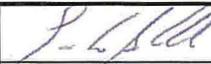
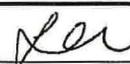


**Newfoundland and Labrador Hydro  
 Coastal Labrador Wind Monitoring Program**

**Final report- Coastal Labrador Wind Monitoring Program**

						
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## Executive Summary

Newfoundland and Labrador Hydro (NLH) commissioned Hatch to perform Wind Resource Assessments (WRA) and related analyses for five communities in coastal Labrador: Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup.

The objective of the Coastal Labrador Wind Monitoring Program was to identify potentially windy areas that also possess other desirable qualities of a wind energy development site.

This final report documents the approach taken and the results of the Coastal Labrador Wind Monitoring Program completed at the five sites from January 2011 to August 2015.

Preliminary site assessment was completed to identify potential site locations in all five communities. This phase included preliminary environmental screening, site visits, permitting and the preliminary evaluation of factors such as wind and constructability.

Following the identification of a specific site in each community, meteorological towers were acquired and installed from July to November 2013. Meteorological data was collected from all five communities for 18 months and towers were dismantled in July 2015.

A wind resource assessment report was completed for each community and are presented in Appendices A to E of this report. The main elements of the WRA reports conclude that the wind monitoring campaign was successfully completed and data recovery rates exceeded industry standards. Energy yield was calculated using the meteorological data collected and was based on a preliminary turbine selection. The results of these calculations are presented in the table below.

**Table 1-1 : Energy Yield per Community**

Project	Layout # - Turbine Model (Number of WTG)	Wind Farm Capacity (KW)	Net Energy Production (MWh/year)	Wake Losses (%)	Additional Losses (%)	Net Capacity Factor (%)
Nain	Layout 1 - EWT900 (2)	1800	6,150	0.5	14.6	39.0
	Layout 2 - NPS100 (12)	1200	4,058	2.5	14.3	38.6
Hopedale	Layout 1 - EWT900 (1)	900	3,398	0.0	14.0	43.1
	Layout 2 - NPS100 (8)	800	2,765	2.2	13.8	39.4
Makkovik	Layout 1 - EWT900 (1)	900	3,102	0.0	14.1	39.3
	Layout 2 - NPS100 (5)	500	1,728	1.1	13.6	39.4
L'Anse au Loup	Layout 1 - EWT900 (4)	3600	11,651	1.2	13.7	36.9
Cartwright	Layout 1 - EWT900 (1)	900	2,898	0.0	14.2	36.7
	Layout 2 - NPS100 (5)	500	1,559	4.0	14.0	35.6



The final phase of the wind monitoring program was to conduct a preliminary evaluation of the feasibility to integrate wind with each of the community's diesel-fuelled electrical generators and to establish the potential economic viability of the projects. This phase was completed using a software known as Homer, using input from NLH and the energy yields estimated in the WRA phase.

It is important to note that a number of additional studies and estimates will require to be completed as part of the detailed design phase. The initial analysis and modelling completed as part of this preliminary evaluation indicates that the implementation of wind in all communities, except L'Anse au Loup, could potentially reduce diesel consumption and may lower the overall costs of energy in four of the communities. A summary of the results of the hybrid modelling and optimisation for the five communities, as well as an overall ranking of the communities, are presented in Appendices F to J.

The installation of WTGs on the grid at each of the communities will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in this report and relevant annexes include no allocation for additional control and communication equipment.

As noted in the reports *Hybrid System Modelling and Optimisation*, provided in Appendices F to J, the cost of energy does not include all applicable costs. As such, this preliminary evaluation of energy costs indicates that the projects may be viable (or not) and warrants further study. Additional costs not reflected here include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

In conclusion, the Coastal Labrador Wind Monitoring Program identified that the implementation of wind turbines in four of the five communities has potential and could possibly result in reductions in diesel consumption if integrated correctly. The overall business case for the investment remains to be validated as additional studies and community consultation will be required prior to completion of the final design.

The Coastal Labrador Wind Monitoring Program was a prefeasibility study and additional studies and validations will be required prior to initiating the detailed design phase and implementation. Many studies and actions will be iterative in nature and will require validation in the planning and implementation phase.



## 1. Introduction

As a follow up to the Coastal Labrador Alternative Energy Study commissioned by the Government of Newfoundland and Labrador in 2008, Newfoundland and Labrador Hydro (NLH) commissioned Hatch to perform Wind Resource Assessments (WRA) and related analyses for five communities in coastal Labrador: Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. The main objective of the program was to identify potentially windy areas that also possess other desirable qualities of a wind energy development site.

The Coastal Labrador Wind Monitoring Program was divided in five phases as follows:

- a. Phase 1: Site Selection and Environmental Screening,
- b. Phase 2: Meteorological Tower Design Validation and Installation,
- c. Phase 3: Meteorological Data Collection for 18 months,
- d. Phase 4: Preparation of Wind Resource Assessment Report for each community, and
- e. Phase 5: Preparation of Hybrid System Modelling and Optimisation Reports for each community.

### 1.1 Report Organization

To simplify the presentation of results in this Final Report, detailed Wind Resource Assessment (WRA) and Hybrid System Modelling and Optimisation Reports were completed for each of the five communities and are included as individual Appendix to this report. This report provides a summary of the methodology and the analysis and findings that are detailed in the appendixes. This report has been organized as follows:

- Section 1: Introduction.
- Section 2: Summary of Methodology and Findings during Site Selection Phase.
- Section 3: Methodology and Findings of Meteorological Tower Design and Installation Phase.
- Section 4: Summary of Findings - Data Collection Phase.
- Section 5: Summary of Findings - Wind Resource Assessment Phase.
- Section 6: Summary of Findings - Hybrid System Modelling and Optimisation Phase.
- Section 7: Conclusions and Recommendations.
- Appendices A-E: Wind Resource Assessment Reports for all 5 communities.
- Appendices F-J: Hybrid System Modelling and Optimisation Reports for all 5 communities.

## 2. Phase 1: Site Selection

This report does not contain all of the information previously included in the site selection report which was provided to NLH in July 2013. Rather, the following is a summary of the methodology and findings of the site selection phase of the project.

The methodology of the site selection phase included the following main steps:

- Preliminary desktop screening of multiple site options including preliminary environmental screening.
- Site visits by members of the project team to validate desktop study results.
- Permitting considerations (e.g., aviation safety, land use).
- Discussion of options within the project team and final approval by the Client.

Site selection for the purpose of installing Meteorological masts and for guiding subsequent wind power development was based on the following main criteria:

- Wind resource & energy estimates.
- Icing potential.
- Constructability (cost of road and grid extension).
- Environmental constraints.
- Land use (including regulatory issues).
- Potential interference with air traffic and communications.

The site selection process was completed based on the following steps:

**Step 1:** At each community, a number of candidate sites were identified based on expert opinion, considering the objectives of the project and the criteria shown above.

**Step 2:** Each of the candidate sites were evaluated against the selection criteria.

**Step 3:** A comparison matrix was used for arriving at a combined ranking for all qualitative criteria.

The preliminary desktop screening was performed by Sikimiut Environmental Management Ltd (Sikimiut) and included a review of the potential environmental restrictions that could be found within each community. It is important to note that the environment screening was completed in 2011 and was preliminary in nature. As such, additional and/or new environmental and community restrictions may exist and this will need to be validated prior to the detailed design phase.

Based on the desktop screening results, site visits were conducted from June 11-15, 2012. The visits served to validate the findings of the desktop screening analysis and to provide



NLH and Hatch staff with a first-hand view of the key sites. The team reviewed the site visit results and discussed site options to determine which measurement sites were to be considered priority. These were further adjusted based on the results of aeronautical clearance applications to NAV Canada and Transport Canada and land use permitting considerations. The possibility of co-locating instruments on existing Bell Aliant towers was considered for some locations but ultimately rejected. The resulting final tower locations were approved and are presented in Section 3 of this report and additional details are included in the WRA reports found in Appendix A to E.

The land use permitting process for the meteorological masts differs by jurisdiction and community. For the 3 northern communities (Nain, Hopedale and Makkovik) which are located in Nunatsiavut territory, a general Research Authorization was received from the Nunatsiavut Government as well as specific permits from the individual Inuit Community Governments (ICGs).

For L'Anse au Loup and Cartwright, Municipal and Crown Land approvals were received from the municipal and provincial governments, respectively.

Maps showing all wind project development locations are included in Appendices A – E for the individual communities.



### 3. Phase 2: Meteorological Tower Design Validation and Installation

#### 3.1 Meteorological Tower Design

Wind varies strongly with geographical locations and is strongly influenced by elevation, topography, surrounding vegetation, large nearby water bodies and local obstacles. Coastal Labrador is known for the relative high incidence of icing in the fall, winter and spring periods. High icing environments present structural and operational challenges for the meteorological towers required for wind resource assessment which needed to be considered in the meteorological tower design process.

As a first step in understanding the local wind resource, relevant sources of wind data and icing information were obtained to determine the appropriate Ice and wind load level requirements for each of the community and investigate off the shelf tubular or lattice towers that could meet these requirements.

Based on this analysis and investigation, a 36 meter lattice tower from Advanced Masts Systems Inc. was selected and a picture of the tower from Nain is provided below.



Figure 3-1 : MetMast at Nain

In order to record wind data measurements throughout the 12 months (including winter months), instrumentation was selected to enable good data recovery rates in icing conditions. Details on specific instrumentation used on all 5 meteorological towers can be found in the table below.

**Table 3-1: Met Tower Instrumentation**

ID	Height (m)	Type	Calibrated / Heated	Heated	Primary (P) or Redundant (R)
N/A	N/A	NRG Symphonie PLUS3	N/A	N/A	N/A
A1	35.0	NRG #40C	Yes	No	P
A2	35.0	NRG Icefree III	Yes	Yes	R
A3	26.0	NRG #40C	Yes	No	P
A5	26.0	RMyoung 5103-AP	Yes	No	R
A4	17.0	NRG #40C	Yes	No	P
V1	33.0	NRG Icefree III	No	Yes	P
V2	26.0	RMyoung 5103-AP	No	No	R
V3	15.0	NRG #200P	No	No	R
T	34.0	NRG #110S	No	No	P

### 3.2 Meteorological Tower Installations

After acquiring the five meteorological towers and all associated equipment and instruments, all the material was shipped to Goose Bay and then redistributed to the respective communities in August and September 2013.

Hatch worked with Sikimiut staff to coordinate logistics and local support.

All five towers were installed and commissioned from 1 October 2013 to 5 November 2013. Copies of the tower installation reports were completed and transferred to NLH for reference.

Other information relevant to the tower installations and specifications on instrumentation can be found in the respective WRA reports in Appendices A to E.

## 4. Phase 3: Meteorological Data Collection for 18 months

The wind measurement campaigns covered a period of 18 months at all 5 communities. The data were collected periodically from the meteorological masts and sent to the Hatch computer network via a satellite communication system. The quality of the data was analysed and data points that were deemed erroneous or unreliable were replaced by redundant data when available, or removed from the data set.

To comply with the best practices in WRA, a 12-month period was selected for every site to better assess the annual energy estimate of the wind project and to avoid seasonal variations in wind.

The following table provides the dates of mast installation, the periods of relevant data collection and the data recovery rates for the main anemometer used in the wind resource assessment analysis.

**Table 4-1: Met Tower Installation, Data Collection Period and Recovery Rate**

Project	Met mast ID	Installation Date	Relevant Data Collection		Recovery Rate (%)
			From	To	
Nain	2601	October 30, 2013	December 1, 2013	November 30, 2014	97.8
Hopedale	2602	October 27, 2013	December 1, 2013	November 30, 2014	98.6
Makkovik	2603	October 25, 2013	November 1, 2013	October 31, 2014	93.8
L'Anse au Loup	2604	October 5, 2013	November 1, 2013	October 31, 2014	99.0
Cartwright	2605	November 5, 2013	December 1, 2013	November 30, 2014	99.3

The data recovery rates at all 5 sites exceeded industry standards for wind monitoring measurements. The high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.

The wind monitoring period as mandated in the RFP covered a period of 18 months in order to ensure that a good recovery rate was obtained and that two winters worth of data were available. The wind monitoring period was considered a success after 18 months of data acquisition as the recovery rates were above standard for all communities. There was an option as part of RFP to extend the monitoring period by an additional 6 months but due to success of the monitoring in first 18 months, this option was not recommended nor exercised.

## 5. Phase 4: Wind Resource Assessment Reports

### 5.1 Wind Characteristics

This section provides a summary of the WRA, including elements that are presented in detail in the respective WRA reports in Appendices A to E. The following table provides the main



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characteristics of the wind regime as it was measured by the meteorological masts installed on the projects' sites.

**Table 5-1: Wind Regime Characteristics**

Project	Met Mast ID	Measurement Height (m)	Avg Wind Speed (m/s)	Wind Shear	Turbulence Intensity (%)	Annual Average Air Density (kg/m <sup>3</sup> )	Icing (%)
<b>Nain</b>	2601	35.0	6.5	0.11	12.6	1.31	5.0
<b>Hopedale</b>	2602	35.0	7.2	0.13	13.6	1.31	5.4
<b>Makkovik</b>	2603	35.0	7.7	0.12	12.0	1.31	1.7
<b>L'Anse au Loup</b>	2604	35.0	7.7	0.19	13.1	1.27	6.8
<b>Cartwright</b>	2605	35.0	6.5	0.11	14.4	1.30	3.1

The wind speeds measured on all five sites range from 6.5 m/s to 7.7 m/s at 35m height. The wind shear exponents were calculated based on the data collected and are consistent with the land cover and topography at the meteorological mast locations. The wind turbulence intensities observed at all sites are moderate. The air density was calculated at each mast according to its elevation and local temperature measurements. The amount of icing estimates was calculated based on the average of icing events detected on the mast during the measurement campaign.

A detailed description of the methodology and the wind characteristics summarized in the table above can be found in Section 3 of the WRA reports provided in Appendices A to E.

## 5.2 Long Term Extrapolation and Wind Flow Modelling

To forecast the energy production of a wind power plant, wind data that represent the historical wind conditions at the site were required. The WRA analysis were conducted using one full year of data, which is not sufficient to capture the year-to-year variability of the wind. Consequently, and based on industry best practice, it was necessary to translate the measured short-term data into long-term data. This was done through a correlation/adjustment process that makes reference to a meteorological station where historical data is available.

Since the top anemometers of the meteorological masts were mounted at a lower height than the expected hub height of the wind turbines, the long-term data were also extrapolated from the anemometer height to the wind turbines' expected hub heights.

The results of the long term adjustments are presented in the following table.



**Table 5-2: Long Term Adjustment**

Project	Met Mast ID	Reference Station Name (ID) [Available Data period]	Correlation - Coefficient of Determination R2	Met Mast Short-term Wind Speed (m/s)	Adjustment Factor (%)	Met Mast Long-term Wind Speed (m/s)	Met Mast Long-term Wind Speed at 37m/40m hub heights (m/s)
<b>Nain</b>	2601	Nain (8502799) [2006-2014]	0.84	6.5	0.35	6.5	6.7 / 6.7
<b>Hopedale</b>	2602	Hopedale AUT (8502400) [2005-2014]	0.73	7.2	-1.4	7.1	7.2 / 7.3
<b>Makkovik</b>	2603	Hopedale AUT (8502400) [2005-2014]	0.69	7.7	-1.9	7.6	7.6 / 7.8
<b>L'Anse au Loup</b>	2604	Lourdes De Blanc Sablon A (7040813) [2000-2014]	0.74	7.7	4.5	8.0	8.1 / 8.2
<b>Cartwright</b>	2605	Cartwright (8501100) [2007-2014]	0.69	6.5	6.4	7.0	7.3 / 7.3

Meteorological masts provide a local estimate of the wind resource. Therefore, it was necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area. The preparation of wind flows for the projects was completed using the WAsP software and this provided wind flow maps for all five project areas which were used to optimise the size and layout and energy of the proposed wind projects. The wind flow and energy production are calculated with specialised software that require, apart from the Meteorological masts long-term data, background maps that contain the information on topography, elevation, roughness lengths and potential obstacles. This is also used in conjunction with the wind turbine characteristics. The wind flow maps can be found in the respective WRA reports in Appendices A to E.

### 5.3 Preliminary Turbine Selection

A preliminary turbine selection analysis was completed based on the following criteria:

- Site's wind speed and turbulence class (IEC class II).
- Extreme wind and weather conditions (operation down to -40C). The coldest 10-minute temperature recording measured during the data collection period ranged from was -30°C in Cartwright to -33.1°C in Hopedale.



- Turbine capacity ranges from 100 KW to 1,000 KW to meet the community load.
- Wind turbine's dimensions and weight versus crane capacity and accessibility.

This preliminary analysis concluded that two turbine models would be suitable for the Coastal Labrador projects: Emergya Wind Technologies 500kW / 900kW (EWT500 / EWT900) and Northern Power 100kW Arctic (NPS100). These models have proven technology in cold and icy environments and are suitable for wind-diesel generation in remote community. Hatch has discussed existing operations of these two turbine models in Alaska which also faces difficult winter conditions. Additional turbine selection analysis will need to be completed prior to initiating the detailed design phase of the respective projects.

The next step required the evaluation of the number of wind turbines that would be optimal based on existing load at each community. The following table shows the results of the WindFarmer optimization which was calculated to establish the optimal number of turbines to meet the community load.

**Table 5-3: Evaluation of Number and Model of Turbines**

Project	Community Load (kW)	Turbine Model	Optimal Number Of Wind Turbine Required	Ranking
<b>Nain</b>	1200	EWT900	2	1
		NPS100	12	2
<b>Hopedale</b>	750	EWT900	1	1
		NPS100	8	2
<b>Makkovik</b>	500	EWT900	1	1
		NPS100	5	2
<b>L'Anse au Loup</b>	3000	EWT900	4	1
		EWT500 <sup>+</sup>	6	2
<b>Cartwright</b>	500	EWT900	1	1
		NPS100	5	2

\* Based on the gross energy output at 30 cents/KWh and the turbine purchase cost only.

<sup>+</sup> From a financial point of view, the EWT500 was discarded due to purchased cost similarity and BOP cost. See the WRA reports for more details.

Even though a more detailed turbine selection exercise will be required at a later phase of the project, the NPS 100 and EWT500/900 were considered suitable candidate turbines in order to complete the preliminary energy estimates for the potential wind projects.



## 5.4 Energy Estimates and Losses

Wind farm layout optimisations were completed using the Windfarmer software, which is one of the leading softwares in the wind industry. The energy production for each wind turbine was calculated using the wind turbines' power curves and thrust curves provided by the turbine manufacturers.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.

**Table 5-4: Energy Production Results**

Project	Layout # - Turbine Model (Number of WTG)	Wind Farm Capacity (KW)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)	Net Energy Production (MWh/year)	Amount excess energy (MWh/y)
Nain	Layout 1 - EWT900 (2)	1800	39.0	0.5	14.6	6,150	1,380
	Layout 2 - NPS100 (12)	1200	38.6	2.5	14.3	4,058	336
Hopedale	Layout 1 - EWT900 (1)	900	43.1	0.0	14.0	3,398	663
	Layout 2 - NPS100 (8)	800	39.4	2.2	13.8	2,765	366
Makkovik	Layout 1 - EWT900 (1)	900	39.3	0.0	14.1	3,102	1,094
	Layout 2 - NPS100 (5)	500	39.4	1.1	13.6	1,728	166
L'Anse au Loup	Layout 1 - EWT900 (4)	3600	36.9	1.2	13.7	11,651	998
Cartwright	Layout 1 - EWT900 (1)	900	36.7	0.0	14.2	2,898	869
	Layout 2 - NPS100 (5)	500	35.6	4.0	14.0	1,559	103

It is also important to note that not all energy produced by potential wind turbine would be used by the existing system as identified in Table 5-4 above.

The layouts are still considered preliminary and additional validation will be required. Land restrictions, communication corridors, noise and visual impacts, and other site-specific



matters such as community acceptance, soil and constructability will need to be evaluated in later phases of the program before the site layout can be considered final.

## 6. Phase 5: Hybrid System Modelling and Optimisation for Each Community

The main objectives of this part of the mandate were to provide the potential wind turbine capacity that can be integrated to the current electrical supply system of the 5 communities. This included the preliminary evaluation of the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

### 6.1 Existing Electrical Supply Systems

The power grid operated by NLH at four of these five communities currently relies exclusively on diesel generators. The fifth community, L'Anse au Loup, is interconnected to the Hydro-Quebec (HQ) grid, which currently provides over 90% of the electricity being used. The remaining power is supplied by diesel generators.

NLH provided information on the current isolated-grid systems such as the quantity of diesel genset units, the capacity of the gensets, the brand, the fuel consumption, the control logic of operation, the costs of replacement and O&M costs for each unit of each community. The following table summarize the current electrical supply systems. (More information is available in Section 2 of the reports *Hybrid System Modelling and Optimisation*, provided in Appendices F to J.)

**Table 6-1: Electrical Supply System in each Community**

Project	Quantity of Diesel Genset Unit	Total Capacity of Diesel Gensets (kW)	Maximum Grid Inertia HQ (MW)
Nain	4	3,755	-
Hopedale	4	2,514	-
Makkovik	3	1,550	-
L'Anse au Loup	6	7,150	4
Cartwright	4	2,220	-

NLH also provided time series of the electrical production, historical load values, load growth forecast and fuel costs forecast for the communities. Table 6-2 below gives NLH's anticipated growth of total yearly energy requirements by community for the years 2015 to 2024.

**Table 6-2: Forecasted Annual Energy Requirements in MWh**

Project	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
<b>Nain</b>	9,019	9,228	9,418	9,608	9,799	9,995	10,195	10,398	10,606	10,819
<b>Hopedale</b>	5,334	5,420	5,599	5,681	5,849	6,024	6,205	6,391	6,551	6,714
<b>Makkovik</b>	4,175	4,214	4,252	4,292	4,330	4,369	4,408	4,448	4,488	4,528
<b>L'Anse au Loup</b>	26,919	27,443	26,687	26,876	27,051	27,211	27,352	27,485	27,609	27,718
<b>Cartwright</b>	4,500	4,536	4,580	4,617	4,661	4,702	4,743	4,784	4,825	4,866

The forecasted load growth and fuel price increase were also considered in the evaluation of the various system configurations as these are important factors over the life of the project. Detailed information on forecasted loads and fuel prices are given in Section 2.4 of the reports *Hybrid System Modelling and Optimisation*, in Appendices F to J.

## 6.2 Methodology and Assumptions

The electrical systems and integration of the wind turbines were modelled and simulated using the software HOMER (Hybrid Optimization of Multiple Electric Renewables). HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or the system's fuel consumption.

The following information and assumptions were used in the model during the optimization process and in the simulation phase:

- The daily load profile was derived from time series and historical values provided by NLH
- The current systems of energy production were defined in HOMER based on information provided by NLH
- Fuel costs and load growths were based on information provided by NLH
- An inflation rate of 2.21% and average NLH long term marginal cost of debt (rounded) of 6.48% were used, according to historical values specified by NLH
- Construction costs have been defined based on information from manufacturers and historical values from past projects
- The long term wind resource calculated in the wind resource assessment campaign was integrated in HOMER and the energy production predicted by the software WindFarmer for each turbine model was used as a target to adjust some parameters in HOMER
- Two wind turbine models were considered and defined in HOMER : the NPS100 and the EWT900 (the following table shows a comparison between the two models with "X" indicating superiority in each category)



- The sizing and optimisation of the proposed wind projects' integration was determined through an iterative process of HOMER simulations in order to minimize the cost of energy.

