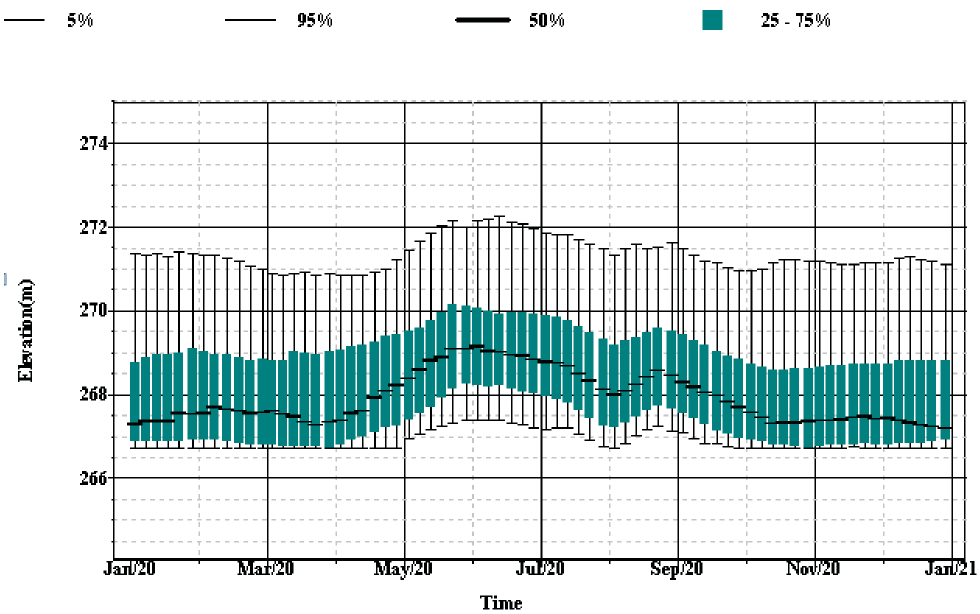

Figure A-1 Meelpaeg Levels: Base Case – 2020

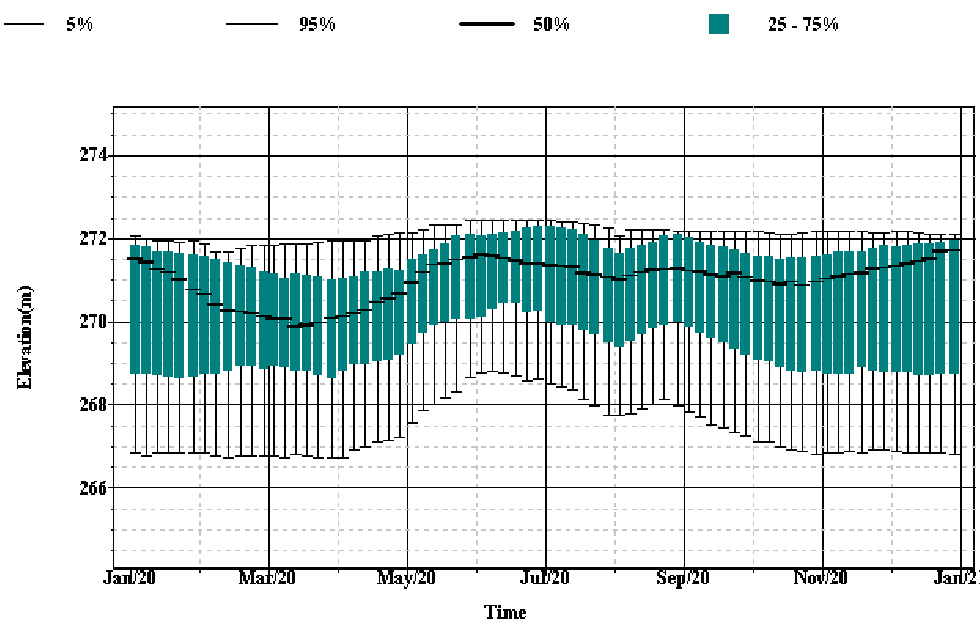

Figure A-2 Meelpaeg Levels: 200 MW Wind – 2020