**Table 6-3: Turbine Model Features**

Category	NPS100	EWT900
Track Record	X	X
Turbine Cost		X
Energy Production		X
Control Capabilities		X
Avoided Emissions		X
O&M		X
Logistics	X	

Of note is the fact that the electrical systems integrating wind turbines were modelled by considering a small spinning reserve. As mentioned in the Help of HOMER, spinning reserve “is surplus operating capacity that can instantly respond to a sudden increase in the electrical load or a sudden decrease in the renewable power output”. It is possible that more spinning reserve would be required to ensure electrical stability to the hybrid systems. To be able to design the system with the appropriate spinning reserve (enough for stability while minimising expenses), more detailed information would be needed, as the load variations on short period of time, and the time required for generators to be powered and be functional. Increase the spinning reserve would certainly reduce the profitability of the systems, since more diesel would be consumed.

The design methodology is described in more details in Section 3 of the reports *Hybrid System Modelling and Optimisation*, Appendix F to J.

### 6.3 Modelling Results

The optimal electrical supply system for each community was designed to minimize the cost of energy. The table below shows a summary of the results. The systems with no wind turbine represent the base case. Their costs of energy are provided as a reference for comparison to the costs of the optimal systems retained.



**Table 6-4: Cost of Energy and Potential Fuel Savings per Community**

Project	No WTG Cost of Energy (\$/kWh)	Optimal System Design	Opt. System Cost of Energy (\$/kWh)	Fuel Saved vs Base Case	Yearly Fuel Savings
<b>Nain</b>	0.321	2 x EWT900	0.263	43.2%	\$1,461,339
<b>Hopedale</b>	0.327	1 x EWT900	0.262	41.0%	\$854,928
<b>Makkovik</b>	0.325	1 x EWT900	0.279	42.6%	\$660,449
<b>L'Anse au Loup</b>	0.130	No WTG	0.130	-	-
<b>Cartwright</b>	0.323	1 x EWT900	0.279	40.3%	\$610,325

As noted in Sections 4.2 and 4.3 of the reports *Hybrid System Modelling and Optimisation*, provided in Appendices F to J, the cost of energy does not include all applicable costs and the costs included are preliminary in nature. As such, this preliminary evaluation of energy costs indicates that the projects are viable (or not) and warrants further study. Additional costs not reflected here include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

The table below shows a summary of the project estimated preliminary costs that were considered for the optimal system retained for each community. It should be noted that these costs were evaluated based on each projects as separate projects and should more than one project be done concurrently, economies of scale would be possible especially for turbine and construction costs. The construction costs presented in table 6-5 are also preliminary in that no firm price proposals were obtained from third parties and additional costs will be defined as part of the detailed design phase when firm quotes will need to be sought from potential contractors.

**Table 6-5: Summary of Construction Costs**

	Nain	Hopedale	Makkovik	L'Anse au Loup	Cartwright
<b>Number of units</b>	<b>2 x EWT900</b>	<b>1 x EWT900</b>	<b>1 x EWT900</b>	<b>No WTG</b>	<b>1 x EWT900</b>
<b>Development costs</b>	\$375,000	\$375,000	\$375,000	N/A	\$375,000
<b>Turbine costs</b>	\$4,750,000	\$2,375,000	\$2,375,000	N/A	\$2,375,000
<b>Construction costs</b>	\$3,291,300	\$1,605,900	\$1,372,700	N/A	\$1,343,550
<b>Project management</b>	\$841,630	\$435,590	\$412,270	N/A	\$409,355
<b>Contingency</b>	\$688,293	\$360,399	\$334,747	N/A	\$331,541
<b>Total project CapEx:</b>	<b>\$9,946,223</b>	<b>\$5,151,889</b>	<b>\$4,869,717</b>	<b>N/A</b>	<b>\$4,834,446</b>
<b>CapEx / installed MW:</b>	\$5,525,679	\$5,724,321	\$5,410,797	N/A	\$5,371,606



Another aspect that was considered in our analysis was the reduction of Greenhouse Gas (GHG) emissions since the installation of a renewable energy system has an impact on the amount of GHG emissions generated for energy production.

NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each litre of diesel fuel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration based on the optimal scenario. The results are shown in the table below.

**Table 6-6: Avoided CO<sub>2</sub> Emissions**

Project	Project description	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
<b>Nain</b>	2 EWT900	3,421	68,421
<b>Hopedale</b>	1EWT900	2,019	40,373
<b>Makkovik</b>	1EWT900	1,450	29,009
<b>L'Anse au Loup</b>	-	-	-
<b>Cartwright</b>	1EWT900	1,429	28,586
<b>Total</b>		8,319	166,389

Note: As of 2010, a total of 8.9 million tonnes per year of GHG emissions were estimated for NL and the installation of 5 EWT900 WTG in 4 communities, would equal to 0.09 % of province's total emissions.

## 6.4 Project Ranking

Since the costs are preliminary and additional cost input are required, the net present value (NPV), which summarises the total value of the project, was not used to rank the projects.

There are a number of factors that can be used to rank the projects such as costs of energy, cost of energy savings per kWh, total costs savings, fuel savings, total CapEx costs and net dollar savings over the project lifetime.

The first comparison looked at existing energy costs versus the optimal wind-diesel energy costs. Project ranking was done by considering the reduction of the cost of energy (\$/kWh) for the electrical supply system retained compared to the base case (no WTG).

**Table 6-7: Project Ranking Method 1**

Project	No WTG Cost of Energy (\$/kWh)	Opt. System Cost of Energy (\$/kWh)	Cost of Energy Savings (\$/kWh)	Ranking
<b>Nain</b>	0.321	0.263	0.0579	2
<b>Hopedale</b>	0.327	0.262	0.0646	1
<b>Makkovik</b>	0.325	0.279	0.0461	3
<b>L'Anse au Loup</b>	0.130	0.130	0	5
<b>Cartwright</b>	0.323	0.279	0.0445	4

The second comparison was done to evaluate overall annual energy savings. The project ranking was established by comparing the discount on the yearly cost of energy for each community. This is shown in the table below using the 2015 forecasted energy and the unit cost of energy savings, as provided in the table above.

**Table 6-8: Project Ranking Method 2**

Project	2015 Forecasted Energy Demand (MWh)	Unit Cost of Energy Savings (\$/kWh)	Cost of Energy Savings (\$/yr)	Ranking
<b>Nain</b>	9,019	0.0579	\$522,376	1
<b>Hopedale</b>	5,334	0.0646	\$344,375	2
<b>Makkovik</b>	4,175	0.0461	\$192,647	4
<b>L'Anse au Loup</b>	26,919	0	-	5
<b>Cartwright</b>	4,500	0.0445	\$200,241	3

The third comparison was done by evaluating the potential yearly fuel savings and the estimated total project CapEx (according to the preliminary cost analysis) and the net savings over the project lifetime.

When combining the preliminary CapEx and the potential estimated fuel savings over the project life (20 years), Nain has been identified as the top ranked site based on the considerations used in this preliminary analysis. Further studies will allow to better defined the viability of each project and their respective ranking based on pre-determined criteria prior to project implementation.

**Table 6-9: Project Ranking Method 3**

Project	Yearly Fuel Savings	Ranking	Total project CapEx	Ranking	Net Savings Over the Project Life	Ranking
Nain	\$1,461,339	1	\$9,946,223	4	\$19,280,557	1
Hopedale	\$854,928	2	\$5,151,889	3	\$11,946,671	2
Makkovik	\$660,449	3	\$4,869,717	2	\$8,339,263	3
L'Anse au Loup	-	5	N/A	5	-	5
Cartwright	\$610,325	4	\$4,834,446	1	\$7,372,054	4

Below is a summary of aforementioned rankings which identifies the top ranked site with the best (lowest) total score.

**Table 6-10: Combined Project Ranking**

Project	Unit Cost of Energy Ranking	Community Cost of Energy Saving Ranking	Fuel Savings Ranking	Net Savings (Fuel – CapEx) Ranking	Total Score	Overall Ranking
Nain	2	1	1	1	5	1
Hopedale	1	2	2	2	7	2
Makkovik	3	4	3	3	13	3
Cartwright	4	3	4	4	15	4
L'Anse au Loup	5	5	5	5	20	5

## 6.5 Additional studies

The Coastal Labrador Wind Monitoring Program was a prefeasibility study and additional studies and validations will be required prior to initiating the detailed design phase and implementation. Many studies and actions will be iterative in nature and will require validation in the planning and implementation phase. Based on a standard project development plan, the following additional studies will need to be completed for the projects that are selected for further development:

- Community consultation to validate location and project particulars,
- Review potential ownership, O & M and financing options,
- Detailed turbine selection and pricing,
- Completion of electrical and mechanical stability study,
- Completion of a constructability and logistic study based on turbine selected,



- Complete detailed design, and
- Prepare contractual agreements for the turbine, construction and O & M.

As mentioned in section 6.2, the electrical stability study will assist in determining the quantity of spinning reserve needed to ensure grid stability. The latter depends on the amount of wind turbines and their technical specifications and the specific anticipated variations in each community. The cost of energy will most likely increase by an increase in spinning reserve. Note that these actions are listed in an order that may vary depending on the proposed development plan, ownership and operation model.

## 7. Conclusions and Recommendations

The Coastal Labrador Wind Monitoring Program was initiated in 2011 with the objective to identify potentially windy areas that also possess other desirable qualities for a wind energy development site. Wind data was collected with success from all five communities and confirmed good wind conditions in all five communities ranging from 6.5 m/sec to 7.7 m/sec. Wind resource assessments including a preliminary turbine selection were completed and overall energy estimates were compiled for all potential projects. The analysis to evaluate the financial feasibility to add wind to the existing diesel generation was completed and showed potential good financial viability for four of the five communities. Additional analysis will be required to validate the business case in each of the community. The preliminary analysis also indicates that the implementation of wind in the communities could potentially provide reduce energy costs and also potentially contribute to reduction of GHG.

The overall business case for the implementation of wind projects in Coastal Labrador communities will remain to be validated as additional studies and community consultation will be required prior to completion of the final design.

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# Appendix A: Wind Resource Assessment Report – Nain



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Project Report

November 15, 2015

## **Newfoundland and Labrador Hydro Nain Wind Project**

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## **Final Wind Resource Assessment Report**



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### DOCUMENT HISTORY

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## EXECUTIVE SUMMARY

In order to assess the potential of Nain site for wind power development, a wind resource assessment (WRA) was completed. The site is located near the community of Nain, Newfoundland and Labrador, Canada. The site was equipped with one met mast that is described in the table below.

Met Mast	Installation Date	Top Anemometer Height (m)	Elevation (m)	Data Collection* Starts...	Data Collection* Ends...
2601	October 30, 2013	35.0	165	October 30, 2013	April 30, 2015

\* A 12 month period is selected to estimate the annual energy production

In the analysis, the quality control process demonstrated that the data recovery rates exceeded 94 % on all instruments which meets industry standards for wind measurement campaign. Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements.

The **wind speed** measured at the mast is **6.5 m/s** on average. The **winds are dominant from west and west-southwest** across the site.

The wind **turbulence intensity** observed at the site is generally **moderate**.

Given the land cover and topography at the mast the **wind shear exponent**, equal to **0.11**, is consistent with the expected value.

Met Mast	Period	Annual Average of Measured Wind Speed* (m/s)	Annual Average of Measured Turbulence Intensity* (%)	Annual Wind Shear
2601	December 1, 2013 to November 30, 2014	6.5	12.6	0.11

\* at Top Anemometer Height

During the data quality control process, icing events were detected on anemometers and wind vanes. **Icing** which affected anemometers, occurred **5.0% of the time** at the site. Given the site elevation and the temperatures associated with these events, it is likely that about 62% of these events were caused by freezing rain and about 38% were caused by rime ice. Icing events mainly occurred during the months of April, May and September to December.

Temperature data were collected at the mast. The monthly averages range from **-19.6°C** in February to **11.7°C** in August, with an **annual average** of **-4.1°C** for the analysis period. The coldest 10-minute temperature recording during the data collection period was **-32.9°C**.

The **air density** was calculated at the mast according to the elevation and the local temperature. The annual value is **1.31 kg/m<sup>3</sup>**.



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The annual average power density is **416 W/m<sup>2</sup>**. The most powerful winds come from west-southwest to west-northwest across the site.

In order to estimate the **long-term wind regime** at the site, several potential **reference stations** with historical data were selected.

The **Nain station** monitored by Environment Canada, located 3 km away from the potential wind farm site, was selected as the reference station for the long-term extrapolation of the data. The reference station data was then correlated to met mast 2601 and used to translate the short-term data into long-term estimates.

The long-term estimates were then extrapolated from measurement height to hub height.

Met Mast	Period	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s) at 37 m / 40 m
2601	December 1, 2013 to November 30, 2014	6.5	6.7 / 6.7

The wind resource estimated at the mast was used to compute the wind flow across the project area. The wind flow was calculated with WASP 11.01.0016 software, which is an appropriate model for the Nain project area which exhibits a moderate terrain complexity.

This wind flow was used to optimise the layout of the potential wind farm and to estimate the energy production with WindFarmer software.

A preliminary turbine selection analysis was completed and two turbine models were selected: Emergya Wind Technologies 900 kW (EWT900) and Northern power 100 (NPS100 Arctic). These models have proven technology in cold and icy environments and are suitable for wind-diesel generation in remote community.

A wind farm layout optimisation was completed taking in consideration energy production, information from the preliminary environmental screening and turbine extreme operating condition.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.

Layout	Wind Farm Capacity (kW)	Net Energy Production (MWh/year)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)
Layout 1 - EWT900	1800	6,150	39.0	0.5	14.6
Layout 2 - NPS100 Arctic	1200	4,058	38.6	2.5	14.3

Other energy production scenarios will be covered under separate portion of the wind penetration report.



## 1. Introduction

Hatch has been mandated by Newfoundland and Labrador Hydro (NLH) to carry out a wind resource assessment (WRA) for a potential wind farm project, located 2 kilometres west of the community of Nain, Newfoundland and Labrador, Canada.

The site was instrumented with one meteorological (“met”) mast. The installation was completed on October 30, 2013. The mast was equipped with sensors at several heights to measure wind speed, wind direction and temperature. The analysed data cover a total measurement period of one year.

The second section of this report presents an overview of the site and the measurement campaign.

The third section presents the main characteristics of the wind climate.

The fourth section details the process used to translate the measured short-term data into long-term data.

The fifth section presents the methodology used to obtain the wind flow map over the project area. The wind flow map optimises the wind farm layout and helps determine monthly and annual energy production estimates. The key resulting values of these estimations are provided, including a description of the losses considered in the net energy calculation.

## 2. General Information

This section summarises general information about the site, the meteorological (met) mast installed and the measurement campaign.

### 2.1 Site Description

#### 2.1.1 Site Overview

The community of Nain is located in an inlet on the Labrador east coast, approximately 370 km north of Happy Valley-Goose Bay. The surroundings of the community consists mainly of bare rock hills with an average elevation of 200m above sea level.





**Figure 2-1: Typical Landscape at the Nain Area**

### 2.1.2 Mast Location

The location of met mast 2601 was chosen with agreement between Hatch and NLH. Hatch proceeded with the installation of the mast and followed industry standards [1].

Table 2-1 provides a description of the mast, including the exact coordinates and the elevation.

The location of the mast is shown on the map provided on next page.

**Table 2-1: Met Mast Characteristics (Coordinate System: NAD83)**

ID	Type	Diameter (m)	Height (m)	Latitude	Longitude	Elevation (m)
2601	Square Lattice	0.404	36	N 56° 32' 26.4"	W 61° 43' 46.3"	165

The Nain met mast 2601 is located west of the community on a rocky hill of approximately 200 metres.

Pictures have been provided in Appendix A with views in the four main geographical directions at the met mast.





## 2.2 Measurement Campaigns

The mast characteristics, instrumentation, installation dates and periods of data collection are provided in this section.

### 2.2.1 Installation and Collection Date

The following table provides the date of mast installation and the period of data collection used in the analysis.

**Table 2-2: Installation Date and Period of Relevant Data Collection**

ID	Installation date	Date and time of first data used	Date and time of last data used
2601	October 30, 2013	December 1, 2013, 00:00 AM	November 30, 2014, 11:50 PM

### 2.2.2 Instrumentation

#### 2.2.2.1 Sensors Mounting

The met mast was equipped with anemometers and wind vanes mounted on booms at several heights. The dimensions of the booms, their heights and orientations on the mast, were designed to comply with the best practices in wind resource assessment as specified in [1] and [2].

For the met mast, the instrument and installation parameters are provided in the table below. All instruments and met mast underwent regular maintenance checks.

Heated anemometers and wind vanes were installed to increase the data recovery rate during icing periods. An Autonomous Power System (A.P.S.) developed by Hatch was installed to power supply the heating instruments. The A.P.S. consists of a set of batteries charged by a small wind turbine through a controller.

**Table 2-3: Installation Parameters of Instruments at the met Mast**

Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
<b>Mast 2601</b>							
<b>Data Acquisition System</b>							
N/A	N/A	N/A	NRG Symphonie PLUS3	Oct 30, 2013	July 21, 2015	N/A	N/A
<b>Anemometers</b>							
#1	A1	35.0	NRG #40C	Oct 30, 2013	July 21, 2015	Yes / No	P
#2	A2	35.0	NRG Icefree III	Oct 30, 2013	July 21, 2015	Yes / Yes	R
#3	A3	26.0	NRG #40C	Oct 30, 2013	July 21, 2015	Yes / No	P
#4	A5	26.0	RMYoung 5103-AP	Oct 30, 2013	July 21, 2015	Yes / No	R



Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
#13	A4	17.0	NRG #40C	Oct 30, 2013	July 21, 2015	Yes / No	P
<b>Wind Vanes</b>							
#7	V1	33.0	NRG Icefree III	<b>Oct 30, 2013</b>	<b>July 21, 2015</b>	<b>No / Yes</b>	<b>P</b>
#8	V2	26.0	RMYoung 5103-AP	Oct 30, 2013	July 21, 2015	No / No	R
#9	V3	15.0	NRG #200P	Oct 30, 2013	July 21, 2015	No / No	R
<b>Temperature Sensor</b>							
#10	T	34.0	NRG #110S	Oct 30, 2013	July 21, 2015	No / No	P

*Note: Lines in bold font correspond to the anemometer and wind vane considered as the principal instruments for wind characterisation at the mast location.*

#### 2.2.2.2 Data Acquisition System

For met mast 2601, the instruments were connected to a data acquisition system which stored the data on a memory card. The data were then sent to Hatch computer network by a satellite communication system every 3 days.



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### 3. Meteorological Data Analysis

This section presents a comprehensive analysis of the data collected. In the first section, the quality of the data is reviewed. The characteristics of the wind measured at the mast are then presented in Section 3.2 through a number of relevant parameters:

- monthly and annual average wind speeds;
- wind speed distribution;
- wind direction distribution;
- wind shear;
- turbulence intensity;
- 50-year recurrence wind speed.

In the final section, other climatic information such as measured temperature, calculated air density, wind power density and icing events is presented and discussed.

#### 3.1 Quality Control

The quality and completeness of the data are key factors that determine the reliability of the wind resource assessment.

Data are collected periodically from the met masts and the quality of the data is analysed. This is done by applying a variety of logical and statistical tests, observing the concurrent readings from different instruments and relating these observations to the physical conditions at the site (e.g. wind shading, freezing potential, etc.). The process is semi-automated: the tests are implemented in a computer program developed by Hatch, but the expertise of quality analysts are required to accept, reject or replace data. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, data logger malfunction, damaged mounting hardware, sensor calibration drift, icing events and different causes of shading (e.g. shading from the mast or from any obstacles at the site). A list of the possible error categories used during quality control is presented in Table 3-1. Data points that are deemed erroneous or unreliable are replaced by redundant data when available, or removed from the data set.

The data recovery rate for the analysis period is then calculated for each of the instruments using the following equation:

$$\text{Data recovery rate (\%)} = \frac{\text{Number of valid observations}}{\text{Number of potential observations}} * 100$$

The “Number of valid observations” is evaluated once erroneous or unreliable data are replaced with available redundant data. The “Number of potential observations” is the theoretical maximum number of measurements that could be recorded during the analysis period. A high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.



**Table 3-1: Quality Control Table**

Error Categories
Unknown event
Icing or wet snow event
Static voltage discharge
Wind shading from tower
Wind shading from building
Wind vane deadband
Operator error
Equipment malfunction
Equipment service
Missing data (no value possible)

### 3.1.1 Data Replacement Policy

Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements. Replacements were done directly or by using a linear regression equation. Direct replacement is applied to anemometers when the replaced and replacing instruments are of the same model, calibrated, at the same height, and well correlated. Direct replacement is also applied to wind vanes as long as they are well correlated.

An acceptable percentage of the dataset is replaced by equivalent instruments (e.g. A1-A2: 9% of replacement) and it is considered to have a small impact on the uncertainty of the measurements.

### 3.1.2 Recovery Rates

The following table presents the recovery rates calculated for each instrument after quality control and after replacements have been completed according to the replacement policy.

**Table 3-2: Instruments Data Recovery Rates**

Mast ID	A1	A3	A4	V1	T
2601	97.8%	97.7%	94.3%	96.5%	100.0%

Note that the recovery rates for the following instruments are identical, given the replacement policy:

- A1 and A2; A3 and A5
- V1, V2 and V3



### 3.1.3 Data History

The data recovery rates exceed industry standards [5]. A number of data were affected for short periods of time by usual effects, such as shading effect and short period of icing events, and were removed.

## 3.2 Wind Characteristics

### 3.2.1 Annual and Monthly Wind Speed

The monthly wind speeds measured at each anemometer are shown in the following figures for mast 2601. The data are presented in two formats (see Figure 3-1 and Figure 3-2):

- a) for all instruments, the averaged monthly wind speed measured;
- b) for A1, all monthly wind speeds are also reported.

Although the results for anemometers A2 and A5 are presented, they will not be considered in further calculations as these sensors were used primarily for quality control and replacement purposes.

As expected, the data confirms that wind speeds increase with height above ground level (see section 3.2.4 for a description of wind shear). Furthermore, the graphs show the seasonal pattern of wind, which decreases towards summer months and increases towards winter months.

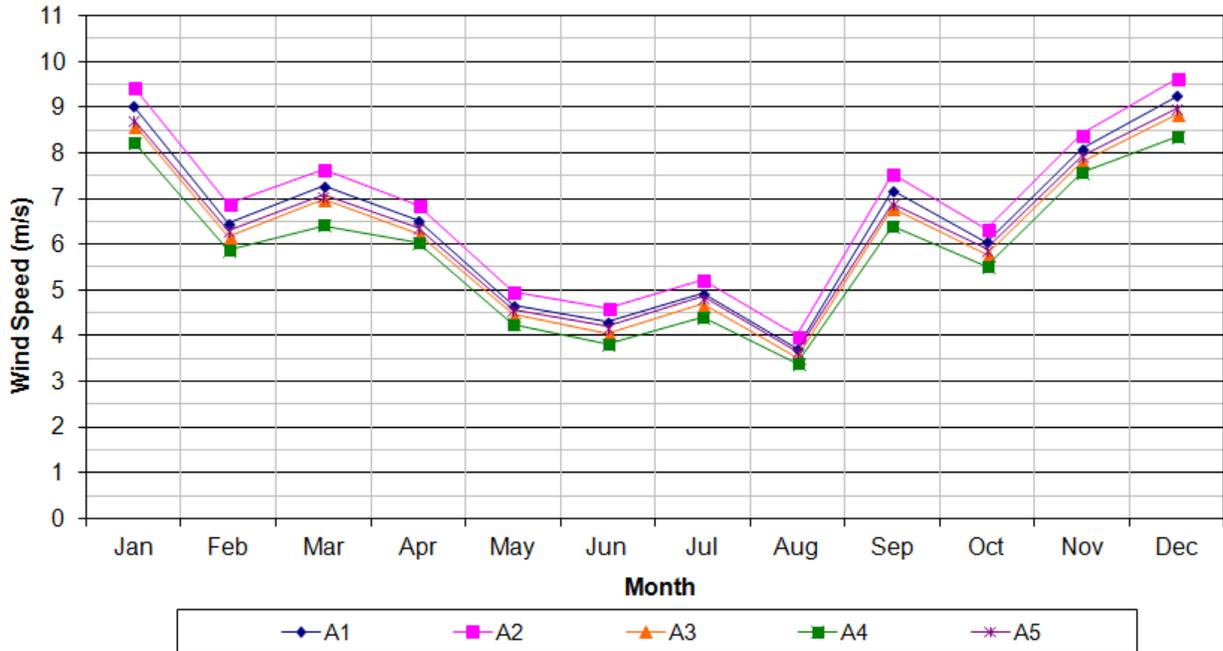
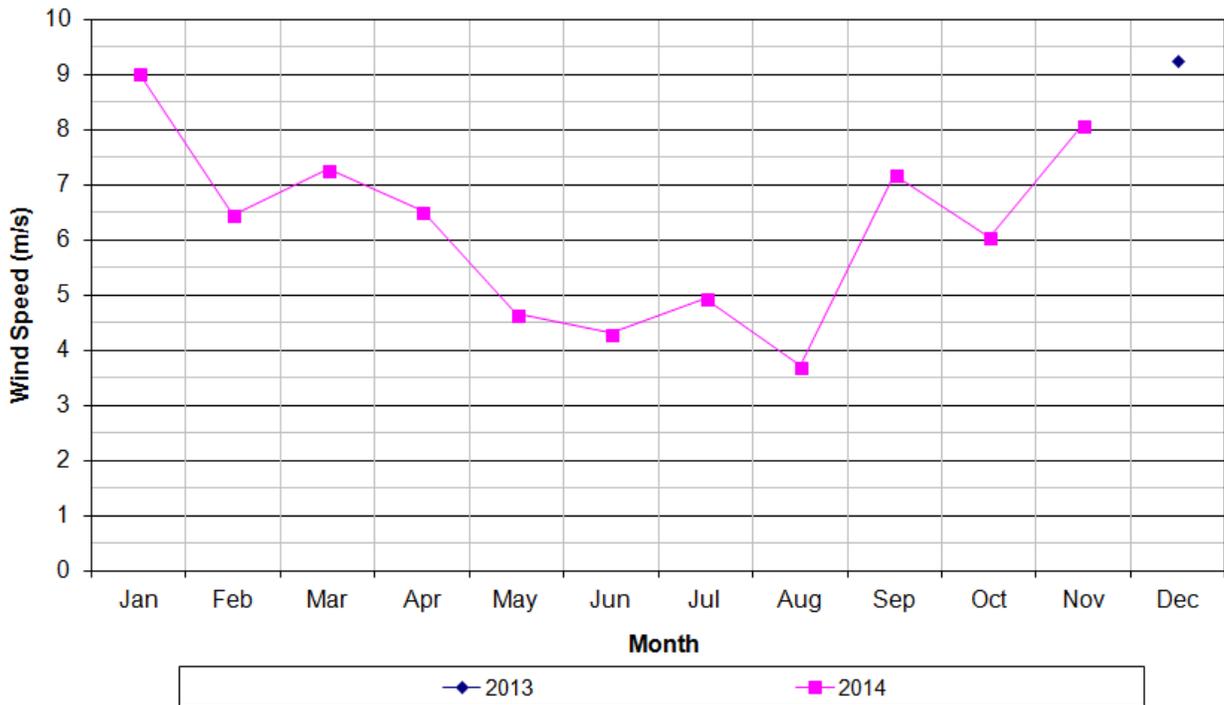


Figure 3-1: Averaged Monthly Wind Speeds for Each Anemometer at Mast 2601, December 1, 2013 to November 30, 2014



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**Figure 3-2: Monthly Wind Speeds Measured at the Top Anemometer at Mast 2601, December 1, 2013 to November 30, 2014**

The following table provides, the average wind speed and the maximum 1-second gust observed, and specifies the averaging method used and the period of data considered. The averaging method varies as it depends upon the available data set:

- Annual: average of the wind speed recorded over one or more full years.
- Annualised: the annualised wind speed is a weighted wind speed that is calculated from all available monthly average wind speeds—e.g. if 2 values are available for January and only one is available for February, the February value will have twice the weight of each January value in the final average.
- Average: due to insufficient data collection, the annual average wind speed was not calculated. The value given is the average of all available data.

**Table 3-3: Wind Speed Characteristics at the Mast**

Mast	Top Anemometer Height (m)	Period	Average Wind Speed (m/s)	Maximum 1-second gust (m/s)	Method
2601	35.0	December 1, 2013 to November 30, 2014	6.5	44.9	Annual



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### 3.2.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds helps to evaluate how much power is contained in the wind (power is proportional to the cube of the wind speed). Wind turbines will produce more power as the wind speed increases (until reaching the “rated” value). Thus, as the frequency of higher wind speeds increases, more power can be produced.

Annual frequency distributions generally exhibit a Weibull shape that is controlled by its “scale factor” (closely linked to the average wind speed) and its shape factor.

The wind speed frequency distribution graph is presented below for the mast<sup>1</sup>.

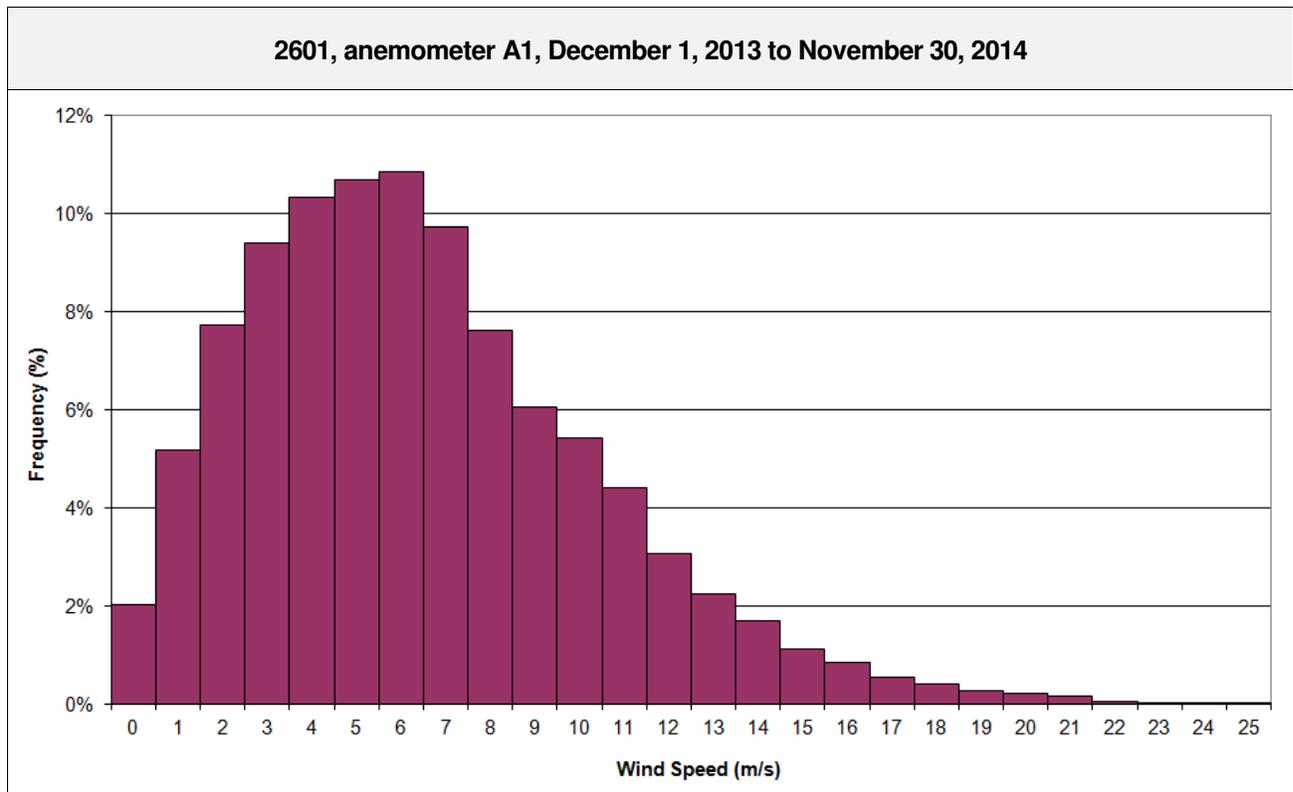


Figure 3-3: Wind Speed Frequency Distribution Graph

### 3.2.3 Wind Rose

The wind rose graph is presented below. The wind rose is divided into the conventional 16 compass sectors (22.5° wide sectors). Note that all compass orientations referenced in this report are based on the true geographic north, rather than the magnetic north.

<sup>1</sup> The 0 m/s wind speed bin indicates the fraction of the total number of measurements with a wind speed between 0 to 0.5 m/s. The other bins are 1 m/s wide and centered on the integer value (e.g.: the 1 m/s wind speed bin indicates the fraction with a wind speed between 0.5 to 1.5 m/s).



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Finally, large topographic variations over short distances may also impact the wind vertical profile and thus affect the wind shear.

Hatch recommends using the log law to estimate the wind shear at mast locations. Internal studies have shown that the accuracy of the wind shear estimate is slightly improved with the log law when compared to the power law. When available, three wind speed measurements, each at a different height, are used and a log law curve is fitted through the average wind speeds at these heights. With the log law, the parameter that reflects roughness is called the roughness length, instead of the wind shear exponent. However, an equivalent wind shear exponent is calculated between the top anemometer height on a mast and the hub height for easier interpretation.

The equivalent wind shear exponent presented in this report was calculated between the top anemometer height of the mast and hub heights of 37 m and 40 m. The calculation was based on the measured wind speed at the anemometer height and the wind speed extrapolated to hub height by the log law method. The log law parameters were determined by fitting a logarithmic curve through the average measured wind speeds at the three measurement heights.

The average equivalent wind shear exponents are reported in the following table.

Based on our knowledge about the vegetation in the area of the mast, this value conforms to expected results.

**Table 3-4: Average Wind Shear at the Mast**

Mast	Period	Wind Shear
2601	December 01, 2013 to November 30, 2014	0.11

### 3.2.5 *Turbulence Intensity*

Turbulence characterises the gustiness of wind or high frequency changes in wind speed and direction (high turbulence is typical of very irregular wind flows, contaminated by whirls or vortices). Turbulence increases in areas with very uneven terrain and behind obstacles, such as buildings. In wind farms, it interferes with the effective operation of the wind turbines and increases their wear and tear.

The measurement of turbulence is expressed in terms of turbulence intensity, which is the standard deviation of the wind speed divided by the mean wind speed, over a given period. Turbulence intensity is expressed as a percentage. In the present study, the standard deviation and mean speed values are calculated from 1 second wind speed data averaged over a 10 minute period.

Turbulence intensity is more erratic and more difficult to quantify at low wind speeds. As a consequence, only wind speeds in excess of 4 m/s are used to calculate of the turbulence intensity. This threshold is consistent with IEC standards for wind turbine power performance measurements [4].

The turbulence intensity value was calculated with the top anemometer data.



The average turbulence intensity is reported in the next table. This value is considered moderate according to the reference values defined in reference [2]<sup>2</sup>. It is expected that turbulence will decrease with height, as the effect of obstacles and surface roughness will diminish.

**Table 3-5: Average Turbulence Intensity at the Mast**

Mast	Anemometer used	Period	Turbulence Intensity (%)
2601	A1	December 01, 2013 to November 30, 2014	12.6

### 3.2.6 50-year recurrence wind speed

The selected wind turbines Northern power 100 (NPS100) and Emergya Wind Technologies 900 kW (EWT900) are designed to survive a certain level of loading caused by an extreme wind event. Based on the specification provided by the manufacturers, the extreme survival wind speed at hub height is 59.5 m/s (see Appendix B).

At least 7 years of data at the met mast location or a nearby reference station is required. The Gumbel distribution was used to predict the once-in-fifty-year extreme wind speed. The data was extrapolated to hub heights of 37 m (NPS100) and 40 m (EWT) with a power law exponent of 0.11 suggested for gusts as per Wind Energy Handbook [2] and IEC 61400-1 standard.

In the case of Nain project, the met mast has only 18 months of data. Thus, data from Nain Environment Canada station were used and based on hourly data at 10 metres height. The data cover the period from 2006 to 2014. The 50-year recurrence maximum wind speeds were estimated to be 46.9 m/s at 37 m and 47.3 m/s at 40 m which respect the turbines' specifications.

## 3.3 Other Climatic Data

### 3.3.1 Temperature

Temperature was measured at a height of 34 m. The following table presents the average monthly and annual temperature measured. The coldest 10-minute temperature recording measured during the data collection period was -32.9°C in the morning of February 3, 2015.

**Table 3-6: Average Monthly and Annual Temperatures**

Mast ID	Monthly Air Temperature (°C)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2601	-17.4	-19.6	-16.8	-7.7	1.0	7.4	9.9	11.7	4.9	2.0	-7.5	-18.3	-4.1

<sup>2</sup> Low levels of turbulence intensity are defined as values less than or equal to 0.10, moderate levels are between 0.10 and 0.25, and high levels are greater than 0.25. This classification is for meteorological turbulence only; it should not be used in comparison with IEC models. Meteorological turbulence should not be used to establish the wind turbine class.



### 3.3.2 Air Density

Wind energy is directly proportional to the air density. Consequently, the amount of energy produced by a wind turbine will also be directly proportional to the air density at the turbine location. Air density decreases with increasing temperature, decreasing pressure and increasing altitude.

Based on the measured temperatures and the standard barometric pressure of 101.3 kPa at sea level, the monthly average air densities were calculated. Note that to correct for changes in atmospheric pressure with height, the calculations account for the site elevation. The values were calculated over the entire analysis period reported in Table 2-2.

**Table 3-7: Monthly and Annual Average Air Density**

Mast ID	Monthly Air Density (kg/m <sup>3</sup> )												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2601	1.34	1.36	1.34	1.30	1.26	1.23	1.22	1.21	1.24	1.25	1.30	1.35	1.31

### 3.3.3 Power density

Wind speed, wind direction and air density data can be combined to provide information about the average power density at mast location. Wind power density indicates how much energy is available at a given instant for conversion by a wind turbine<sup>3</sup>. For example, strong winds in the winter, when the air is colder and denser, will have a higher power density (i.e. carry more energy) than the same strong winds in the summer. Though power is an instantaneous value, it is calculated as an average over a given period of time.

Tables of the power density distribution per direction and per month were produced at the top anemometer height and are presented below.

At mast 2601, the most powerful winds come from west-southwest to west-northwest, and appear in winter months. The annual average power density is 416 W/m<sup>2</sup> at 35.0 m.

**Table 3-8: Table of Wind Power Density per Direction, December 1, 2013 to November 30, 2014**

Wind Power Density per Direction (W/m <sup>2</sup> )															
N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
250	278	233	137	78	415	144	76	56	59	167	556	710	713	339	330

**Table 3-9: Table of Wind Power Density per Month, December 1, 2013 to November 30, 2014**

Wind Power Density per Month (W/m <sup>2</sup> )													Annual Average
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
962	306	522	406	142	116	149	78	447	255	582	777	416	

<sup>3</sup> Note that the units "W/m<sup>2</sup>" refer to m<sup>2</sup> of rotor swept area.



### 3.3.4 Icing Events

Icing affects the operation of wind turbines. Icing on any exposed part of the turbine can occur in the form of wet snow (generally associated with temperatures between 0°C to 1°C), super-cooled rain or drizzle (that can occur at temperatures between 0°C to -8°C, but mostly in the upper part of this range), or in-cloud icing (that can occur below - 2°C). Losses during production due to ice occur in several ways:

- Ice accumulation on the blades alters their aerodynamic profile, reducing the power output.
- Nacelle-mounted instruments accumulate ice and give inaccurate readings. The turbine control system may detect a fault condition due to the turbine output being much greater than expected. This expectation is based on the wind speed. As a result, the turbine will be shut down until the ice is removed from the instruments and the turbine is reset.
- Asymmetric icing causes mass or aerodynamic imbalance leading to vibrations. Control systems that sense vibrations will normally shut down when these vibrations occur.

Icing is a complex phenomenon and predicting icing from meteorological conditions is notoriously difficult, requires a good set of observations from a number of meteorology variables, and can be misleading. As no reliable instrument is presently available to detect and quantify icing events for the purpose of estimating their impact on wind energy production, Hatch uses several tests during data quality control to detect icing events: detection of unusual standard deviations or changes with time of wind speeds and directions, comparison of measurements from a heated anemometer and a standard anemometer at the same level, in parallel with the measurement of temperature.

These tests cannot distinguish between the different types of icing, but a rough approximation can be done by utilising the temperature ranges measured during icing events. Therefore, in the following estimate, we will consider two categories: “glaze”, which is assumed to include wet snow, super-cooled rain and drizzle, and “rime ice”, which is assumed to include in-cloud icing and the very low temperature part of super-cooled rain or drizzle. The threshold of -5°C is used to differentiate between rime ice (below -5°C) and glaze (above -5°C).

The following table presents the estimated number of icing events in a month and the type of event assumed to occur in the project area. This estimate is based on the average of icing events detected on the mast during the measurement campaign.

**Table 3-10: Estimated Hours of Icing Events, October 30, 2013 to April 30, 2015**

	January	February	March	April	May	June	
<b>Hours</b>	12	15	25	65	54	1	
<b>Rime</b>	100%	100%	80%	10%	0%	0%	
<b>Glaze</b>	0%	0%	20%	90%	100%	100%	
	July	August	September	October	November	December	Annual Average
<b>Hours</b>	0	0	49	38	87	94	438
<b>Rime</b>	-	-	0%	0%	30%	100%	38%
<b>Glaze</b>	-	-	100%	100%	70%	0%	62%



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## 4. Long-term Wind Speed at Hub Height

The previous section presented the analysis of the wind regime as it was measured by the met mast installed on the project site. However, to forecast the energy production of a wind power plant, wind data that represents the historical wind conditions at the site are required. Unfortunately, wind resource assessments are generally conducted for a limited number of years, often no more than one or two years, which is not sufficient to capture the year-to-year variability of wind. For example, in North America, the annual average wind speed exhibits a standard deviation of about 6% (or  $1\sigma$  from a normal distribution) of the long-term average wind speed. Hence, the maximum deviation from the average wind speeds could reach as much as 20% (or  $3.3\sigma$ ). Consequently, it is necessary to translate the measured short term data into long-term data. This is done through a correlation/adjustment process that makes reference to a meteorological station where historical data is available.

Moreover, when the top anemometers of the met masts are mounted at a lower height than the expected hub height of the wind turbines, the long-term data must also be extrapolated from these anemometer heights to the wind turbine's hub height.

The long-term projection process is presented in the next section and is followed by the extrapolation to hub height.

### 4.1 Long-term Projection

When required, selecting a reference data set to perform a long-term correlation and adjustment is determined by the following process:

- A quality assessment of the potential long-term reference stations for the site (history, similarity of the local climate with regards to the meteorology mast climate, etc.);
- A quality assessment of the correlation equations obtained with acceptable long-term reference stations and the measured data for the concurrent period;
- A comparison of the long-term correlation results obtained with all acceptable reference stations;
- A crosscheck of the resulting long-term adjustments with the measured data and the long-term trends at nearby reference stations or at a regional level.

Once the reference data set is selected, it is used to adjust the met mast data to long-term conditions. This can be achieved either by synthesizing non existing years of data at the met mast site or by applying an adjustment factor to the measured data in order to better reflect the reference period. The process is as follows:

- The measured data from the met mast is correlated with the reference data set;
- If the correlation parameters meet the synthesis criteria, then data are synthesized at the measurement mast for the complete reference data period; this method is referred to as the Measure-Correlate-Predict (MCP);
- If the criteria are not met but a good correlation can still be obtained with hourly or daily intervals, then the measured data set is scaled up (or down) to long-term using the reference long-term average wind speed and the correlation equation obtained; this method is referred to as the Long-term Adjustment;
- If no correlation can be clearly established between a reference site and the met mast site, the measured data stays unchanged.



#### 4.1.1 Selection of reference data set

The present section summarises the results of the analysis.

Among the possible set of reference stations, one station was selected and considered suitable for the long-term projection of the data at the met mast. This station is Nain monitored by Environment Canada (EC). The location of this station is given in the table below.

**Table 4-1: Identification of the Long-term Reference**

Name	ID	Instruments Height (m)	Latitude	Longitude	Elevation (m)
Nain	8502799	10.0	N 56° 33' 00.0"	W 61° 41' 00.0"	7.6

#### 4.1.2 Long-term Adjustment

The long-term adjustment consists of:

- Correlating short term data at the met mast with short term data at the reference station;
- Using the obtained linear regression equation,  $Y = m X + b$ , where  $X$  represents the long-term average wind speed at the reference station and  $Y$  is the estimated long-term average at the met mast;
- Applying an adjustment factor (to speed up or scale down) to the met mast short term data in order to obtain an average wind speed equal to the estimated long-term average at met mast (i.e.  $Y$ ).

For masts 2601, which displayed 18 months of data recorded, the long-term adjustment method was used for the long-term projection.

The wind speed data of the met mast was correlated to the concurrent wind speed data at the long-term reference station Nain. Good correlation results were obtained with daily average values ( $R^2$  greater than or equal to 0.7 is good correlation, above 0.85 is excellent). The results of the correlation are given in the following table. Linear regression equations were used to compare the data, where  $m$  is the slope of the equation,  $b$  is the intercept, and  $R^2$  is the coefficient of determination.

**Table 4-2: Correlations between Reference Station and met mast Wind Speeds**

Reference Station	Met Mast	Correlation Period		Daily Wind Speed Correlations		
		Beginning	End	$m$	$b$	$R^2$
Nain	2601	December 1, 2013	November 30, 2014	0.885	1.8	0.84

The regression equations were then used to estimate the long-term average wind speed at the mast as a function of the long-term wind speed at the reference station. The estimated



long-term average at the Nain station is 5.3 m/s. It was estimated by averaging all annual averages over the period 2006 to 2014 (except 2012 having very low recovery rate). The results are presented in the following table.

**Table 4-3: Long-term Adjustment factor at the met mast**

Met Mast	Wind Speed over Correlation Period (m/s)	Long-term Annual Wind Speed (m/s)	Adjustment Factor (%)
2601	6.5	6.5	0.4

Finally, the 10-minute measured data recorded at the met mast were scaled by the adjustment factor to reflect the long-term value. In terms of the wind direction data, the one-year dataset for the met mast remained untouched. As a result, the mast has a set of wind speeds and wind directions that are the best estimate of the long-term wind regime.

## 4.2 Extrapolation to Hub Height

The wind shear exponent, calculated with the measured data, was used to adjust the dataset to hub heights. The results are presented in the following table.