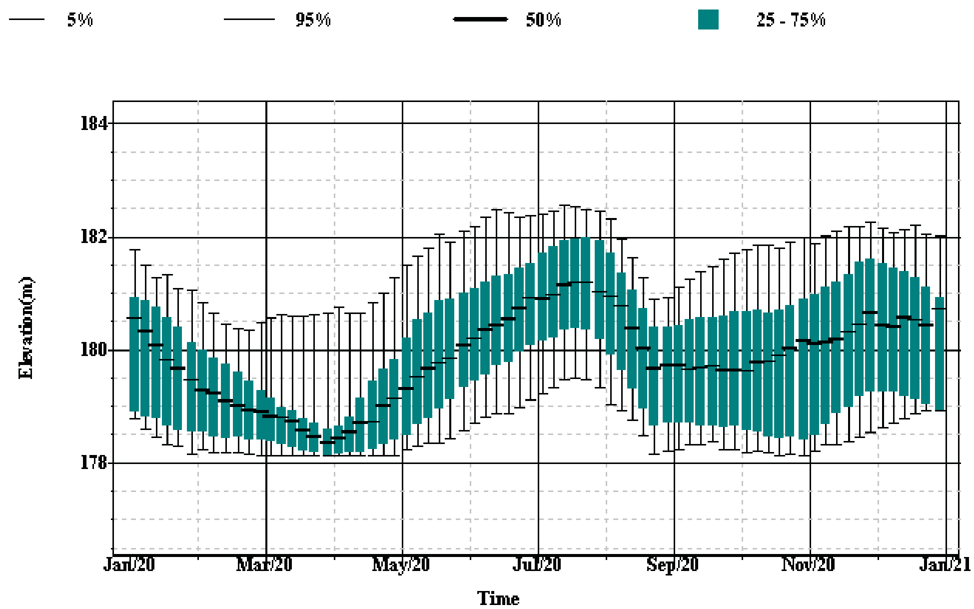

Figure A-3 Long Pond Levels: Base Case – 2020

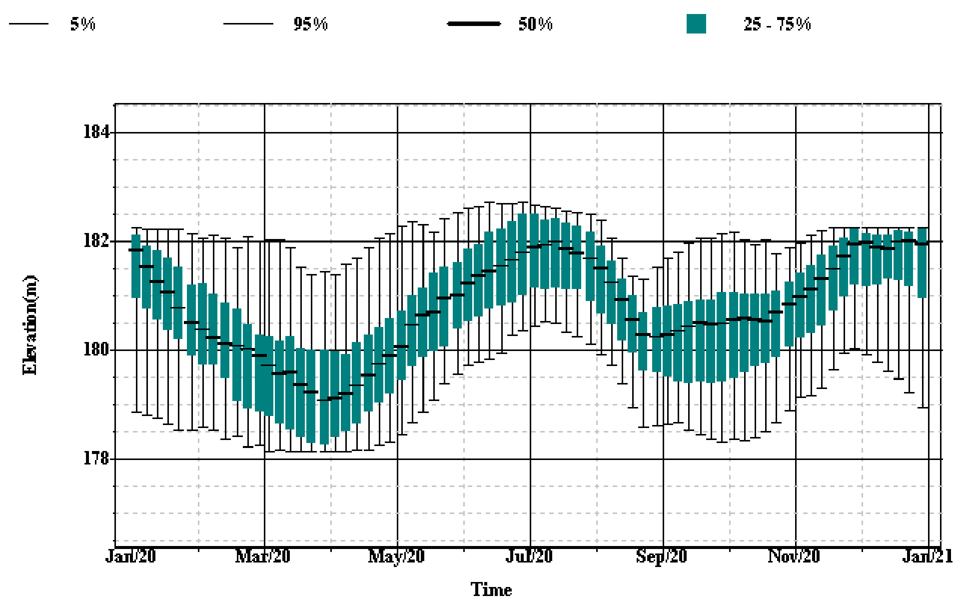

Figure A-4 Long Pond Levels: 200 MW Wind – 2020