**Table 4-4: Estimated Long-term Wind Speed at Hub Heights\***

Met Mast	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2601	6.5	6.7	6.7

\* Estimated using the calculated wind shear



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## 5. Wind Resource Mapping and Projected Energy Production

Met masts provide a local estimate of the wind resource. Met mast locations are chosen based on how representative they are of the project site and in particular for potential wind turbine locations. However, since the number of met masts is usually limited compared to the expected number of wind turbines, it is necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area.

Wind modeling software, such as MS-Micro and WAsP, are known to produce erroneous wind flows over complex terrain. In this case, Hatch applies a method based on the Ruggedness Index (RIX) to calculate the wind flow for each mast data set while correcting errors on wind speed<sup>4</sup>. All produced wind flows are then merged by a distance-weighting process. When the RIX correction is not applicable, wind flows are calculated with each mast dataset and simply merged together by a distance-weighting process, without a RIX correction.

Once the wind flow map is built, it is possible to optimise the size and layout of the foreseen wind farm for the project, and then to calculate the projected energy production. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow (see section 3.2.4). These corrections result in an effective hub height for each wind turbine.

The wind flow and energy production are calculated with specialised software that require, apart from the met masts long-term data, background maps that contain the information on topography, elevation, roughness lengths (related to the land cover) and potential obstacles. This is also used in conjunction with the wind turbine characteristics. Finally, wind farm losses must be estimated in order to complete the energy estimate.

The first part of this section introduces the information and the methodology used to calculate the wind flow.

The next part will present the optimisation process and the results in terms of energy production.

The software used to map the wind resource and to calculate the energy production include:

- WAsP Issue 11.01.0016 from Risø for wind resource mapping;
- Wind Farmer Issue 4.2.2 from Garrad Hassan for layout optimisation and energy production calculations.

### 5.1 Background Data

#### 5.1.1 Topography and elevation

The topographic and elevation data comes from files provided by the National Topographic Data Base (NTDB).

The contour line interval is 5 m within the project area and 20 m outside.

<sup>4</sup> Bowen, A.J. and N.G. Mortensen (2004). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.

### 5.1.2 *Roughness*

The base map for roughness lengths was determined from land cover information included in the NTDB files. This map was then checked and corrected using satellite imagery from Google Earth. Around mast location and wind turbines, pictures and information noted during site visits were also used to check and modify the land cover information. The spatial resolution considered for the roughness lengths is 30 m.

The following table details the roughness lengths used by land cover category.

**Table 5-1: Roughness Lengths Categories**

<b>Land Cover Type</b>	<b>Roughness Length (m)</b>
Open farmland, high grass	0.04
Forest	0.8
Water	0
Building	0.5

### 5.1.3 *Background Map*

The background map, showing topography and contour lines is provided on the next page.





## 5.2 Wind Flow Calculation

### 5.2.1 *Terrain Complexity*

The wind flow is produced over semi-complex terrain. Wind modeling software, such as MS-Micro (used in Windfarm) and WAsP, are known to produce erroneous wind flows over complex terrain. Depending on the topography, predicted wind speeds can be over or underestimated at a given location. Errors can reach more than 20% in very complex areas.

In the present case, the complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 5.2.2 *Parameters*

The following parameters were used to calculate the wind flow map.

**Table 5-2: Wind Flow Calculation Parameters**

Parameter	Value
<b>Wind Resource Grid Spatial Resolution</b>	50 m
<b>Calculation Area</b>	5.7 km by 5.7 km
<b>Reference Mast</b>	2601
<b>Reference Height</b>	Top Anemometer Height
<b>Calculation height</b>	37 m
<b>Vertical Extrapolation Method</b>	Based on measured wind shear
<b>Roughness Change Model</b>	WAsP Standard Model

### 5.2.3 *Results*

The wind flow map used for layout optimisation and energy production estimates is presented on the next page.



### 5.3 Forecasting Energy Production

The layout was initially designed in order to maximise energy production. Turbines were spread out inside the project boundaries to minimise wake effects. The preliminary environmental screening and turbine extreme operating conditions also contributed to set the turbine locations.

#### 5.3.1 Preliminary Turbine Selection

A preliminary turbine selection was performed using Windographer software by comparing the performance of different turbines at the location of the met mast, where the dataset was recorded. The main parameters used for the comparison were the capacity factor of the wind turbine for the site specific conditions as well as the turbine purchase cost. Only turbines that meet the following criteria were considered:

- Site's turbine and turbulence class (IEC class II)
- Extreme wind and weather conditions (operation down to -40°C). The minimum 10-minute temperature recording of -32.9°C during the monitoring campaign confirms the site conditions are within the operating range of the turbine.
- Turbine capacity ranges from 100 kW to 1,000 kW to meet the community load
- Wind turbine's dimensions and weight versus crane capacity and accessibility

Hub heights of about 40 m to 50 m were used for this preliminary analysis.

Standard losses considered include: 12.5% technical losses and 2% wake losses.

The following table provides a summary of the turbine comparison.

**Table 5-3: Windographer Results at the Mast Location**

Turbine type	Turbine Class	Hub height (m)	Turbine Capacity (kW)	Mean Energy Output (MWh/yr)	Capacity Factor (%)	Turbine purchase cost (\$)
Northern Power NPS100 Arctic	IIA	37	100	234	26.7	325,000
Aeronautica AW/Siva29-250	IIA/IIIA	37	250	514	23.5	656,000
Aeronautica AW/Siva47-500	IB/IIA	47	500	1,353	30.9	1,632,000
EWT DW52-250 (EWT250)	IIA	37	250	1,008	46.0	1,980,000
EWT DW52-500 (EWT500)	IIA	37	500	1,536	35.1	1,990,000
EWT DW52-900 (EWT900)	IIA	40	900	1,972	25.0	2,000,000

The capacity factors listed above in table 5-3 are taken from Windographer and may change as a function of the site's optimized layout and should only be used for turbine comparison.

Due the lack of proven experience in remote arctic conditions, the Aeronautica wind turbine models were discarded from the analysis. Northern Power and EWT wind turbines have



been installed and are operating in similar site conditions in Nome, Alaska for EWT or in Kasigluk, Alaska for Northern Power and were thus further compared as part of the analysis.

The average community load at Nain during the project lifetime is around 1200 kW. The following table shows the results of the WindFarmer optimization models using the required number of turbines to meet that load. The turbines were ranked based on their capacity factor, energy output and simple payback.

**Table 5-4: Preliminary Turbine Selection Results**

Turbine type	Number of wind turbine required	Total Capacity (kW)	Gross Energy Output (MWh/yr)	Gross Capacity Factor (%)	Total purchase cost (Million \$)	Ranking
<b>Northern Power NPS100 Arctic</b>	<b>12</b>	<b>1200</b>	<b>4738</b>	<b>45.0</b>	<b>3.900</b>	<b>2</b>
EWT250	5	1250	7357	67.1	9.900	4
EWT500	3	1500	7562	57.5	5.970	3
<b>EWT900</b>	<b>2</b>	<b>1800</b>	<b>7201</b>	<b>45.6</b>	<b>4.000</b>	<b>1</b>

\* Based on the gross energy output at 30 cents/kWh divided by the turbine purchase cost only.

Based on information provided by EWT, the 250 kW wind turbine has the same foundation design as the 500 kW and 900 kW machines and nearly the same price (\$10,000 difference). Because of the similar turbine costs of the three EWT models, from a financial point of view, the EWT900 becomes the most suitable having the lowest simple payback, and would also benefit from potential lower constructability and BOP cost.

The Northern power NPS100 Arctic can also be considered as potential candidates for the Nain project since it is a proven turbine in arctic conditions, and would provide for more redundancy due to number of turbine. The NPS 100 has the advantage of being a smaller turbine and would be less difficult from a logistic and crane accessibility stand point.

The NPS100 and EWT900 turbines are two models that meet the wind class of the site and have proven technology for cold and icy environments.

Even though a more detailed turbine selection exercise will be required in later phase of the project, the NPS 100 and EWT900 are considered suitable candidate turbines in order to complete the preliminary energy estimates for the potential Nain project.

### 5.3.2 *Layout Optimization*

The following section shows the WindFarmer modeling results which further refines the energy estimates for the turbines selected at the potential turbine positions and to confirm the capacity factor values. The table below outlines the parameters and constraints assumed to influence optimisation.



**Table 5-5: Layout Optimisation Parameters and Constraints**

Parameter / Constraint	Value	
<b>Annual Air Density</b>	1.31 kg.m <sup>-3</sup> at 199 m.a.s.l.	
<b>Turbulence Intensity</b>	12.6% at mast 2601 <i>Note: average value for information, the turbulence intensity is actually entered by wind-speed bins and by direction for energy prediction calculation</i>	
<b>Exclusion areas</b>	Due to the lack of information in regard to setbacks for wind energy projects in Newfoundland and Labrador, general restriction rules were used: - 500 m from habitations - 100 m from public roads - 50 m from lakes and rivers - 2 km by 1 km buffer zone from the airport track	
<b>WTG Minimum Separation Distance</b>	Elliptical separation: Minimum of 10 rotor diameters on long axis Minimum of 6 rotor diameters on short axis Bearing of long axis: 255 degrees	
<b>WTG Model</b>	EWT900	NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>WTG Power Curve</b>	See Appendix B	
<b>WTG Thrust Curve</b>	See Appendix B	
<b>Number of WTG's</b>	2	12
<b>Wind Farm Capacity (kW)</b>	1800	1200
<b>Wake Model</b>	Eddy Viscosity Model	
<b>Maximum Slope</b>	10 degrees	
<b>Optimization Strategy</b>	Layout designed in order to maximise energy production.	

The project layouts are presented at the end of this section.

The layouts are still considered preliminary. Land restrictions, communication corridors, noise and visual impacts, and other site-specific matters need to be evaluated through a detailed environmental assessment. Available land, road and collection system costs are also issues that will need to be addressed before the site layout can be finalized.



### 5.3.3 Energy production

Once the optimised layout has been produced, the energy production for each wind turbine is calculated. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow. These corrections result in an effective hub height for each wind turbine.

The calculation was executed with the power curves and thrust curves used for the optimisation and are presented in Appendix B. The additional losses are described in the next section.

Note that air density is corrected by the software for each turbine location according to its elevation.

The following table is a summary of the estimated energy production. Detailed energy figures are presented per wind turbine on the next page.

**Table 5-6: Wind Farm Energy Production Summary**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>Number of Wind Turbines</b>	2	12
<b>Wind Farm Capacity (kW)</b>	1800	1200
<b>Mean Free Wind Speed across Wind Farm (m/s)</b>	8.7	8.4
<b>Average Wake Losses (%)</b>	0.5	2.5
<b>Energy Production Before Additional Losses* (MWh/yr)</b>	7,201	4,738
<b>Capacity Factor Before Additional Losses* (%)</b>	45.6	45.0
<b>Additional Losses (%)</b>	14.6	14.3
<b>Net Energy Production (P50) (MWh/yr)</b>	<b>6,150</b>	<b>4,058</b>
<b>Net Capacity Factor (%)</b>	<b>39.0</b>	<b>38.6</b>

\* Includes topographic effect and wake losses

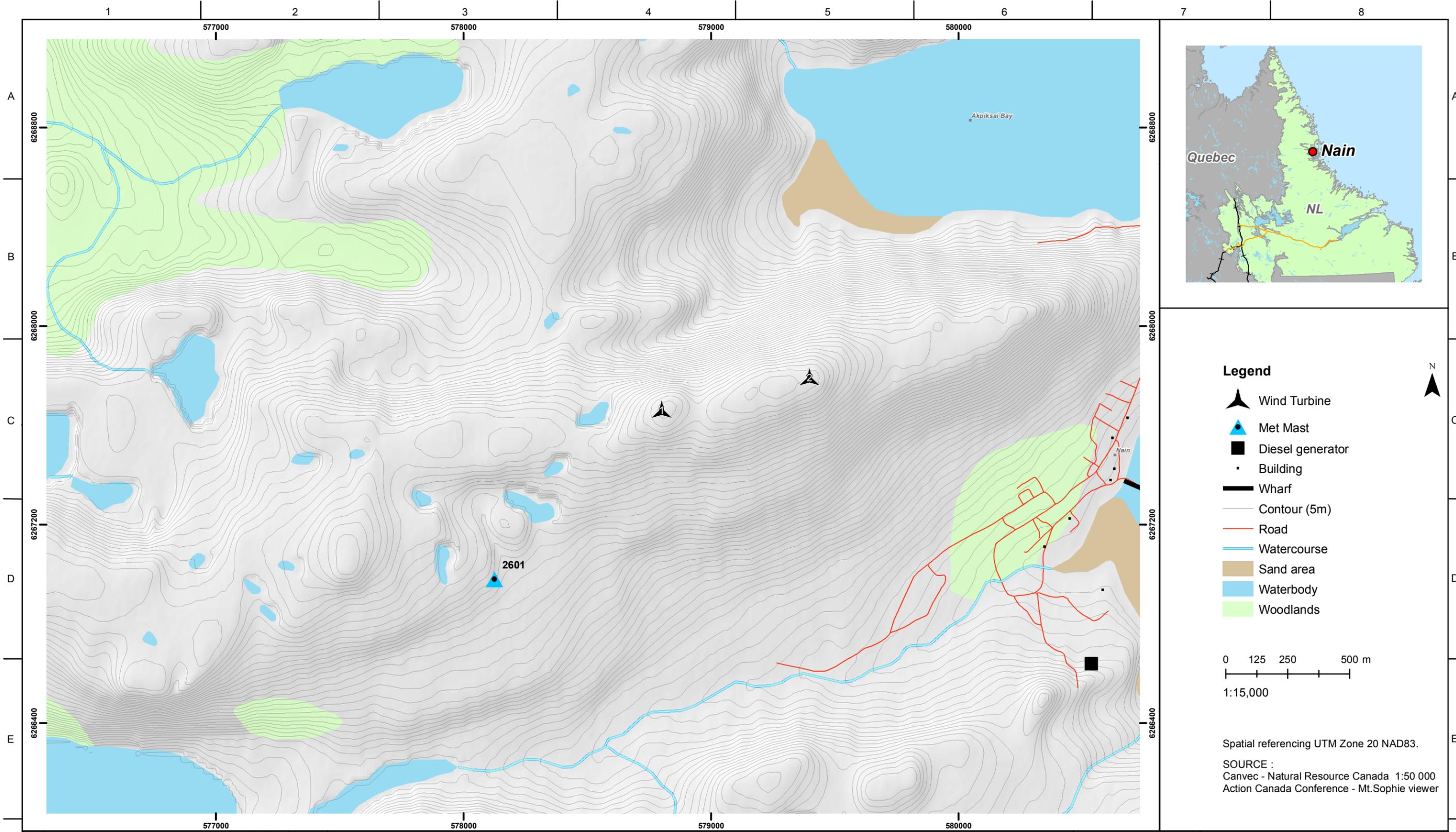


**Table 5-7: Forecasted Energy Production at Wind Turbines**

Turbine ID	Easting (m)	Northing (m)	Altitude (m)	Mean Free Wind Speed (m/s)	Gross Energy Production* (MWh / Year)	Wake Losses (%)	Gross Energy - Wake* (MWh / Year)	Turbulence Intensity** (%)
<b>Layout 1 - EWT900</b>								
1	578801	6267665	250	8.5	3,563	0.1	3,559	12.6
2	579397	6267796	247	8.8	3,671	0.8	3,642	12.4
<b>Layout 2 - NPS100 Arctic</b>								
1	577543	6267026	244	8.3	399	1.0	395	14.1
2	577542	6267090	245	8.3	398	1.3	393	14.3
3	577548	6267155	244	8.2	395	1.3	390	14.3
4	577552	6267221	238	8.1	385	0.3	384	14.1
5	578849	6267625	246	8.2	397	3.2	384	14.1
6	579145	6267678	247	8.3	402	2.8	390	14.1
7	579268	6267697	246	8.5	411	5.0	391	14.7
8	579374	6267749	246	8.7	420	5.8	396	14.9
9	579423	6267824	240	8.7	420	3.5	405	13.9
10	579281	6267801	249	8.7	418	3.4	404	14.1
11	579151	6267762	247	8.4	407	2.0	398	13.7
12	578798	6267674	248	8.5	411	0.8	408	13.0

\* Gross energy production includes topographic effect; "Gross energy – Wake" includes topographic effect and wake losses.

\*\* Turbulence Intensity includes ambient turbulence and incident turbulence. The values represent true meteorological turbulence; they should not be compared directly with IEC models and consequently should not be used to establish the wind turbine class.



NO	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					
1					
2					

Turbine model: EWT DW52-900  
 Number of turbines: 2  
 Site capacity: 1800 KW  
 Turbine rated power: 900 KW  
 Hub height: 40 m  
 File reference: Nain\_WF2\_Lay4.txt

**HATCH**

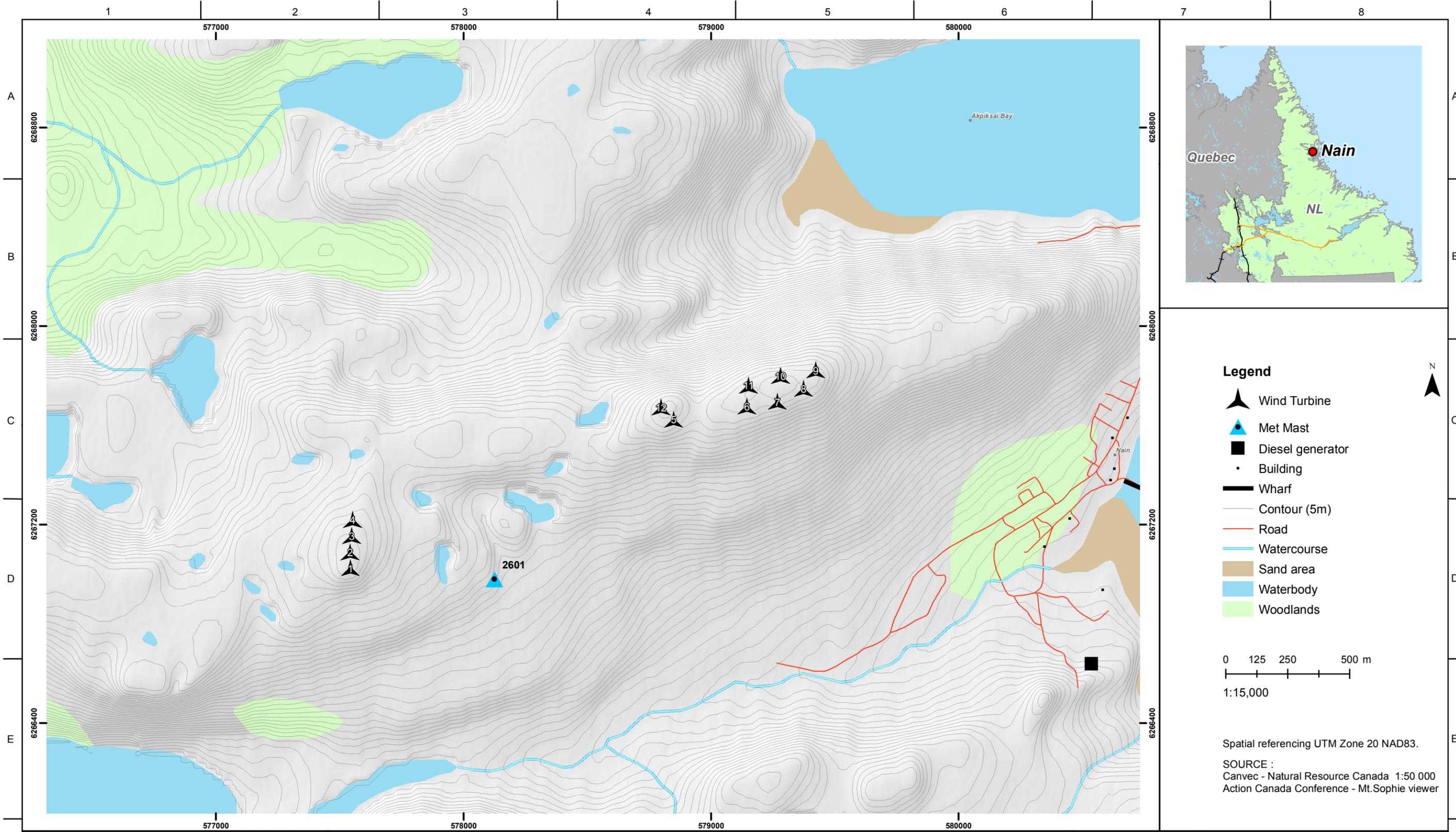
DESIGNED BY DANY AWAD DATE: August 31, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 31, 2015
CHECKED BY Dany Awad DATE: August 31, 2015	

NALCOR

## Nain - Layout 1

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SCALE BAR	REV 3
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**Legend**

- Wind Turbine
- Met Mast
- Diesel generator
- Building
- Wharf
- Contour (5m)
- Road
- Watercourse
- Sand area
- Waterbody
- Woodlands

0 125 250 500 m  
1:15,000

Spatial referencing UTM Zone 20 NAD83.  
SOURCE :  
Canvec - Natural Resource Canada 1:50 000  
Action Canada Conference - Mt.Sophie viewer

Turbine model: Northern Power 100  
Number of turbines: 12  
Site capacity: 1200 KW  
Turbine rated power: 100 KW  
Hub height: 37 m  
File reference: Nain\_WF2\_Lay5.txt

**HATCH**

DESIGNED BY DANY AWAD DATE: August 31, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 31, 2015
CHECKED BY Dany Awad DATE: August 31, 2015	

NALCOR

**Nain - Layout 2**

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NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

SCALE BAR	REV 3
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### 5.3.4 Losses

This section provides a description of the estimated losses included in the P50 estimate. These losses include environmental, electrical, availability, turbine performance losses and wake effects. The P50 is defined as the exceedance probability that denotes the level of annual wind-driven electricity generation that is forecasted to be exceeded 50% of the year. Half of the year’s output is expected to surpass this level, and the other half is predicted to fall below it. Loss estimates should be reviewed as more detailed information becomes available.

The losses considered are presented in the following table and described hereafter.

**Table 5-8: Wind Farm Losses**

Loss Category	Loss Type	Losses (%)			
		Layout 1 - EWT900		Layout 2 - NPS100 Arctic	
<b>Environmental</b>	Blade Soiling and Degradation	1.0		1.0	
	High Wind Hysteresis	0.2		0.2	
	Icing	3.6	<b>5.2</b>	3.5	<b>4.7</b>
	Lightning	0.0		0.0	
	Low Temperature Shutdown	0.4		0.0	
<b>Electrical</b>	Collection Network	1.3	<b>3.5</b>	1.3	<b>2.1</b>
	Auxiliary power	2.2		0.8	
<b>Availability</b>	Wind Turbine Availability	5.0		6.5	
	Collection Network Outage	0.6	<b>5.8</b>	0.7	<b>7.3</b>
	Grid Availability	0.2		0.2	
<b>Turbine Performance</b>	Out-of-range Operation	1.0	<b>1.0</b>	1.0	
<b>Wake effects</b>	Internal Wake Effects	0.5	<b>0.4</b>	2.5	<b>2.5</b>
	External Wake Effects	0.0		0.0	
<b>Total*</b>		<b>15.0</b>		<b>16.5</b>	

\* The total is the cumulated effect of the different losses and not their direct summation

**Blade soiling and Degradation** refers to the reduction of the blade’s aerodynamic performance due to dust and/or insects. It also takes into account the future blade degradation attributed to wear of the blade’s surface. The Nain project is not situated in a particularly dusty environment. This value is consistent with what is generally observed within the industry.