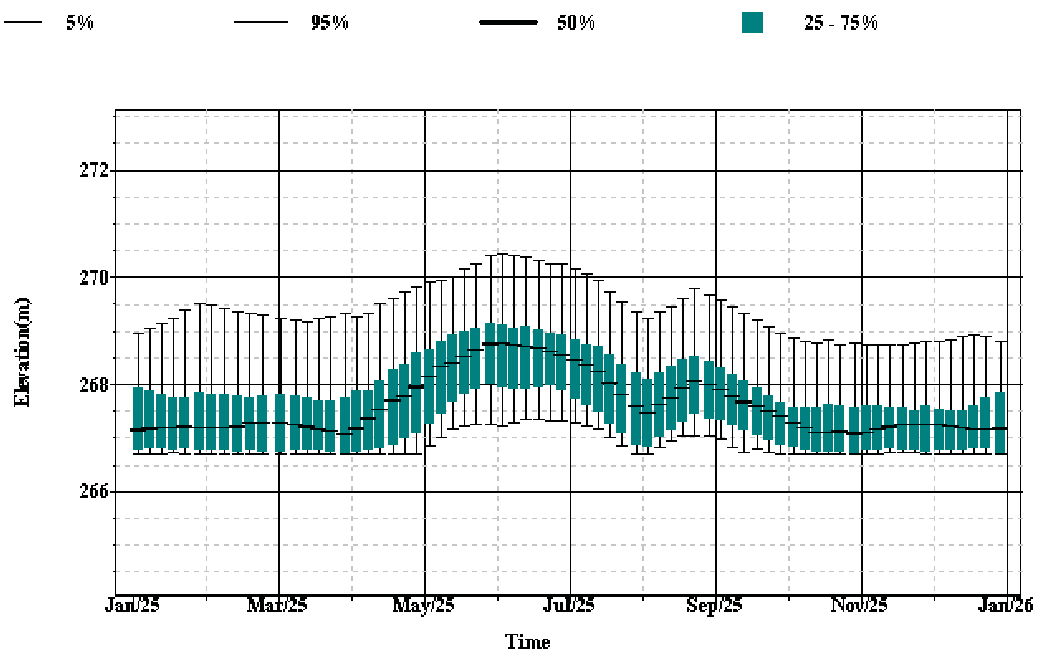

Figure A-5 Meelpaeg Levels: Base Case – 2025

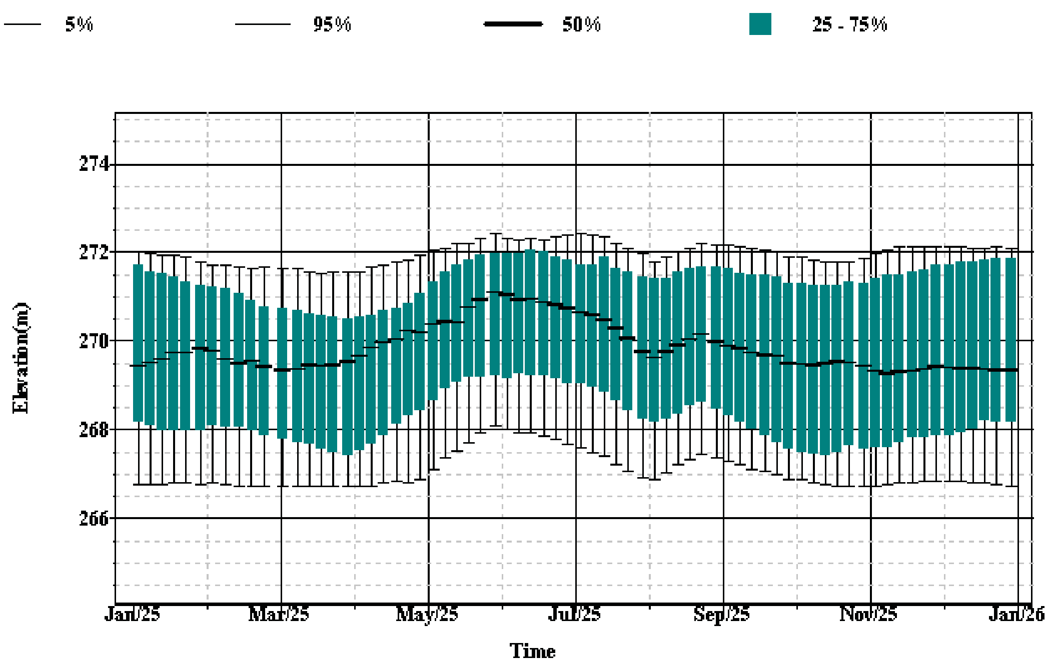

Figure A-6 Meelpaeg Levels 200 MW Wind – 2025

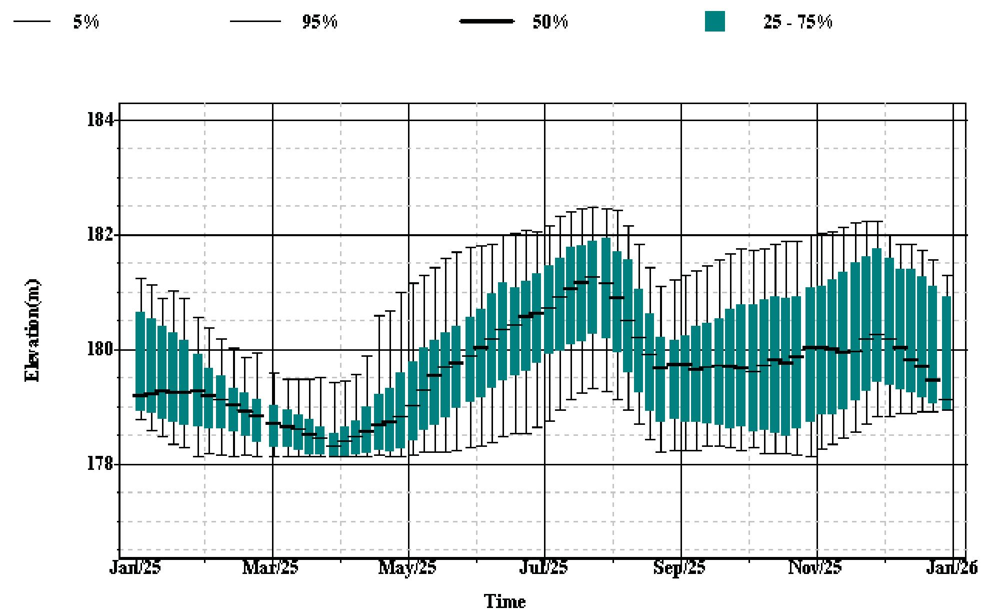