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**High wind hysteresis** losses are caused by the control loop of the turbine around cut-out wind speed. They depend on the wind turbine design.

These estimations are based on the turbines' control loop specifications and high wind hysteresis simulations. Based on the available wind distribution at the mast, the loss induced by the hysteresis loop is 0.2%.

**Icing** losses happen in different ways: ice accumulation on blades alter their aerodynamic performance, nacelle-mounted instruments affected by ice give inaccurate readings and induce turbine control system errors, asymmetric icing causes mass or aerodynamic imbalance leading to vibrations that may force control systems to shut down the turbine. Icing can have different impact on the production of the turbine and the effect is site-specific. Some areas will be more affected by freezing rain or glaze ice and other regions are more prone to have rime ice or in-cloud icing.

Icing losses are estimated from the detection of icing events during met masts data quality control and translating the icing events into production losses. The level of ice is considered moderate as compared to other northern sites (up to 10% of icing losses).

Values should be taken with caution since no proven methodology is available and because the effect and characteristics of ice are highly site-specific. The uncertainty associated to these aspects is taken into account in the global uncertainty assessment.

**Lightning** has the potential to damage the turbine control system but also the blade integrity. Modern wind turbines have protection devices that most of the time allow continuous operation even after a lightning strike. There is however, a small chance that lightning will impact turbine operation. The lightning losses were estimated according to Environment Canada maps<sup>5</sup>.

**Low temperature shutdown** losses depend on the local climate, the turbine design and the control algorithm. In cold climates, turbine shutdowns can be driven by low temperature detection, even if the wind is blowing. According to the manufacturers' specifications, the wind turbines with cold weather package have an operation threshold of - 40°C. The loss is estimated based on the long-term temperature data measured at Nain Environment Canada station.

**Collection network** loss is considered at the interconnection point. It takes into account various elements, including the length of the cables connecting the wind turbines to the substation and the losses in the substation itself. Losses depend on the design of these elements.

These losses have been estimated by Hatch according to previous experiences with similar project size and conditions. They should be confirmed when the design of the collection network is finalized.

**Auxiliary power** losses account for various subsystems of a wind turbine that require electrical power, such as control systems or heaters. All of these losses are not always

<sup>5</sup> <http://ec.gc.ca/foudre-lightning/default.asp?lang=En&n=42ADA306-1>

accounted for in the power curve. For example, cold packages designed for cold climate wind turbines can require energy even when the turbine is stopped.

Based on Hatch's experience, an estimated value is used to account for the consumption of standard auxiliary systems. Specific losses have been added for the Cold Package system delivered with the wind turbines. They have been estimated by simulation according to the Cold Package specifications of the EWT900 and NPS100 wind turbines.

**Wind turbine availability** losses represent the percentage of time over a year that the turbine is unavailable for power production. Losses include regular maintenance time and unexpected turbine shutdowns. A given availability rate is normally guaranteed by utility-scale wind turbine manufacturers such as EWT (95%), but in the case of smaller wind turbines (NPS100), no availability warranty will be offered by the manufacturer.

Based on Hatch's experience on wind farms in similar conditions and technology for isolated sites, Hatch considers the estimate of 6.5% to be adequate for the Project with NPS100 units. This estimation considers a standard maintenance schedule of 1 day per year per turbine, plus unscheduled repairs and delays due to site accessibility and weather conditions. This is based on information provided by the client that wind turbines will be considered as non-essential grid components and thus deficiencies will be considered as low priority, so that individual units may remain out of service for periods longer than normally considered.

**Collection Network Availability:** The collection network may be out of service, stopping energy delivery from the turbines to the grid. Collection network outage losses include shutdown time for scheduled maintenance and unexpected outages.

Based on the information provided by the client, the Nain based operators will manage the site and are expected to have the skills and manpower required to fix any collection system problem in a timely manner. The presence of a support team onsite has a positive impact on the availability of the collection network.

**Grid availability** losses depend on the utility distribution system quality and capacity. It represents the percentage of time in a year when the grid is not able to accept the energy produced by the wind turbines.

The value used assumes the wind turbines will be connected to the grid operated by NLH, which is assumed to be well maintained and operated.

**Out-of-range Operation** losses take into account the aspects usually not covered by the power curve warranty such as turbulence, wind shear and yaw errors. Parameters specific to the Project have been used to perform this loss estimate.

**Wake Effect** corresponds to the deficit in wind speed downstream of a wind turbine. Several models exist to quantify this effect in terms of induced energy losses. Hatch uses the Eddy Viscosity model which corresponds to a CFD calculation representing the development of the velocity deficit field using a solution of the Navier Stokes equations. Because of higher precision as compared to the Park model and recommendations from WindFarmer, the Eddy Viscosity model is used to assess to the wake of the Project. Wake losses are highly



dependent on the layout, especially regarding the distance between the turbine and the layout's compactness.

One of the input in the wake losses calculation is the thrust curve provided by the turbine manufacturer for the Project turbine model under consideration.

No other wind farm currently exists in the vicinity of the project. In addition, no future wind farm that may impact the Project in terms of wake is planned. Thus, there are no additional wake losses.



## 6. Conclusions and Recommendations

### 6.1 Objectives of Analysis

The purpose of this report is to present a full wind resource assessment for the Nain site, including the estimation of the forecasted annual energy production.

### 6.2 Data Quality and Adjustments

The wind data recovery rates at the monitoring site, for the analysis period, exceed industry standards, with recovery rates ranging from 94.3% to 97.8% for the primary anemometers and 96.5% for the primary wind vane.

The measured data were adjusted to long-term through correlation with Environment Canada's Nain station, located 3 km away from the project area. The long-term adjustment method was applied since it was considered to be the best method for producing a representative data set for the expected life of the project.

### 6.3 Wind Resource

The annual average wind speed at the met mast is a result of the measurements and the long-term adjustment. These wind speeds are summarised in the table below for top anemometer and hub heights.

**Table 6-1: Estimated Long-term Wind Speeds**

Mast (Measurement Height)	Estimated Long-term Wind Speed at Measurement Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2601 (35 m)	6.5	6.7	6.7

The long-term dataset at the met mast was used to build the wind flow across the project area.

The complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 6.4 Forecasted Energy Production

The preliminary turbine selection analysis specified two suitable turbine models: EWT900 and NPS100 Arctic. These models were proven to be best in class for cold and icy environments and suitable for wind-diesel generation in remote community.

The main results of the energy production modeling are summarised in the table below.



**Table 6-2: Forecasted Annual Energy Production**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
Number of Wind Turbines	2	12
Wind Farm Capacity (kW)	1800	1200
Annual Net Energy Production (MWh/yr)	<b>6,150</b>	<b>4,058</b>
Net Capacity Factor (P50) (%)	<b>39.0</b>	<b>38.6</b>

There remains some uncertainty regarding loss estimates, which should be reassessed as more information becomes available, particularly in relation to warranty contracts and maintenance schedules. Note that the Annual Net Energy Production represents the total forecasted energy production by the wind turbines. The effective energy production used to displace fuel will be a bit lower and vary depending on the chosen layout scenario (type and number of wind turbines), timewise power load and wind resource.

## 6.5 Recommendations

It should be noted that a number of additional studies and more detailed analysis will be required to refine and validate the turbine selected, the turbine position, the energy and losses.

The integration optimization report will show which turbine model is considered optimal for the Nain site based on energy cost, control capabilities and logistics and provide recommendations for further analysis and studies prior to implementation.

## References

- [1] International Energy Agency Programme, *Recommended practices for wind turbine testing and evaluation – Task 11: Wind Speed Measurement and Use of Cup Anemometer*, 1999
- [2] National Renewable Energy Laboratory, *Wind Resource Assessment Handbook*, 1999
- [3] International Electrotechnical Commission, *Wind Turbines - Part 1: Design Requirements*, IEC 61400-1, Ed. 3, 2005-08.
- [4] International Electrotechnical Commission, *Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines*, IEC 61400-12-1, Ed. 1, 2005.
- [5] A Practical Guide to Developing a Wind Project, *Wind Resource Assessment*, 2011



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# Appendix A

## Views at Mast Site



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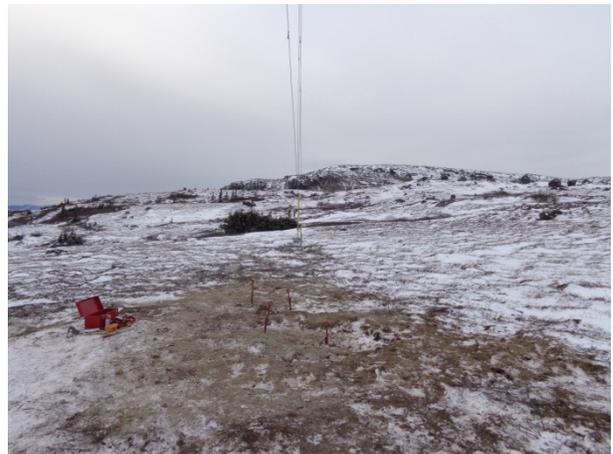
**View Facing North**



**View Facing East**



**View Facing South**



**View Facing West**

**Figure – A1: Views from Base of Mast 2601**

# Appendix B

## Wind Turbine Data



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**EWT DW52-900**

The power curve and the thrust curve were provided to Hatch by Emergya Wind Technologies.

**Table – B1: EWT Wind Turbine Performance Curves**

Rotor Diameter: 51.5 m		Hub Height: 40 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0	0	0	0	0	0.000	0	0.000
1	0	0	0	1	0.000	1	0.000
2	0	0	0	2	0.000	2	0.000
3	7	7	0.866	3	0.866	3	0.866
4	30	30	0.828	4	0.828	4	0.828
5	69	69	0.776	5	0.776	5	0.776
6	124	124	0.776	6	0.776	6	0.776
7	201	201	0.776	7	0.776	7	0.776
8	308	308	0.753	8	0.753	8	0.753
9	439	439	0.722	9	0.722	9	0.722
10	559	559	0.692	10	0.692	10	0.692
11	698	698	0.613	11	0.613	11	0.613
12	797	797	0.516	12	0.516	12	0.516
13	859	859	0.441	13	0.441	13	0.441
14	900	900	0.368	14	0.368	14	0.368
15	900	900	0.296	15	0.296	15	0.296
16	900	900	0.241	16	0.241	16	0.241
17	900	900	0.199	17	0.199	17	0.199
18	900	900	0.168	18	0.168	18	0.168
19	900	900	0.143	19	0.143	19	0.143
20	900	900	0.124	20	0.124	20	0.124
21	900	900	0.109	21	0.109	21	0.109
22	900	900	0.096	22	0.096	22	0.096
23	900	900	0.085	23	0.085	23	0.085
24	900	900	0.075	24	0.075	24	0.075
25	900	900	0.067	25	0.067	25	0.067

**NPS100**

The power curve and the thrust curve were provided to Hatch by Northern Power.

**Table – B2: NPS100 Wind Turbine Performance Curves\***

Rotor Diameter: 20.7 m		Hub Height: 37 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0		0		0		0	
1		0		1		0	
2		0		2		0	
3		0		3		0	
4		3.7		4		1.072	
5		10.5		5		0.963	
6		19.0		6		0.866	
7		29.4		7		0.820	
8		41.0		8		0.754	
9		54.3		9		0.687	
10		66.8		10		0.616	
11		77.7		11		0.548	
12		86.4		12		0.491	
13		92.8		13		0.436	
14		97.3		14		0.391	
15		100.0		15		0.347	
16		100.8		16		0.316	
17		100.6		17		0.286	
18		99.8		18		0.261	
19		99.4		19		0.239	
20		98.6		20		0.222	
21		97.8		21		0.206	
22		97.3		22		0.194	
23		97.3		23		0.184	
24		98.0		24		0.175	
25		99.7		25		0.167	

\* Power curve of the Northern Power 100 – standard model

Dany Awad  
DA:da



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Engineering

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Created by:	JT	Creation Date:	24-07-09
Checked by:	MB	Checked Date:	24-07-09
Approved by:	TY	Approved Date:	05-04-11

Title:

Specification

# DIRECTWIND 52/54\*900 Technical Specification

Revision	Date	Author	Approved	Description of changes
02	02-03-12	MB	TY	Format, minor text, blades, options
01	28-11-11	LE	TY	Corrections and drawings
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

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## 1 Introduction

This document provides a technical overview of the *DIRECTWIND* 52/54\*900 Wind Turbine designed for the IEC class II/III application. It is to be read in conjunction with document S-1000921 "Directwind 52/54\*900 Electrical Specification".



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## 2 Technical Description

The *DIRECTWIND* 52/54\*900 is a direct-drive, variable speed, pitch regulated, horizontal axis, three-bladed upwind rotor wind turbine.

The gearless direct-driven synchronous generator operates at variable speed. This is made possible by an actively controlled AC-DC-AC IGBT power converter connected to the grid. Benefits of this design are low maintenance, constant power output at wind speed above rated, and relatively low structural loads compared to constant-speed stall-controlled or constant-speed pitch-controlled wind turbines.

The generator is fully integrated into the structural design of the turbine, which allows for a very compact nacelle design. The drive-train makes use of only one main bearing, whereas classic designs have separately supported main shaft, gearbox and generator. All dynamically loaded interfaces from the blades to the foundation are sturdy flange connections with machined surfaces, and high tensile steel pre-stressed bolt connections are used.

### 2.1 Operation and safety system

The turbine operates automatically under all wind conditions and is controlled by an industrial PLC (Programmable Logic Controller). The cut-in wind speed is approximately 3m/s. When the rotational speed reaches the cut-in threshold, the power converter begins to deliver power to the grid.

The power converter controls the generator power output and is programmed with a power set-point versus rotor speed curve. Below rated wind speed the power output is controlled to optimise rotor speed versus aerodynamic performance (optimum  $\lambda$ -control). Above rated wind speed the power output is kept constant at rated value by PD-controlled active blade pitching.

The dynamic responses of the drive train and power controller are optimised for high yield and negligible electrical power fluctuations. The variable speed rotor acts as a flywheel, absorbing fluctuating aerodynamic power input. The turbine controllers are located in the rotor hub and the tower base (with remote IO in the nacelle) and carry out all control functions and safety condition monitoring. In the case of a fault, or extreme weather conditions, the turbine is stopped by feathering of the blades to vane position (blades swivelled to 90° with respect to rotor's rotational plane). In case of power loss, an independent battery backup system in each blade ensures the blades are feathered.

In the case of less serious faults which have been resolved, or when extreme weather conditions have passed, the turbine restarts automatically to minimise downtime.

### 2.2 Generator

The multiple-pole, direct-drive generator is directly mounted to the hub. The stator is located in the non-moving outer ring and the wound pole, separately excited rotor rotates on the inner ring.

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The generator is designed such that all aerodynamic forces are directly transferred to the nacelle construction without interfering with the generator-induced loads.

## 2.3 Power Converter

The power converter is an AC-DC-AC IGBT active switching converter. It controls the generator to operate in its optimum range, and maintains power quality to the grid. The inverter can produce unity power factor ( $\cos\Phi=1$ ) to the grid under all load conditions. Power factor is also controllable within limits.

## 2.4 Rotor

The rotor is a three bladed construction, mounted up-wind of the tower. Rotational speed is regulated by active blade adjustment towards vane position. Blade pitch is adjusted using an electric servomotor on each of the blades.

Each blade has a complete, fully independent pitch system that is designed to be fail-safe. This construction negates the need for a mechanical rotor brake. The pitch system is the primary method of controlling the aerodynamic power input to the turbine.

At below rated wind speed the blade pitch setting is constant at optimum aerodynamic efficiency. At above rated wind speed the fast-acting control system keeps the average aerodynamic power at the rated level by keeping the rotor speed close to nominal, even in gusty winds.

The rigid rotor hub is a nodular cast iron structure mounted on the main bearing. Each rotor blade is connected to the hub using a pre-stressed ball bearing. It is sufficiently large to provide a comfortable working environment for two service technicians during maintenance of the pitch system, the three pitch bearings and the blade root from inside the structure.

## 2.5 Rotor blade set

The rotor blades are made of fibreglass-reinforced epoxy. The aerodynamic design represents state-of-the-art technology and is based on a pitch-regulated concept. No extenders are used and the aerodynamic design is optimal for this rotor diameter.

## 2.6 Main bearing

The large-diameter main bearing is a specially designed three row cylindrical roller bearing. The inner non-rotating ring is mounted to the generator stator. The outer rotating ring is mounted between the hub and generator rotor. The bearing takes axial and radial loads as well as bending moments. Entrance to the hub is through the inner-bearing ring. The bearing is greased by a fully automatic lubrication system controlled by the turbine PLC.

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## 2.7 Nacelle

The nacelle is a compact welded construction which houses the yaw mechanism, a service hoist and a control cabinet. Both the generator and the tower are flanged to the nacelle. The geometry of the construction assures an ideal transfer of loads to the tower and, with the absence of a shaft and gearbox, results in a simple design ensuring easy personnel access.

## 2.8 Yaw system

The yaw bearing is an internally geared ring with a pre-stressed four point contact ball bearing. Electric planetary gear motors yaw the nacelle. The yaw brake is passive and is based on the friction of brake pads sitting directly on the bearing ring, keeping the yaw system rigid under most loading conditions.

## 2.9 Tower

The nacelle assembly is supported on a tubular steel tower, fully protected against corrosion. The tower allows access to the nacelle via a secure hinged access door at its base. The tower is fitted with an internal ladder with safety wire and optional climb assistance, rest platforms and lighting. Standard hub heights are 35, 40, 50 and 75 metres.

## 2.10 Anchor

The turbine is supported by a concrete foundation. The connection to this foundation is provided by means of a cast-in tube or rod anchor.

## 2.11 Control System

### 2.11.1 Bachmann PLC

The M1 controller perfectly combines the openness of a PC-based controller with the reliability of industrial hardware platforms. Designed to withstand the toughest ambient conditions it guarantees error-free use over long periods of time.

A modern system architecture designed for consistent network-capability permits the easy integration of the M1 into the environment of the controller and system peripherals. Real-time ethernet permits the real-time networking of the controllers, and the support of all standard Fieldbus systems permits the connection of standard external components.

### 2.11.2 DMS

*DIRECTWIND* Monitoring System – EWT’s proprietary HMI featuring local monitoring and control at the turbine, integrated into a remote-access SCADA. DMS offers individual turbine control and total park monitoring and data logging from your Wind Turbine, Wind Park or internet access point.

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## 2.12 Earthing and lightning protection

The complete earthing system of the wind turbine incorporates:

1. Protective earthing:

A PE connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

2. Functional earthing:

Earthing system to minimize and/or remove the source of electrical interference that can adversely affect operation of sensitive electrical and control equipment.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, the functional earth connection may carry electric current during the normal operation of the turbine.

3. Lightning protection:

To provide predictable conductive path for the over-currents in case of a lightning strike and electromagnetic induction caused by lightning strike and to minimize and/or remove dangerous situations for humans and sensitive electrical equipment.

Since the mechanical construction is made of metal (steel), all earthing systems are combined.

## 2.13 Options

The following options are available:

- Cold climate operation (rated for operation down to -40°C)
- Ice detection and/or prevention system
- Aviation lights
- Shadow flicker prevention
- Low Voltage Ride-through (LVRT)
- Service lift (75m tower only)
- G59 protection relay

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### 3 Technical Data

Where data are separated by "/" this refers to the respective rotor diameter (52 / 54 m).

#### 3.1 Wind and Site Data

Wind class	II / III according to IEC 61400 – 1
Max 50-year extreme	59.5 / 52.5 m/s
Turbulence class	A ( $I_{15} = 0.16$ )
Maximum flow inclination (terrain slope)	8°
Max ann. mean wind speed at hub height	8.5 / 7.5 m/s
Nominal air density	1.225 kg/m <sup>3</sup>

#### 3.2 Operating Temperature

	Standard	Cold Climate
Min ambient operating	-20°C	-40°C
Max ambient operating	+40°C	+40°C

#### 3.3 Cooling

Generator cooling	Air cooled
Converter cooling	Water or air cooled (configuration-dependent)

#### 3.4 Operational Data

Cut in wind speed	3 m/s
Cut out wind speed	25 m/s
Rated wind speed	14 / 13.5 m/s
Rated rotor speed	26 rpm
Rotor speed range	12 to 33 rpm
Power output	900kW
Power factor	1.0 (adjustable 0.95 lagging to 0.95 leading) Measured at LV terminals

#### 3.5 Rotor

Diameter	52 / 54 m
Type	3-Bladed, horizontal axis
Position	Up-wind
Swept area	2,083 / 2,290 m <sup>2</sup>
Power regulation	Pitch control; Rotor field excitation
Rotor tilt angle	5°

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### 3.6 Blade Set

Type	PMC 24.5 / 25.8
Blade length	24.5 / 25.8 m
Chord at 22.0 m	0.879 m (90% of 24.5m blade radius)
Chord at 23.5 m	0.723 m (90% of 25.8m blade radius)
Chord Max at 5.5 m	2.402 m
Aerodynamic profile	DU 91, DU 98 and NACA 64618
Material	Glass reinforced epoxy
Leading edge protection	PU coating
Surface colour	Light grey RAL 7035
Twist Distribution	11.5° from root to 5.5m then decreases linearly to 0.29°, then non-linearly to 0°

### 3.7 Transmission System

Type	Direct drive
Couplings	Flange connections only

### 3.8 Controller

Type	Bachmann PLC
Remote monitoring	DIRECTWIND Monitoring System, proprietary SCADA

### 3.9 Pitch Control and Safety System

Type	Independent blade pitch control
Activation	Variable speed DC motor drive
Safety	Redundant electrical backup

### 3.10 Yaw System

Type	Active
Yaw bearing	4 point ball bearing
Yaw drive	3 x constant speed electric geared motors
Yaw brake	Passive friction brake

### 3.11 Tower

Type	Tapered tubular steel tower
Hub height options	HH = 35, 40, 50, 75 m
Surface colour	Interior: White RAL 9001, Exterior: Light grey RAL 7035

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### 3.12 Mass Data

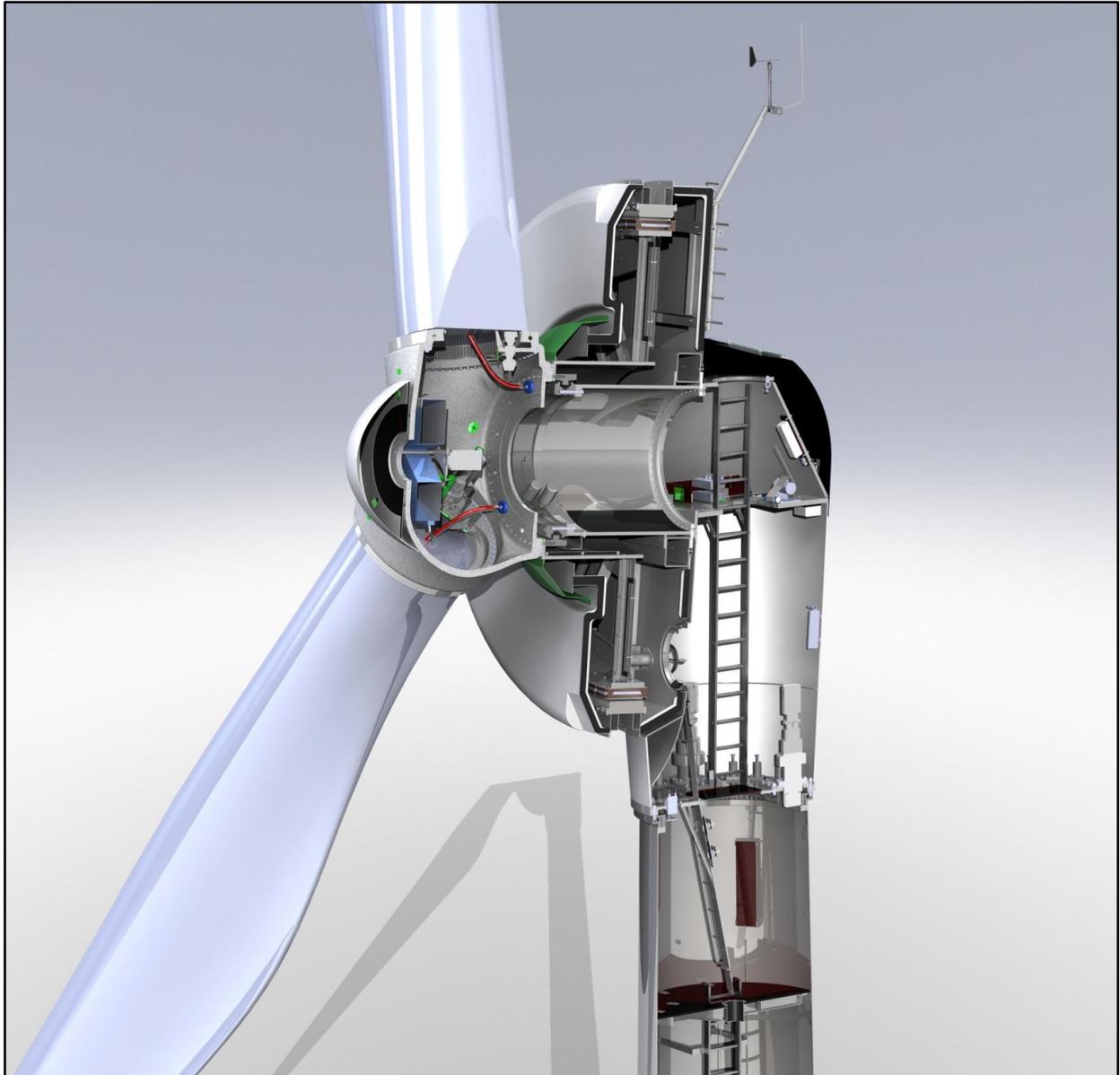
Hub	9,303 kg
Blade – each	1,919 / 1,931 kg
Rotor assembly	15,060 / 15,096 kg
Generator	30,000 kg
Nacelle assembly	10,000 kg
Tower HH35	28,300 kg
Tower HH40	34,000 kg
Tower HH50	46,000 kg
Tower HH75	86,500 kg

### 3.13 Service Brake

Type	Maintenance brake
Position	At hub flange
Calipers	Hydraulic 1-piece

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## APPENDIX 1: 3D image of main turbine components

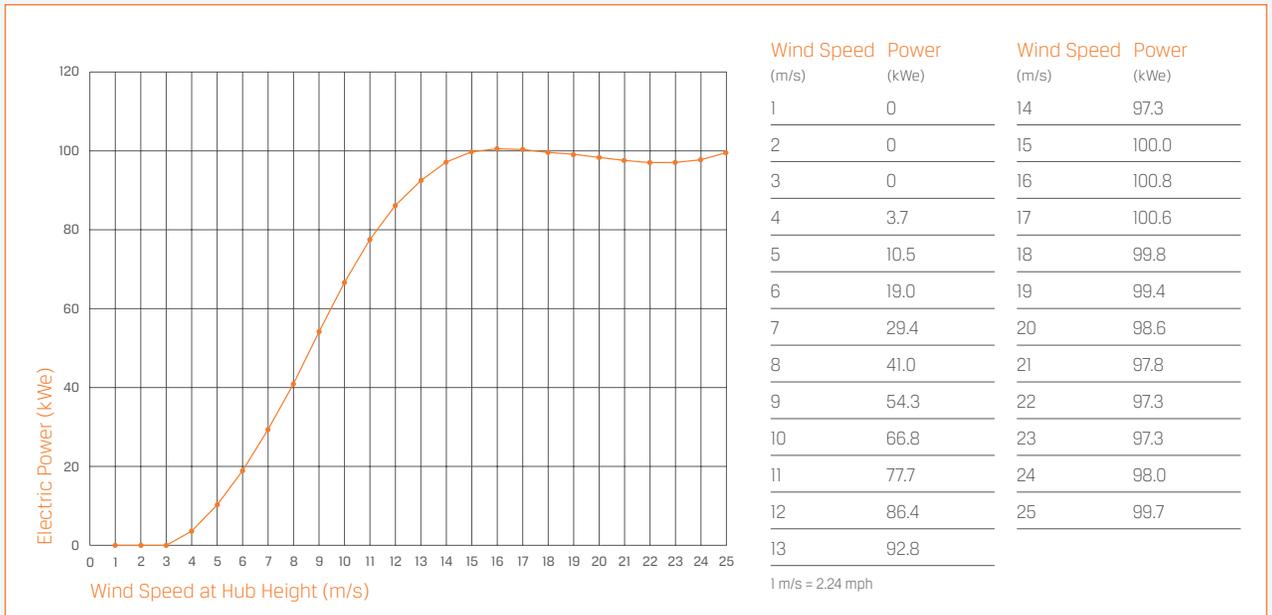


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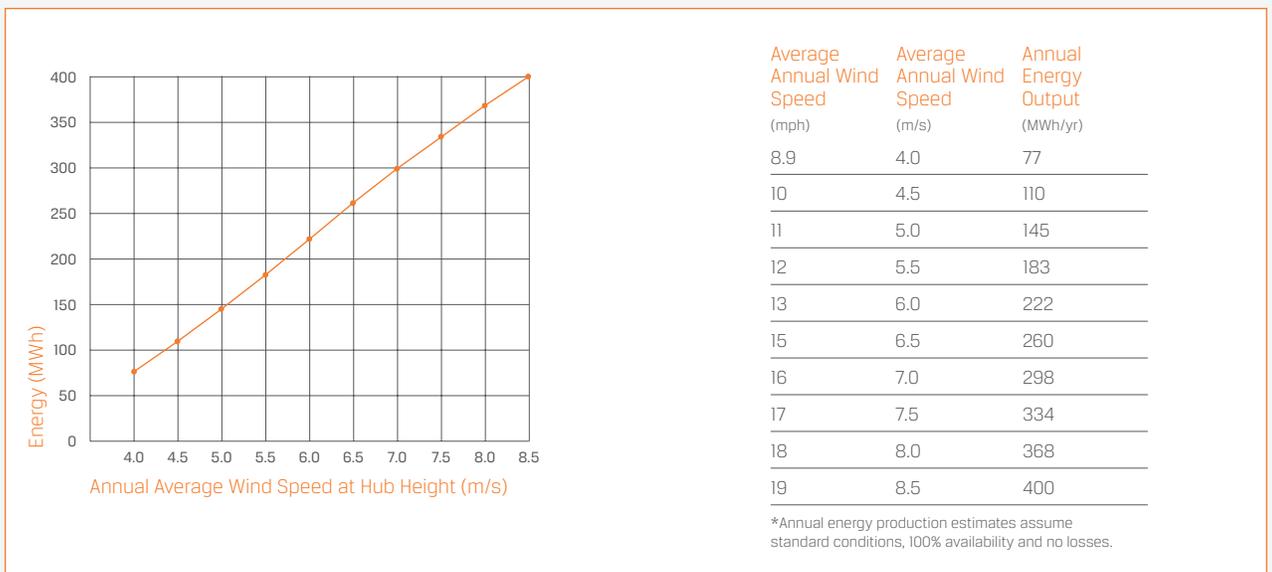


# Northern Power<sup>®</sup> 100

Power Curve: 21-Meter Rotor Standard Air Density (1.225 kg/m<sup>3</sup>)



Annual Energy Production\*: 21-Meter Rotor Standard Air Density, Rayleigh Wind Speed Distribution



## Specifications



GENERAL CONFIGURATION	DESCRIPTION
Model	Northern Power® 100
Design Class	IEC IIA (air density 1.225 kg/m <sup>3</sup> , average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 years
Hub Height	37 m (121 ft) / 30 m (98 ft)
Tower Type	Tubular steel monopole
Orientation	Upwind
Rotor Diameter	21 m (69 ft)
Power Regulation	Variable speed, stall control
Certifications	UL1741, UL1004-4, CSA C22.2 No.107.1-01, CSA C22.2 No. 100.04, and CE compliant
PERFORMANCE	DESCRIPTION
Rated Electrical Power	(standard conditions: air density of 1.225 kg/m <sup>3</sup> , equivalent to 15°C (59°F) at sea level) 100 kW, 3 Phase, 480 VAC, 60/50 Hz
Rated Wind Speed	14.5 m/s (32.4 mph)
Maximum Rotation Speed	59 rpm
Cut-In Wind Speed	3.5 m/s (7.8 mph)
Cut-Out Wind Speed	25 m/s (56 mph)
Extreme Wind Speed	59.5 m/s (133 mph)
WEIGHT	DESCRIPTION
Rotor (21-meter) & Nacelle (standard)	7,200 kg (16,100 lbs)
Tower (37-meter)	13,800 kg (30,000 lbs)
DRIVE TRAIN	DESCRIPTION
Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet, passively cooled
BRAKING SYSTEM	DESCRIPTION
Service Brake Type	Two motor-controlled calipers
Normal Shutdown Brake	Generator dynamic brake and two motor-controlled calipers
Emergency Shutdown Brake	Generator dynamic brake and two spring-applied calipers
YAW SYSTEM	DESCRIPTION
Controls	Active, electromechanically driven with wind direction/speed sensors and automatic cable unwind
CONTROL/ELECTRICAL SYSTEM	DESCRIPTION
Controller Type	DSP-based multiprocessor embedded platform
Converter Type	Pulse-width modulated IGBT frequency converter
Monitoring System	SmartView remote monitoring system, ModBus TCP over ethernet
Power Factor	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive Power	+/- 45 kVAR
NOISE	DESCRIPTION
Apparent Noise Level	55 dBA at 30 meters (98 ft)
ENVIRONMENTAL SPECIFICATIONS	DESCRIPTION
Temperature Range: Operational	-20°C to 50°C (-4°F to 122°F)
Temperature Range: Storage	-40°C to 55°C (-40°F to 131°F)
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection
Icing Protection	Turbine designed in accordance with Germanischer Lloyd Wind Guidelines Edition 2003

All Specifications subject to change without notice.

NPS100SS-2222011-US

# Appendix B: Wind Resource Assessment Report – Hopedale



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H340923-0000-05-124-0012, Rev. B

Project Report

November 15, 2015

## **Newfoundland and Labrador Hydro Hopedale Wind Project**

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## **Final Wind Resource Assessment Report**



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H340923-0000-05-124-0002, Rev. 2  
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In preparing this report, various assumptions and forecasts were made by Hatch concerning current and future conditions and events. These assumptions and forecasts were made using the best information and tools available to Hatch at the time of writing this report. While these assumptions and forecasts are believed to be reasonable, they may differ from what actually might occur. In particular, but without limiting the foregoing, the long-term prediction of climatological data implicitly assumes that the future climate conditions will be identical to the past and present ones. Though it is not possible to definitively quantify its impact, the reality of the climate change is recognised by the scientific community and may affect this assumption.

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## DOCUMENT HISTORY

Revision	Date	Description
1	September 1, 2015	Final Version
2	November 15, 2015	Few edits based on comments from NLH on October 30, 2015 – Final Version



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## EXECUTIVE SUMMARY

In order to assess the potential of Hopedale site for wind power development, a wind resource assessment (WRA) was completed. The site is located near the community of Hopedale, Newfoundland and Labrador, Canada. The site was equipped with one met mast that is described in the table below.

Met Mast	Installation Date	Top Anemometer Height (m)	Elevation (m)	Data Collection* Starts...	Data Collection* Ends...
2602	October 27, 2013	35.0	89	October 27, 2013	April 30, 2015

\* A 12 month period is selected to estimate the annual energy production

In the analysis, the quality control process demonstrated that the data recovery rates exceeded 98.6 % on main instruments (A1 and V1) which meets industry standards for wind measurement campaign. Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements.

The **wind speed** measured at the mast is **7.2 m/s** in average. The **winds are dominant from west-southwest and north-northwest** across the site.

The wind **turbulence intensity** observed at the site is generally **moderate**.

Given the land cover and topography at the mast the **wind shear exponent**, equal to **0.13**, is consistent with the expected value.

Met Mast	Period	Annual Average of Measured Wind Speed* (m/s)	Annual Average of Measured Turbulence Intensity* (%)	Annual Wind Shear
2602	December 1, 2013 to November 30, 2014	7.2	13.6	0.13

\* at Top Anemometer Height

During the data quality control process, icing events were detected on anemometers and wind vanes. **Icing occurred 5.4% of the time** at the site. Given the site elevation and the temperatures associated with these events, it is likely that about 57% of these events were caused by freezing rain and about 43% were caused by rime ice. Icing events mainly occurred during the months of November, December and April.

Temperature data were collected at the mast. The monthly averages range from **-18.4°C** in February to **12.2°C** in August, with an **annual average** of **-3.4°C**. The coldest 10-minute temperature recording during the data collection period was **-33.1°C**.

The **air density** was calculated at the mast according to the elevation and the local temperature. The annual value is **1.31 kg/m<sup>3</sup>**.



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The annual average power density is **499 W/m<sup>2</sup>**. The most powerful winds come from northwest across the site.

In order to estimate the **long-term wind regime** at the site, several potential **reference stations** with historical data were selected.

The **Hopedale (AUT) station** monitored by Environment Canada, located 2 km away from the potential wind farm site, was selected as the reference station for the long-term extrapolation of the data. The reference station data were then correlated to met mast 2602 and used to translate the short-term data into long-term estimates.

The long-term estimates were then extrapolated from measurement height to hub heights.

Met Mast	Period	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s) at 37 m / 40 m
2602	December 1, 2013 to November 30, 2014	7.1	7.2 / 7.3

The wind resource estimated at the mast was used to compute the wind flow across the project area. The wind flow was calculated with WAsP 11.02.0062 software, which is an appropriate model for the Hopedale project area which exhibits a moderate terrain complexity.

This wind flow was used to optimise the layout of the potential wind farm and to estimate the energy production with WindFarmer software.

A preliminary turbine selection analysis was completed and two turbine models were selected: Emergya Wind Technologies 900 kW (EWT900) and Northern power 100 (NPS100 Arctic). These models have proven technology in cold and icy environments and are suitable for wind-diesel generation in remote community.

A wind farm layout optimisation was completed taking in consideration energy production, information from the preliminary environmental screening and turbine extreme operating condition.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.

Layout	Wind Farm Capacity (kW)	Net Energy Production (MWh/year)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)
Layout 1 - EWT900	900	3,398	43.1	0.0	14.0
Layout 2 - NPS100 Arctic	800	2,765	39.4	2.2	13.8

Other energy production scenarios will be covered under separate portion of the wind penetration report.



## 1. Introduction

Hatch has been mandated by Newfoundland and Labrador Hydro (NLH) to carry out a wind resource assessment (WRA) for a potential wind farm project, located 1 kilometre west of the community of Hopedale, Newfoundland and Labrador, Canada.

The site was instrumented with one meteorological (“met”) mast. The installation was completed on October 27, 2013. The mast was equipped with sensors at several heights to measure wind speed, wind direction and temperature. The analysed data cover a total measurement period of one year.

The second section of this report presents an overview of the site and the measurement campaign.

The third section presents the main characteristics of the wind climate.

The fourth section details the process used to translate the measured short-term data into long-term data.

The fifth section presents the methodology used to obtain the wind flow map over the project area. The wind flow map optimises the wind farm layout and helps determine monthly and annual energy production estimates. The key resulting values of these estimations are provided, including a description of the losses considered in the net energy calculation.

## 2. General Information

This section summarises general information about the site, the meteorological (met) mast installed and the measurement campaign.

### 2.1 Site Description

#### 2.1.1 Site Overview

The community of Hopedale is located in an inlet on the Labrador east coast, approximately 240 km north of Happy Valley-Goose Bay. The surroundings of the met tower consists mainly of bare rock hills with an average elevation of 100 m above sea level.





**Figure 2-1: Typical Landscape at the Hopedale Area**

### 2.1.2 *Mast Location*

The location of met mast 2602 was chosen with agreement between Hatch and NLH. Hatch proceeded with the installation of the mast and followed industry standards [1].

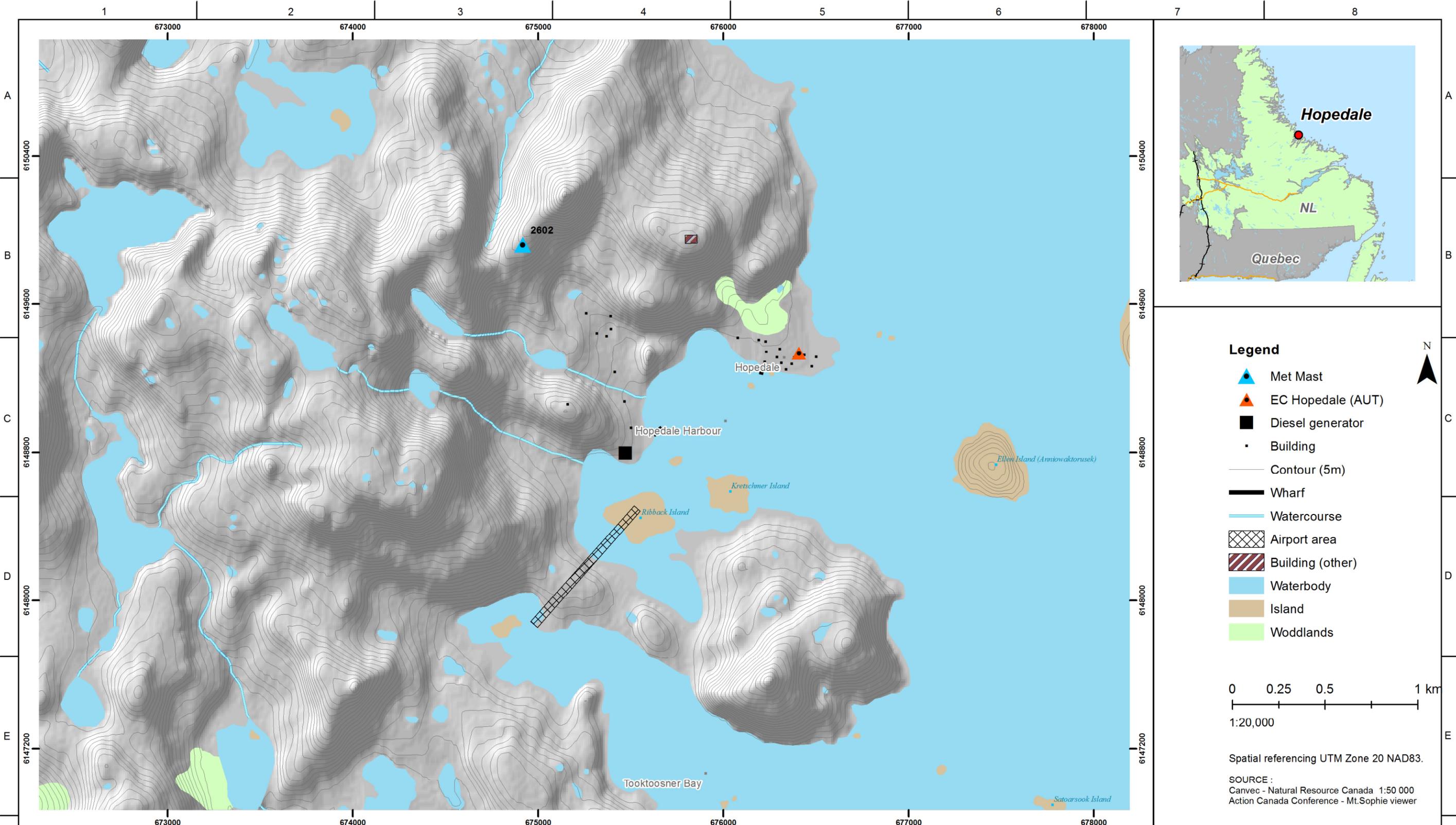
Table 2-1 provides a description of the mast, including the exact coordinates and the elevation.

The location of the mast is shown on the map provided on next page.

**Table 2-1: Met Mast Characteristics (Coordinate System: NAD83)**

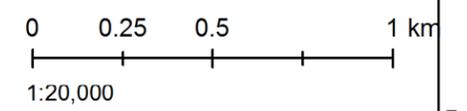
ID	Type	Diameter (m)	Height (m)	Latitude	Longitude	Elevation (m)
2602	Square Lattice	0.404	36	N 55° 27' 50.80"	W 60° 13' 59.40"	89

Pictures have been provided in Appendix A with views in the four main geographical directions at the met mast.



**Legend**

- Met Mast
- EC Hopedale (AUT)
- Diesel generator
- Building
- Contour (5m)
- Wharf
- Watercourse
- Airport area
- Building (other)
- Waterbody
- Island
- Woddlands



Spatial referencing UTM Zone 20 NAD83.

SOURCE :  
Canvec - Natural Resource Canada 1:50 000  
Action Canada Conference - Mt.Sophie viewer

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

**HATCH**

DESIGNED BY SLADJANA PAVLOVIC DATE: March 10, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: March 10, 2015
CHECKED BY Patrice Menard DATE: March 10, 2015	

NALCOR

**Hopedale - Overview Map**

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## 2.2 Measurement Campaigns

The mast characteristics, instrumentation, installation dates and periods of data collection are provided in this section.

### 2.2.1 Installation and Collection Dates

The following table provides the date of mast installation and the period of data collection used in the analysis.

**Table 2-2: Installation Date and Period of Relevant Data Collection**

ID	Installation date	Date and time of first data used	Date and time of last data used
2602	October 27, 2013	December 01, 2013, 00:00	November 30, 2014, 23:50

### 2.2.2 Instrumentation

#### 2.2.2.1 Sensors Mounting

The met mast was equipped with anemometers and wind vanes mounted on booms at several heights. The dimensions of the booms, their heights and orientations on the mast, were designed to comply with the best practices in wind resource assessment as specified in [1] and [2].

For the met mast, the instrument and installation parameters are provided in the table below. All instruments and met mast underwent regular maintenance checks.

Heated anemometers and wind vanes were installed to increase the data recovery rate during icing periods. An Autonomous Power System (A.P.S.) developed by Hatch was installed to power supply the heating instruments. The A.P.S. consists of a set of batteries charged by a small wind turbine through a controller.