Figure A-7 Long Pond Levels: Base Case – 2025

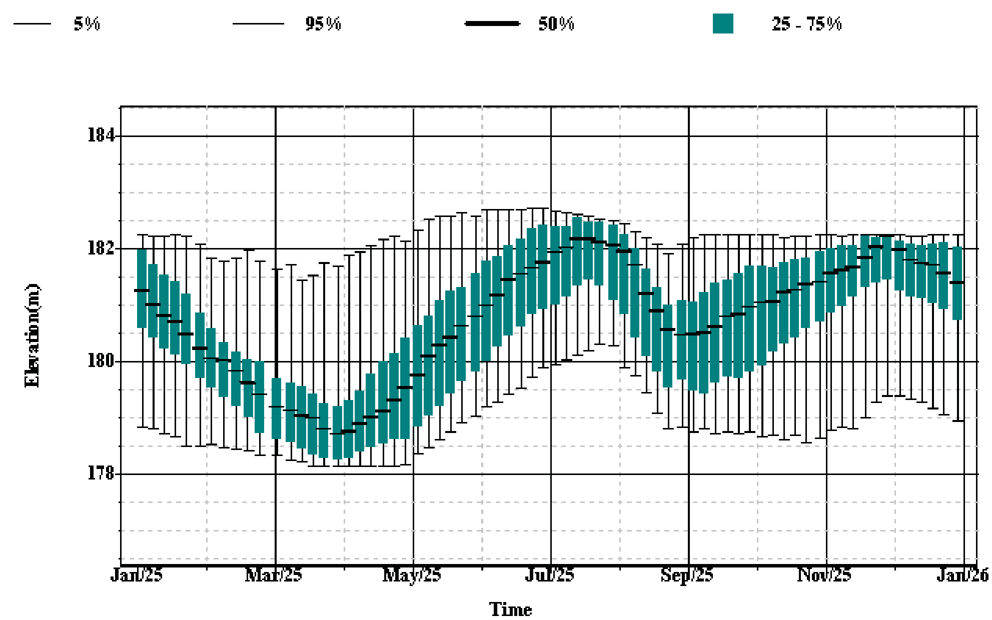

Figure A-8 Long Pond Levels 200 MW Wind – 2025

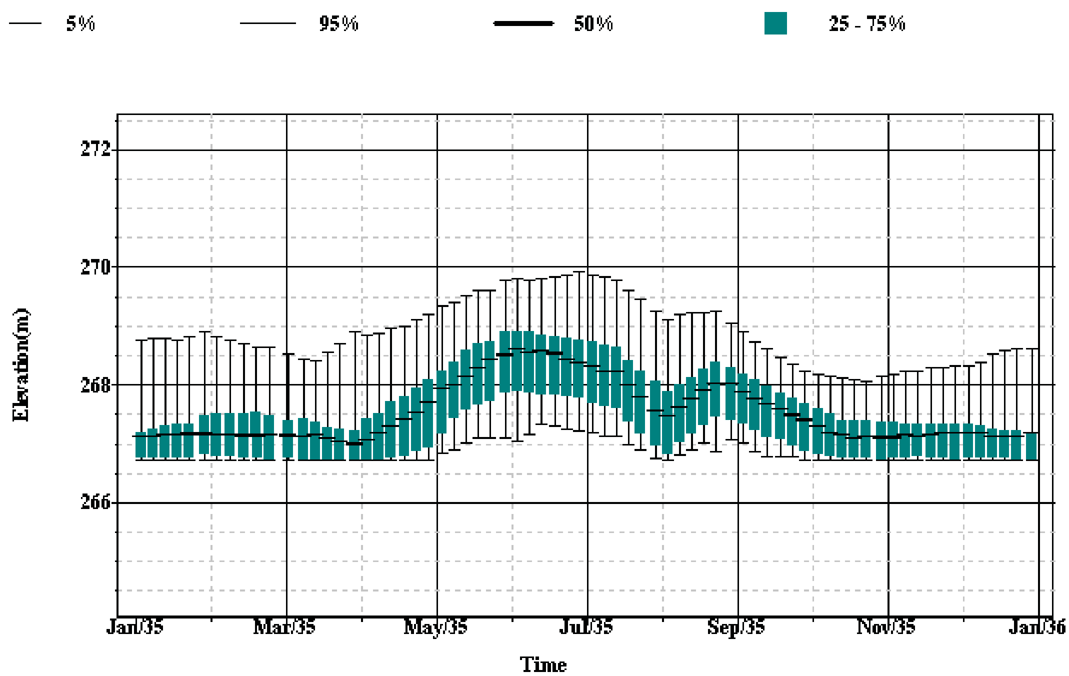