**Table 2-3: Installation Parameters of Instruments at the Met Mast**

Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
<b>Mast 2602</b>							
<b>Data Acquisition System</b>							
N/A	N/A	N/A	NRG Symphonie PLUS3	Oct 27, 2013	July 23, 2015	N/A	N/A
<b>Anemometers</b>							
#1	A1	35.0	NRG #40C	Oct 27, 2013	July 23, 2015	Yes/No	P
#2	A2	35.0	NRG Icefree III	Oct 27, 2013	July 23, 2015	Yes/Yes	R
#3	A3	26.0	NRG #40C	Oct 27, 2013	July 23, 2015	Yes/No	P



Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
#4	A5	26.0	RMYoung 5103-AP	Oct 27, 2013	July 23, 2015	Yes/No	R
#13	A4	17.0	NRG #40C	Oct 27, 2013	July 23, 2015	Yes/No	P
<b>Wind Vanes</b>							
<b>#7</b>	<b>V1</b>	<b>33.0</b>	<b>NRG Icefree III</b>	<b>Oct 27, 2013</b>	<b>July 23, 2015</b>	<b>No/Yes</b>	<b>P</b>
#8	V2	26.0	RMYoung 5103-AP	Oct 27, 2013	July 23, 2015	No/No	R
#9	V3	15.0	NRG #200P	Oct 27, 2013	July 23, 2015	No/No	R
<b>Temperature Sensor</b>							
#10	T	34.0	NRG #110S	Oct 27, 2013	July 23, 2015	No/No	P

*Note: Lines in bold font correspond to the anemometer and wind vane considered as the principal instruments for wind characterisation at the mast location.*

#### 2.2.2.2 Data Acquisition System

For met mast 2602, the instruments were connected to a data acquisition system which stored the data on a memory card. The data were then sent to Hatch computer network by a satellite communication system every 3 days.



### 3. Meteorological Data Analysis

This section presents a comprehensive analysis of the data collected. In the first section, the quality of the data is reviewed. The characteristics of the wind measured at the mast are then presented in Section 3.2 through a number of relevant parameters:

- monthly and annual average wind speeds;
- wind speed distribution;
- wind direction distribution;
- wind shear;
- turbulence intensity;
- 50-year recurrence wind speed.

In the final section, other climatic information such as measured temperature, calculated air density, wind power density and icing events is presented and discussed.

#### 3.1 Quality Control

The quality and completeness of the data are key factors that determine the reliability of the wind resource assessment.

Data are collected periodically from the met masts and the quality of the data is analysed. This is done by applying a variety of logical and statistical tests, observing the concurrent readings from different instruments and relating these observations to the physical conditions at the site (e.g. wind shading, freezing potential, etc.). The process is semi-automated: the tests are implemented in a computer program developed by Hatch, but the expertise of quality analysts are required to accept, reject or replace data. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, data logger malfunction, damaged mounting hardware, sensor calibration drift, icing events and different causes of shading (e.g. shading from the mast or from any obstacles at the site). A list of the possible error categories used during quality control is presented in Table 3-1. Data points that are deemed erroneous or unreliable are replaced by redundant data when available, or removed from the data set.

The data recovery rate for the analysis period is then calculated for each of the instruments using the following equation:

$$\text{Data recovery rate (\%)} = \frac{\text{Number of valid observations}}{\text{Number of potential observations}} * 100$$

The “Number of valid observations” is evaluated once erroneous or unreliable data are replaced with available redundant data. The “Number of potential observations” is the theoretical maximum number of measurements that could be recorded during the analysis period. A high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.



**Table 3-1: Quality Control Table**

Error Categories
Unknown event
Icing or wet snow event
Static voltage discharge
Wind shading from tower
Wind shading from building
Wind vane deadband
Operator error
Equipment malfunction
Equipment service
Missing data (no value possible)

### 3.1.1 Data Replacement Policy

Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements. Replacements were done directly or by using a linear regression equation. Direct replacement is applied to anemometers when the replaced and replacing instruments are of the same model, calibrated, at the same height, and well correlated. Direct replacement is also applied to wind vanes as long as they are well correlated.

An acceptable percentage of the dataset is replaced by equivalent instruments (e.g. A1-A2: 10% of replacement) and it is considered to have a small impact on the uncertainty of the measurements.

### 3.1.2 Recovery Rates

The following table presents the recovery rates calculated for each instrument after quality control and after replacements have been completed according to the replacement policy.

**Table 3-2: Instruments Data Recovery Rates**

Mast ID	A1	A3	A4	V1	T
2602	98.6%	98.1%	85.1%	97.4%	100.0%

Note that the recovery rates for the following instruments are identical, given the replacement policy:

- A1 and A2; A3 and A5
- V1, V2 and V3



### 3.1.3 Data History

The data recovery rates exceed industry standards [5] except for A4. A number of data were affected for short periods of time by usual effects, such as shading effect and short period of icing events, and were removed. An occasional interruption in the signal continuity for A4 has been encountered during the period of measurement which decreases its recovery rate.

## 3.2 Wind Characteristics

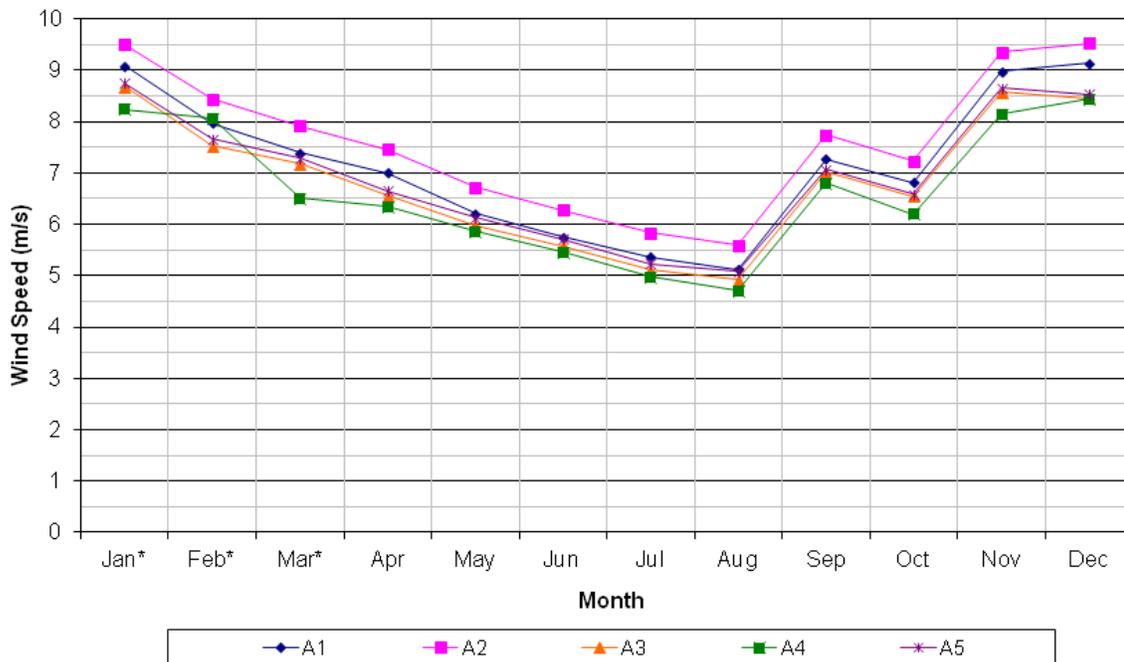
### 3.2.1 Annual and Monthly Wind Speed

The monthly wind speeds measured at each anemometer are shown in the following figures for mast 2602. The data are presented in two formats (see Figure 3-1 and Figure 3-2):

- a) for all instruments, the averaged monthly wind speed measured;
- b) for A1, all monthly wind speeds are also reported.

Although the results for anemometers A2 and A5 are presented, they will not be considered in further calculations as these sensors were used primarily for quality control and replacement purposes.

As expected, the data confirm that wind speeds increase with height above ground level (see section 3.2.4 for a description of wind shear). Furthermore, the graphs show the seasonal pattern of wind, which decreases towards summer months and increases towards winter months.

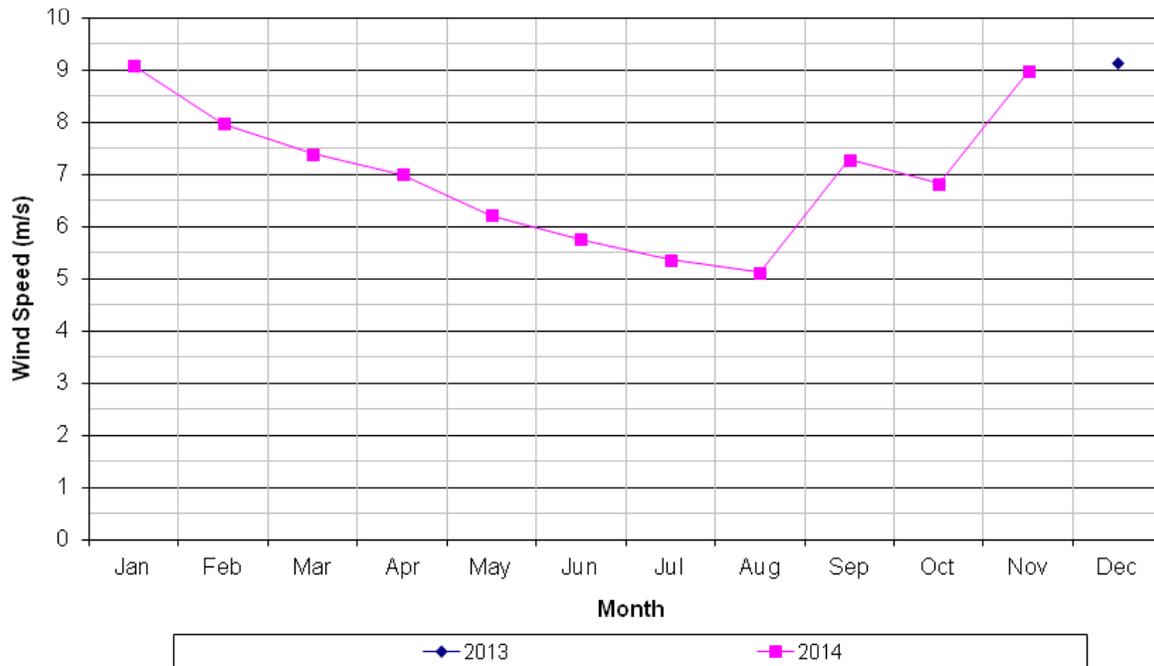


**Figure 3-1: Averaged Monthly Wind Speeds for Each Anemometer at Mast 2602, December 01, 2013 to November 30, 2014**

\* Low recovery rates for A4 recorded in: January, February and March 2014



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**Figure 3-2: Monthly Wind Speeds Measured at the Top Anemometer at Mast 2602, December 01, 2013 to November 30, 2014**

The following table provides, the average wind speed and the maximum 1-second gust observed, and specifies the averaging method used and the period of data considered. The averaging method varies as it depends upon the available dataset:

- Annual: average of the wind speed recorded over one or more full years.
- Annualised: the annualised wind speed is a weighted wind speed that is calculated from all available monthly average wind speeds—e.g. if 2 values are available for January and only one is available for February, the February value will have twice the weight of each January value in the final average.
- Average: due to insufficient data collection, the annual average wind speed was not calculated. The value given is the average of all available data.

**Table 3-3: Wind Speed Characteristics at the Mast**

Mast	Top Anemometer Height (m)	Period	Average Wind Speed (m/s)	Maximum 1-second gust (m/s)	Method
2602	35.0	December 01, 2013 to November 30, 2014	7.2	33.34	Annual



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### 3.2.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds helps to evaluate how much power is contained in the wind (power is proportional to the cube of the wind speed). Wind turbines will produce more power as the wind speed increases (until reaching the “rated” value). Thus, as the frequency of higher wind speeds increases, more power can be produced.

Annual frequency distributions generally exhibit a Weibull shape that is controlled by its “scale factor” (closely linked to the average wind speed) and its shape factor.

The wind speed frequency distribution graph is presented below for the mast<sup>1</sup>.

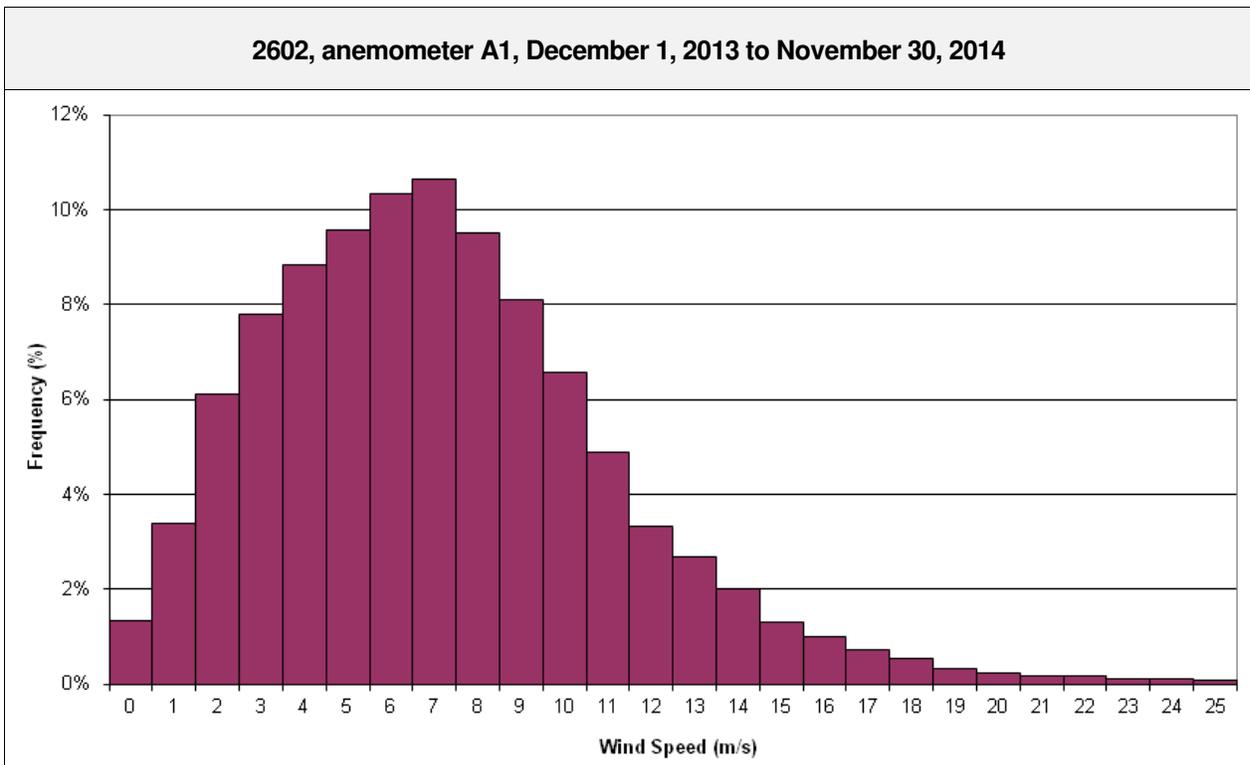


Figure 3-3: Wind Speed Frequency Distribution Graph

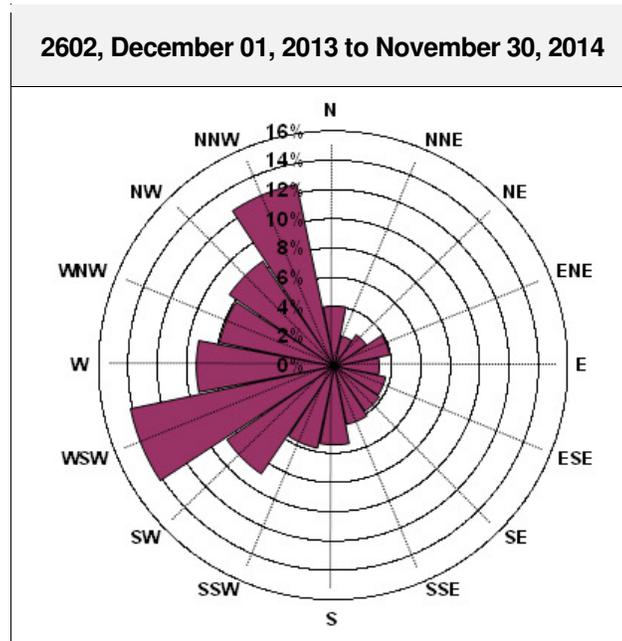
### 3.2.3 Wind Rose

The wind rose graph is presented below. The wind rose is divided into the conventional 16 compass sectors (22.5° wide sectors). Note that all compass orientations referenced in this report are based on the true geographic north, rather than the magnetic north.

<sup>1</sup> The 0 m/s wind speed bin indicates the fraction of the total number of measurements with a wind speed between 0 to 0.5 m/s. The other bins are 1 m/s wide and centered on the integer value (e.g.: the 1 m/s wind speed bin indicates the fraction with a wind speed between 0.5 to 1.5 m/s).



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**Figure 3-4: Wind Rose Graph**

The wind rose indicates that a significant proportion of the wind blows from west-southwest, and north-northwest, across the project area.

Note that wind roses are not adjusted to the long-term. Moreover, differences in wind directions between the levels of measurement are small enough to be neglected. As a consequence, the present wind rose will be considered as representative of the long-term wind rose at hub height.

**3.2.4 Wind Shear**

Wind speeds typically increase with height above the ground, because the frictional drag decreases with altitude. The increase in wind speed with height is referred to as wind shear and is commonly modeled either by a logarithmic law or by a power law.

When the power law is used, the wind shear can be quantified by a wind shear exponent. “Rough” surfaces, such as forested lands and urban areas, have a more pronounced frictional drag than “smooth” surfaces, such as a snow covered field or grasslands—the former will be associated with higher wind shear exponents. Over a smooth, level, grass-covered terrain, the wind shear exponent is typically around 0.14; over snow or calm sea it may be as low as 0.10; and over urban areas or tall buildings it may be as high as 0.40.

The roughness is not the only surface property that has a direct effect on the wind shear. When there is dense vegetation, the vertical wind speed profile is displaced vertically above the canopy, thereby displacing the level of zero wind speed to a certain fraction of the vegetation height above the ground. The “displacement height” is defined as the height at which the zero wind speed level is displaced above the ground. The displacement height is taken into account in all wind shear estimations.



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Finally, large topographic variations over short distances may also impact the wind vertical profile and thus affect the wind shear.

Hatch recommends using the log law to estimate the wind shear at mast locations. Internal studies have shown that the accuracy of the wind shear estimate is slightly improved with the log law when compared to the power law. When available, three wind speed measurements, each at a different height, are used and a log law curve is fitted through the average wind speeds at these heights. With the log law, the parameter that reflects roughness is called the roughness length, instead of the wind shear exponent. However, an equivalent wind shear exponent is calculated between the top anemometer height on a mast and the hub height for easier interpretation.

The equivalent wind shear exponent presented in this report was calculated between the top anemometer height of the mast and hub heights of 37 m and 40 m. The calculation was based on the measured wind speed at the anemometer height and the wind speed extrapolated to hub height by the log law method. The log law parameters were determined by fitting a logarithmic curve through the average measured wind speeds at the three measurement heights.

The average equivalent wind shear exponents are reported in the following table.

Based on our knowledge about the vegetation in the area of the mast, this value conforms to expected results.

**Table 3-4: Average Wind Shear at the Mast**

Mast	Period	Wind Shear
2602	December 01, 2013 to November 30, 2014	0.13

### 3.2.5 *Turbulence Intensity*

Turbulence characterises the gustiness of wind or high frequency changes in wind speed and direction (high turbulence is typical of very irregular wind flows, contaminated by whirls or vortices). Turbulence increases in areas with very uneven terrain and behind obstacles, such as buildings. In wind farms, it interferes with the effective operation of the wind turbines and increases their wear and tear.

The measurement of turbulence is expressed in terms of turbulence intensity, which is the standard deviation of the wind speed divided by the mean wind speed, over a given period. Turbulence intensity is expressed as a percentage. In the present study, the standard deviation and mean speed values are calculated from 1 second wind speed data averaged over a 10 minute period.

Turbulence intensity is more erratic and more difficult to quantify at low wind speeds. As a consequence, only wind speeds in excess of 4 m/s are used to calculate of the turbulence intensity. This threshold is consistent with IEC standards for wind turbine power performance measurements [4].

The turbulence intensity value was calculated with the top anemometer data. The average turbulence intensity is reported in the next table. This value is considered moderate



according to the reference values defined in reference [2]<sup>2</sup>. It is expected that turbulence will decrease with height, as the effect of obstacles and surface roughness will diminish. A moderate value of turbulence can also be observed in the main wind directions (WSW and NNW).

**Table 3-5: Average Turbulence Intensity at the Mast**

Mast	Anemometer used	Period	Turbulence Intensity (%)
2602	A1	December 01, 2013 to November 30, 2014	13.6

### 3.2.6 50-year recurrence wind speed

The selected wind turbines Northern power 100 (NPS100) and Emergya Wind Technologies 900 kW (EWT900) are designed to survive a certain level of loading caused by an extreme wind event. Based on the specification provided by the manufacturers, the extreme survival wind speed at hub height is 59.5 m/s (see Appendix B).

At least 7 years of data at the met mast location or a nearby reference station are required. The Gumbel distribution was used to predict the once-in-fifty-year extreme wind speed. The data were extrapolated to hub heights of 37 m (NPS100) and 40 m (EWT900) with a power law exponent of 0.11 suggested for gusts as per Wind Energy Handbook [2] and IEC 61400-1 standard.

In the case of Hopedale project, the met mast has only 18 months of data. Thus, data from Hopedale (AUT) Environment Canada station were used and based on hourly data at 10 metres height. The data cover the period from 2005 to 2014. The 50-year recurrence maximum wind speed was estimated to be 48.3 m/s at 37 m and 48.7 m/s at 40 m which respect the turbines' specifications.

## 3.3 Other Climatic Data

### 3.3.1 Temperature

Temperature was measured at a height of 34 m. The following table presents the average monthly and annual temperature measured. The coldest 10-minute temperature recording measured during the data collection period was -33.1 °C in the morning of January 2, 2015.

**Table 3-6: Average Monthly and Annual Temperatures**

Mast ID	Monthly Air Temperature (°C)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2602	-16.8	-18.4	-15.6	-6.2	-0.1	7.2	11.0	12.2	6.2	3.3	-6.8	-17.8	-3.4

<sup>2</sup> Low levels of turbulence intensity are defined as values less than or equal to 0.10, moderate levels are between 0.10 and 0.25, and high levels are greater than 0.25. This classification is for meteorological turbulence only; it should not be used in comparison with IEC models. Meteorological turbulence should not be used to establish the wind turbine class.



### 3.3.2 Air Density

Wind energy is directly proportional to the air density. Consequently, the amount of energy produced by a wind turbine will also be directly proportional to the air density at the turbine location. Air density decreases with increasing temperature, decreasing pressure and increasing altitude.

Based on the measured temperatures and the standard barometric pressure of 101.3 kPa at sea level, the monthly average air densities were calculated. Note that to correct for changes in atmospheric pressure with height, the calculations account for the site elevation. The values were calculated over the entire analysis period reported in Table 2-2.

**Table 3-7: Monthly and Annual Average Air Density**

Mast ID	Monthly Air Density (kg/m <sup>3</sup> )												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2602	1.35	1.36	1.35	1.30	1.27	1.24	1.22	1.22	1.25	1.26	1.30	1.36	1.31

### 3.3.3 Power density

Wind speed, wind direction and air density data can be combined to provide information about the average power density at mast location. Wind power density indicates how much energy is available at a given instant for conversion by a wind turbine<sup>3</sup>. For example, strong winds in the winter, when the air is colder and denser, will have a higher power density (i.e. carry more energy) than the same strong winds in the summer. Though power is an instantaneous value, it is calculated as an average over a given period of time.

Tables of the power density distribution per direction and per month were produced at the top anemometer height and are presented below.

At mast 2602, the most powerful winds come from northwest, and appear in winter months. The annual average power density is 499 W/m<sup>2</sup> at 35.0 m.