Figure A-9 Meelpaeg Levels Base Case – 2035

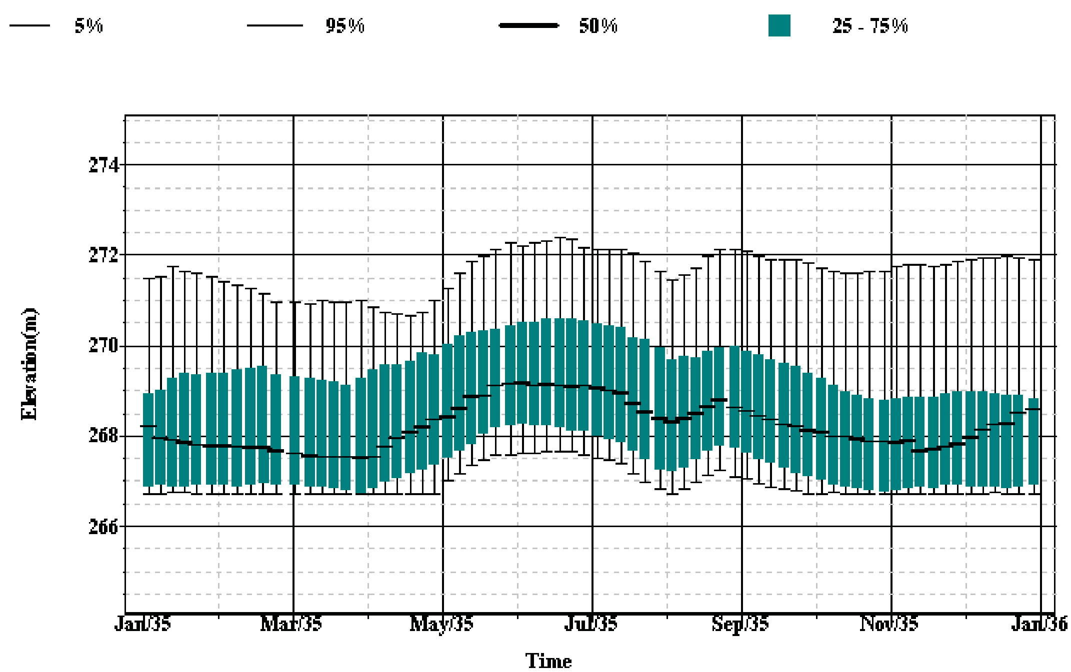

Figure A-10 Meelpaeg Levels: 200 MW Wind – 2035

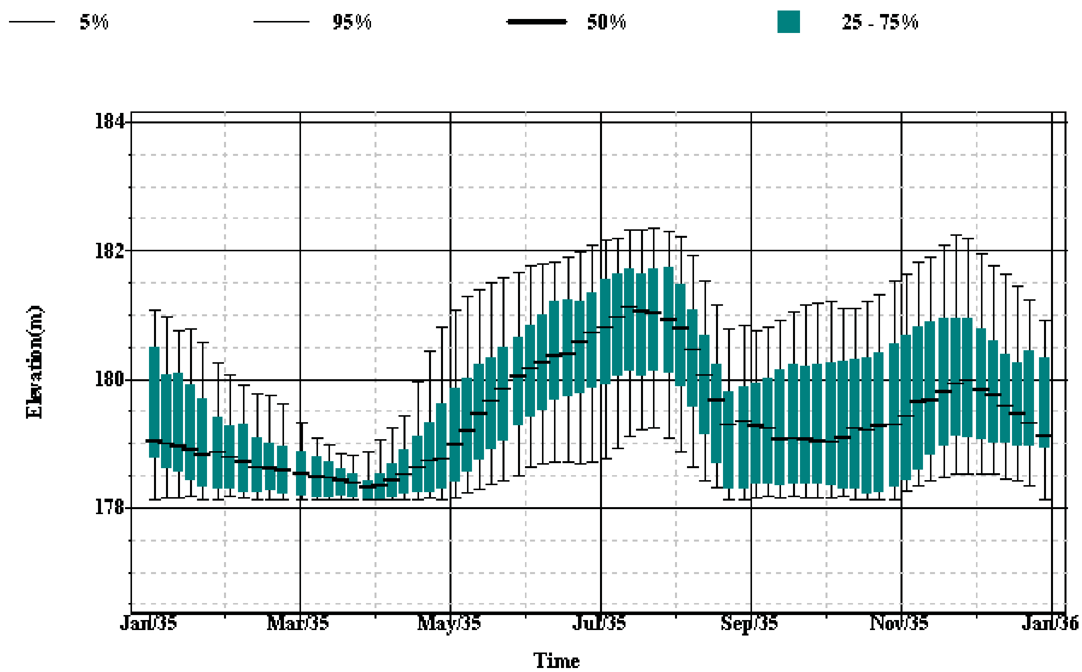

Figure A-11 Long Pond Levels: Base Case – 2035

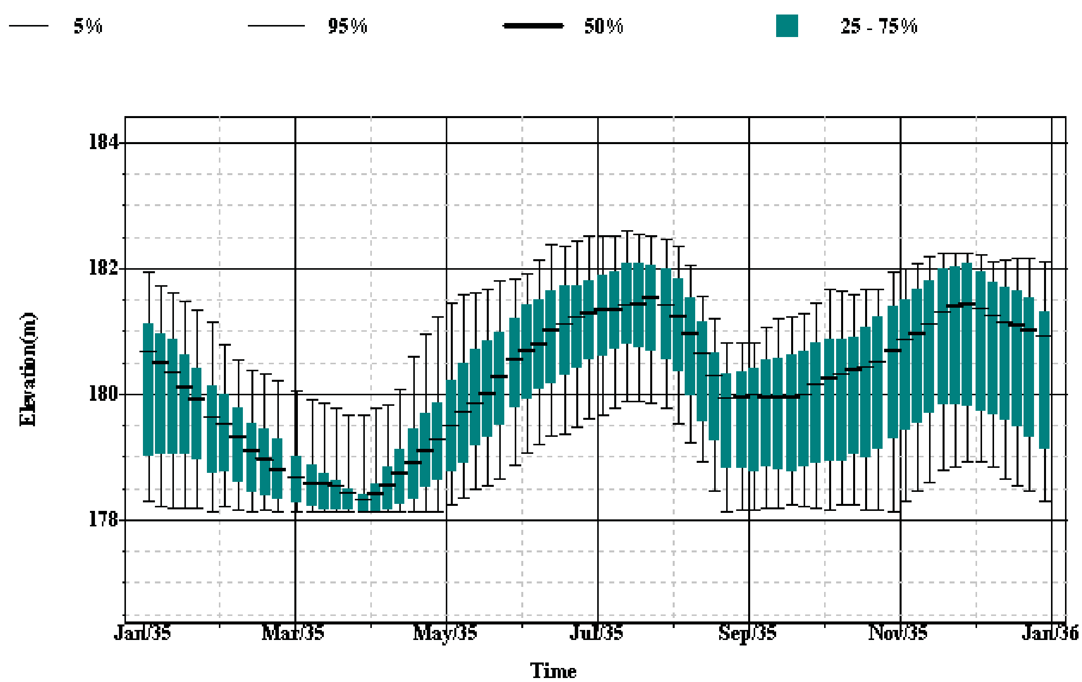

Figure A-12 Long Pond Levels 200 MW Wind – 2035

Tryggvi Olason/
TO:kln

Suite 500, 4342 Queen Street
Niagara Falls, Ontario, Canada L2E 7J7
Tel 905 374 5200 ◆ Fax 905 374 1157

HATCH™

Suite 500, 4342 Queen Street
Niagara Falls, Ontario, Canada L2E 7J7
Tel 905 374 5200 ◆ Fax 905 374 1157