**Table 3-8: Table of Wind Power Density per Direction, December 1, 2013 to November 30, 2014**

Wind Power Density per Direction (W/m <sup>2</sup> )															
N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
522	169	118	218	363	476	113	117	235	308	327	643	505	543	1069	721

**Table 3-9: Table of Wind Power Density per Month, December 1, 2013 to November 30, 2014**

Wind Power Density per Month (W/m <sup>2</sup> )													Annual Average
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
883	700	701	451	291	272	225	173	496	356	808	744	499	

<sup>3</sup> Note that the units "W/m<sup>2</sup>" refer to m<sup>2</sup> of rotor swept area.



### 3.3.4 Icing Events

Icing affects the operation of wind turbines. Icing on any exposed part of the turbine can occur in the form of wet snow (generally associated with temperatures between 0°C to 1°C), super-cooled rain or drizzle (that can occur at temperatures between 0°C to -8°C, but mostly in the upper part of this range), or in-cloud icing (that can occur below - 2°C). Losses during production due to ice occur in several ways:

- Ice accumulation on the blades alters their aerodynamic profile, reducing the power output.
- Nacelle-mounted instruments accumulate ice and give inaccurate readings. The turbine control system may detect a fault condition due to the turbine output being much greater than expected. This expectation is based on the wind speed. As a result, the turbine will be shut down until the ice is removed from the instruments and the turbine is reset.
- Asymmetric icing causes mass or aerodynamic imbalance leading to vibrations. Control systems that sense vibrations will normally shut down when these vibrations occur.

Icing is a complex phenomenon and predicting icing from meteorological conditions is notoriously difficult, requires a good set of observations from a number of meteorology variables, and can be misleading. As no reliable instrument is presently available to detect and quantify icing events for the purpose of estimating their impact on wind energy production, Hatch uses several tests during data quality control to detect icing events: detection of unusual standard deviations or changes with time of wind speeds and directions, comparison of measurements from a heated anemometer and a standard anemometer at the same level, in parallel with the measurement of temperature.

These tests cannot distinguish between the different types of icing, but a rough approximation can be done by utilising the temperature ranges measured during icing events. Therefore, in the following estimate, we will consider two categories: “glaze”, which is assumed to include wet snow, super-cooled rain and drizzle, and “rime ice”, which is assumed to include in-cloud icing and the very low temperature part of super-cooled rain or drizzle. The threshold of -5°C is used to differentiate between rime ice (below -5°C) and glaze (above -5°C).

The following table presents the estimated number of icing events in a month and the type of event assumed to occur in the project area. This estimate is based on the average of icing events detected on the mast during the measurement campaign.

**Table 3-10: Estimated Hours of Icing Events, October 27, 2013 to April 30, 2015**

	January	February	March	April	May	June	
<b>Hours</b>	37	49	8	83	24	5	
<b>Rime</b>	100%	100%	10%	10%	0%	0%	
<b>Glaze</b>	0%	0%	90%	90%	100%	100%	
	July	August	September	October	November	December	Annual
<b>Hours</b>	0	0	0	13	139	113	470
<b>Rime</b>	-	-	-	0%	10%	80%	43%
<b>Glaze</b>	-	-	-	100%	90%	20%	57%



## 4. Long-term Wind Speed at Hub Height

The previous section presented the analysis of the wind regime as it was measured by the met mast installed on the project site. However, to forecast the energy production of a wind power plant, wind data that represent the historical wind conditions at the site are required. Unfortunately, wind resource assessments are generally conducted for a limited number of years, often no more than one or two years, which is not sufficient to capture the year-to-year variability of wind. For example, in North America, the annual average wind speed exhibits a standard deviation of about 6% (or  $1\sigma$  from a normal distribution) of the long-term average wind speed. Hence, the maximum deviation from the average wind speeds could reach as much as 20% (or  $3.3\sigma$ ). Consequently, it is necessary to translate the measured short term data into long-term data. This is done through a correlation/adjustment process that makes reference to a meteorological station where historical data are available.

Moreover, when the top anemometers of the met masts are mounted at a lower height than the expected hub height of the wind turbines, the long-term data must also be extrapolated from these anemometer heights to the wind turbine's hub height.

The long-term projection process is presented in the next section and is followed by the extrapolation to hub height.

### 4.1 Long-term Projection

When required, selecting a reference dataset to perform a long-term correlation and adjustment is determined by the following process:

- A quality assessment of the potential long-term reference stations for the site (history, similarity of the local climate with regards to the meteorology mast climate, etc.);
- A quality assessment of the correlation equations obtained with acceptable long-term reference stations and the measured data for the concurrent period;
- A comparison of the long-term correlation results obtained with all acceptable reference stations;
- A crosscheck of the resulting long-term adjustments with the measured data and the long-term trends at nearby reference stations or at a regional level.

Once the reference dataset is selected, it is used to adjust the met mast data to long-term conditions. This can be achieved either by synthesizing non existing years of data at the met mast site or by applying an adjustment factor to the measured data in order to better reflect the reference period. The process is as follows:

- The measured data from the met mast are correlated with the reference dataset;
- If the correlation parameters meet the synthesis criteria, then data are synthesized at the measurement mast for the complete reference data period; this method is referred to as the Measure-Correlate-Predict (MCP);
- If the criteria are not met but a good correlation can still be obtained with hourly or daily intervals, then the measured dataset is scaled up (or down) to long-term using the reference long-term average wind speed and the correlation equation obtained; this method is referred to as the Long-term Adjustment;
- If no correlation can be clearly established between a reference site and the met mast site, the measured data stay unchanged.



#### 4.1.1 Selection of reference dataset

The present section summarises the results of the analysis.

Among the possible set of reference stations, one station was selected and considered suitable for the long-term projection of the data at the met mast. This station is Hopedale (AUT) monitored by Environment Canada (EC). The location of this station is given in the table below.

**Table 4-1: Identification of the Long-term Reference**

Name	ID	Instruments Height (m)	Latitude	Longitude	Elevation (m)
Hopedale (AUT)	8502400	10.0	N 55° 27' 00.0"	W 60° 13' 00.0"	11.9

#### 4.1.2 Long-term Adjustment

The long-term adjustment consists of:

- Correlating short term data at the met mast with short term data at the reference station;
- Using the obtained linear regression equation,  $Y = m X + b$ , where  $X$  represents the long-term average wind speed at the reference station and  $Y$  is the estimated long-term average at the met mast;
- Applying an adjustment factor (to speed up or scale down) to the met mast short-term data in order to obtain an average wind speed equal to the estimated long-term average at met mast (i.e.  $Y$ ).

For masts 2602, which displayed 18 months of data recorded, the long-term adjustment method was used for the long-term projection.

The wind speed data of the met mast was correlated to the concurrent wind speed data at the long-term reference station Hopedale (AUT). Good correlation results were obtained with hourly average values ( $R^2$  greater than or equal to 0.70 is good correlation, above 0.85 is excellent). The results of the correlation are given in the following table. Linear regression equations were used to compare the data, where  $m$  is the slope of the equation,  $b$  is the intercept, and  $R^2$  is the coefficient of determination.

**Table 4-2: Correlations between Reference Station and met mast Wind Speeds**

Reference Station	Met Mast	Correlation Period		Hourly Wind Speed Correlations		
		Beginning	End	$m$	$b$	$R^2$
Hopedale (AUT)	2602	December 1, 2013	November 30, 2014	1.056	1.4	0.73



The regression equations were then used to estimate the long-term average wind speed at the mast as a function of the long-term wind speed at the reference station. The estimated long-term average at the Hopedale (AUT) is 5.4 m/s. It was estimated by averaging all annual averages over the period 2005 to 2014 (except 2011 having a low recovery rate). The results are presented in the following table.

**Table 4-3: Long-term Adjustment factor at the met mast**

Met Mast	Wind Speed over Correlation Period (m/s)	Long-term Annual Wind Speed (m/s)	Adjustment Factor (%)
2602	7.2	7.1	-1.4

Finally, the 10-minute measured data recorded at the met mast were scaled by the adjustment factor to reflect the long-term value. In terms of the wind direction data, the one-year dataset for the met mast remained untouched. As a result, the mast has a set of wind speeds and wind directions that are the best estimate of the long-term wind regime.

## 4.2 Extrapolation to Hub Height

The wind shear exponent, calculated with the measured data, was used to adjust the dataset to hub heights. The results are presented in the following table.

**Table 4-4: Estimated Long-term Wind Speed at Hub Heights\***

Met Mast	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2602	7.1	7.2	7.3

\* Estimated using the calculated wind shear

## 5. Wind Resource Mapping and Projected Energy Production

Met masts provide a local estimate of the wind resource. Met mast locations are chosen based on how representative they are of the project site and in particular for potential wind turbine locations. However, since the number of met masts is usually limited compared to the expected number of wind turbines, it is necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area.

Wind modeling software, such as MS-Micro and WAsP, are known to produce erroneous wind flows over complex terrain. In this case, Hatch applies a method based on the Ruggedness Index (RIX) to calculate the wind flow for each mast data set while correcting errors on wind speed<sup>4</sup>. All produced wind flows are then merged by a distance-weighting process. When the RIX correction is not applicable, wind flows are calculated with each mast dataset and simply merged together by a distance-weighting process, without a RIX correction.

Once the wind flow map is built, it is possible to optimise the size and layout of the foreseen wind farm for the project, and then to calculate the projected energy production. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow (see section 3.2.4). These corrections result in an effective hub height for each wind turbine.

The wind flow and energy production are calculated with specialised software that require, apart from the met masts long-term data, background maps that contain the information on topography, elevation, roughness lengths (related to the land cover) and potential obstacles. This is also used in conjunction with the wind turbine characteristics. Finally, wind farm losses must be estimated in order to complete the energy estimate.

The first part of this section introduces the information and the methodology used to calculate the wind flow.

The next part will present the optimisation process and the results in terms of energy production.

The software used to map the wind resource and to calculate the energy production include:

- WAsP Issue 11.02.0062 from Risø for wind resource mapping;
- Wind Farmer Issue 4.2.20 from Garrad Hassan for layout optimisation and energy production calculations.

### 5.1 Background Data

#### 5.1.1 Topography and elevation

The topographic and elevation data come from DEM (Digital Elevation Model) files provided by Geobase.

The contour line interval is 5 m within the project area and 20 m outside.

<sup>4</sup> Bowen, A.J. and N.G. Mortensen (2004). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.



### 5.1.2 *Roughness*

The base map for roughness lengths was determined from land cover information included in the NTDB files. This map was then checked and corrected using satellite imagery from Google Earth. Around most locations and wind turbines, pictures and information noted during site visits were also used to check and modify the land cover information. The spatial resolution considered for the roughness lengths is 30 m.

The following table details the roughness lengths used by land cover category.

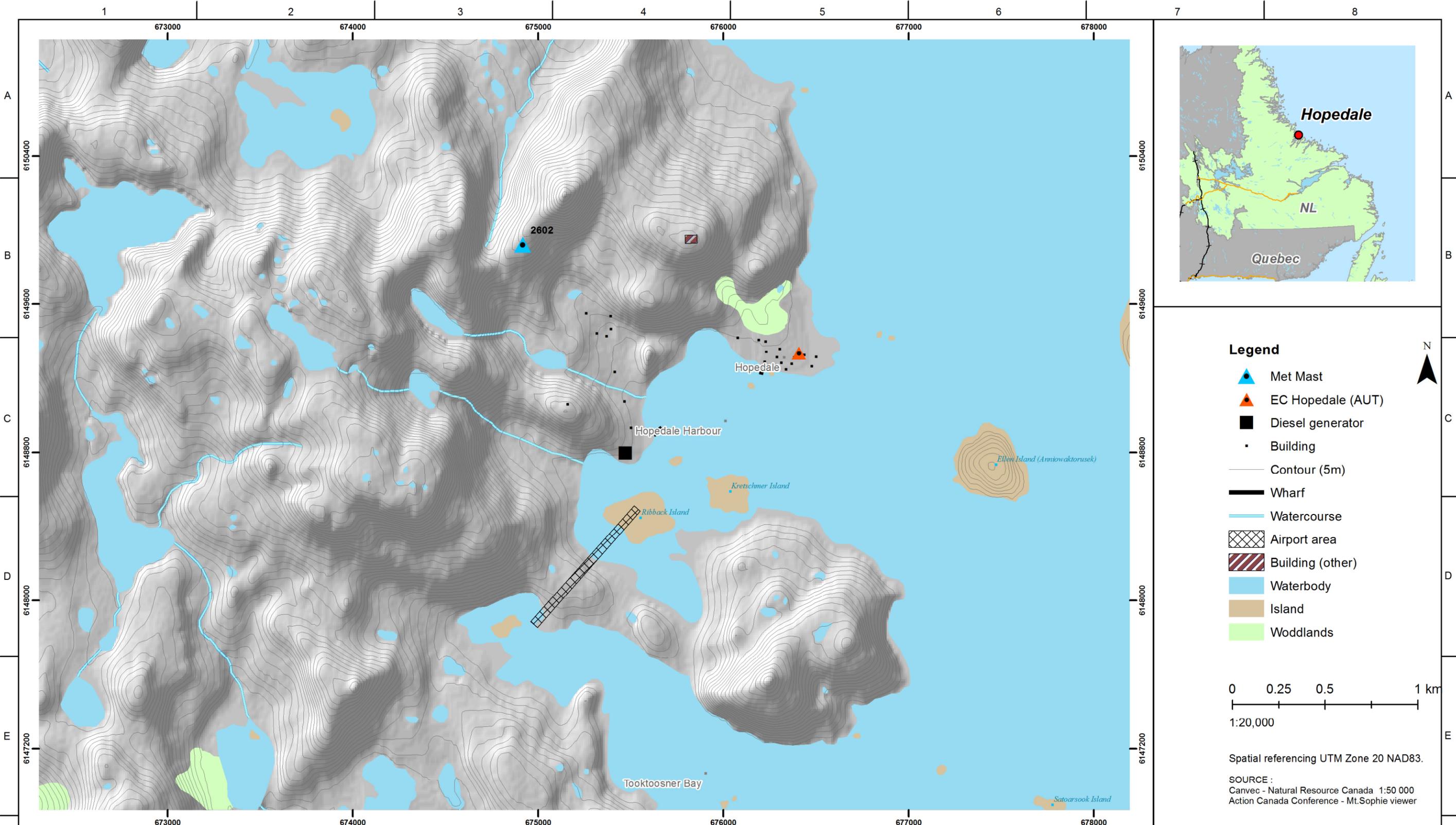
**Table 5-1: Roughness Lengths Categories**

Land Cover Type	Roughness Length (m)
Generic vegetation	0.06
Forest	0.5
Water	0
Building	1

### 5.1.3 *Background Map*

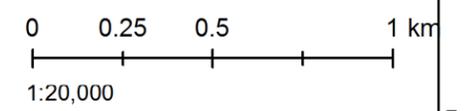
The background map, showing topography and contour lines is provided on the next page.





**Legend**

- Met Mast
- EC Hopedale (AUT)
- Diesel generator
- Building
- Contour (5m)
- Wharf
- Watercourse
- Airport area
- Building (other)
- Waterbody
- Island
- Woddlands



Spatial referencing UTM Zone 20 NAD83.

SOURCE :  
Canvec - Natural Resource Canada 1:50 000  
Action Canada Conference - Mt.Sophie viewer

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

**HATCH**

DESIGNED BY SLADJANA PAVLOVIC DATE: March 10, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: March 10, 2015
CHECKED BY Patrice Menard DATE: March 10, 2015	

NALCOR

**Hopedale - Overview Map**

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## 5.2 Wind Flow Calculation

### 5.2.1 *Terrain Complexity*

The wind flow is produced over semi-complex terrain. Wind modeling software, such as MS-Micro (used in Windfarm) and WAsP, are known to produce erroneous wind flows over complex terrain. Depending on the topography, predicted wind speeds can be over or underestimated at a given location. Errors can reach more than 20% in very complex areas.

In the present case, the complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 5.2.2 *Parameters*

The following parameters were used to calculate the wind flow map.

**Table 5-2: Wind Flow Calculation Parameters**

Parameter	Value
Wind Resource Grid Spatial Resolution	50 m
Calculation Area	3.5 km by 3.3 km
Reference Mast	2602
Reference Height	Top Anemometer Height
Calculation height	37 m
Vertical Extrapolation Method	Based on measured wind shear
Roughness Change Model	WAsP Standard Model

### 5.2.3 *Results*

The wind flow map used for layout optimisation and energy production estimates is presented on the next page.



### 5.3 Forecasting Energy Production

The layout was initially designed in order to maximise energy production. Turbines were spread out inside the project boundaries to minimise wake effects. The preliminary environmental screening and turbine extreme operating conditions also contributed to set the turbine locations.

#### 5.3.1 Preliminary Turbine Selection

A preliminary turbine selection was performed using Windographer software by comparing the performance of different turbines at the location of the met mast, where the dataset was recorded. The main parameters used for the comparison were the capacity factor of the wind turbine for the site specific conditions as well as the turbine purchase cost. Only turbines that meet the following criteria were considered:

- Site's turbine and turbulence class (IEC class II)
- Extreme wind and weather conditions (operation down to -40°C). The minimum 10-minute temperature recording of -33.1 °C during the monitoring campaign confirms the site conditions are within the operating range of the turbine.
- Turbine capacity ranges from 100 kW to 1,000 kW to meet the community load
- Wind turbine's dimensions and weight versus crane capacity and accessibility

Hub heights of about 40 m to 50 m were used for this preliminary analysis.

Standard losses considered include: 12.5% technical losses and 2% wake losses.

The following table provides a summary of the turbine comparison.

**Table 5-3: Windographer Results at the Mast Location**

Turbine type	Turbine Class	Hub height (m)	Turbine Capacity (kW)	Mean Energy Output (MWh/yr)	Capacity Factor (%)	Turbine purchase cost (\$)
Northern Power NPS100 Arctic	IIA	37	100	264	30.2	325,000
Aeronautica AW/Siva29-250	IIA/IIIA	37	250	583	26.6	656,000
Aeronautica AW/Siva47-500	IB/IIA	47	500	1,465	33.5	1,632,000
EWT DW52-250 (EWT250)	IIA	37	250	1,129	51.6	1,980,000
EWT DW52-500 (EWT500)	IIA	37	500	1,741	39.7	1,990,000
EWT DW52-900 (EWT900)	IIA	40	900	2,210	28.0	2,000,000

The capacity factors listed above in table 5-3 are taken from Windographer and may change as a function of the site's optimized layout and should only be used for turbine comparison.

Due the lack of proven experience in remote arctic conditions, the Aeronautica wind turbine models were discarded from the analysis. Northern Power and EWT wind turbines have



been installed and are operating in similar site conditions in Nome, Alaska for EWT or in Kasigluk, Alaska for Northern Power and were thus further compared as part of the analysis.

The average community load at Hopedale during the project lifetime is around 750 kW. The following table shows the results of the WindFarmer optimization models using the required number of turbines to meet that load. The turbines were ranked based on their capacity factor, energy output and simple payback.

**Table 5-4: Preliminary Turbine Selection Results**

Turbine type	Number of wind turbine required	Total Capacity (kW)	Gross Energy Output (MWh/yr)	Gross Capacity Factor (%)	Total purchase cost (Million \$)	Ranking
<b>Northern Power NPS100 Arctic</b>	<b>8</b>	<b>800</b>	<b>3,207</b>	<b>45.7</b>	<b>2.600</b>	<b>2</b>
EWT250	3	750	4,643	70.6	5.940	4
EWT500	2	1000	5,273	60.2	3.980	3
<b>EWT900</b>	<b>1</b>	<b>900</b>	<b>3,950</b>	<b>50.1</b>	<b>2.000</b>	<b>1</b>

\* Based on the gross energy output at 30 cents/kWh and the turbine purchase cost only.

Based on information provided by EWT, the 250 kW wind turbine has the same foundation design as the 500 kW and 900 kW machines and nearly the same price (\$10,000 difference). Because of the similar turbine costs of the three EWT models, from a financial point of view, the EWT900 becomes the most suitable having the lowest simple payback, and would also benefit from potential lower constructability and BOP cost.

The Northern power NPS100 Arctic can also be considered as potential candidates for the Hopedale project since it is a proven turbine in arctic conditions, and would provide for more redundancy due to number of turbines. The NPS100 has the advantage of being a smaller turbine and would be less difficult from a logistic and crane accessibility stand point.

The NPS100 and EWT900 turbines are two models that meet the wind class of the site and have proven technology for cold and icy environments.

Even though a more detailed turbine selection exercise will be required in later phase of the project, the NPS100 and EWT900 are considered suitable candidate turbines in order to complete the preliminary energy estimates for the potential Hopedale project.

### 5.3.2 *Layout Optimization*

The following section shows the WindFarmer modeling results which further refines the energy estimates for the turbines selected at the potential turbine positions and to confirm the capacity factor values. The table below outlines the parameters and constraints assumed to influence optimisation.



**Table 5-5: Layout Optimisation Parameters and Constraints**

Parameter / Constraint	Value	
<b>Annual Air Density</b>	1.31 kg.m <sup>-3</sup> at 123 m.a.s.l.	
<b>Turbulence Intensity</b>	13.6% at mast 2602 <i>Note: average value for information, the turbulence intensity is actually entered by wind-speed bins and by direction for energy prediction calculation</i>	
<b>Exclusion areas</b>	Due to the lack of information in regard to setbacks for wind energy projects in Newfoundland and Labrador, general restriction rules were used: - 500 m from habitations - 100 m from public roads - 50 m from lakes and rivers - 2 km by 1 km buffer zone from the airport track	
<b>WTG Minimum Separation Distance</b>	4 rotor diameters	
<b>WTG Model</b>	EWT900	NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>WTG Power Curve</b>	See Appendix B	
<b>WTG Thrust Curve</b>	See Appendix B	
<b>Number of WTG's</b>	1	8
<b>Wind Farm Capacity (kW)</b>	900	800
<b>Wake Model</b>	Modified Park Model used for optimisation and Eddy Viscosity Model for final energy calculation as recommended by Garrad Hassan	
<b>Maximum Slope</b>	10 degrees	
<b>Optimization Strategy</b>	Layout designed in order to maximise energy production.	

The project layouts are presented at the end of this section.

The layouts are still considered preliminary. Land restrictions, communication corridors, noise and visual impacts, and other site-specific matters need to be evaluated through a detailed environmental assessment. Available land, road and collection system costs are also issues that will need to be addressed before the site layout can be finalized.



### 5.3.3 Energy production

Once the optimised layout has been produced, the energy production for each wind turbine is calculated. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow. These corrections result in an effective hub height for each wind turbine.

The calculation was executed with the power curves and thrust curves used for the optimisation and presented in Appendix B. The additional losses are described in the next section.

Note that air density is corrected by the software for each turbine location according to its elevation.

The following table is a summary of the estimated energy production. Detailed energy figures are presented per wind turbine on the next page.

**Table 5-6: Wind Farm Energy Production Summary**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
WTG Rotor Diameter (m)	51.5	20.7
WTG Hub Height (m)	40.0	37.0
Number of Wind Turbines	1	8
Wind Farm Capacity (kW)	900	800
Mean Free Wind Speed across Wind Farm (m/s)	9.1	8.3
Average Wake Losses (%)	0.0	2.2
Energy Production Before Additional Losses* (MWh/yr)	3,950	3,207
Capacity Factor Before Additional Losses* (%)	50.1	45.7
Additional Losses (%)	14.0	13.8
Net Energy Production (P50) (MWh/yr)	<b>3,398</b>	<b>2,765</b>
Net Capacity Factor (%)	<b>43.1</b>	<b>39.4</b>

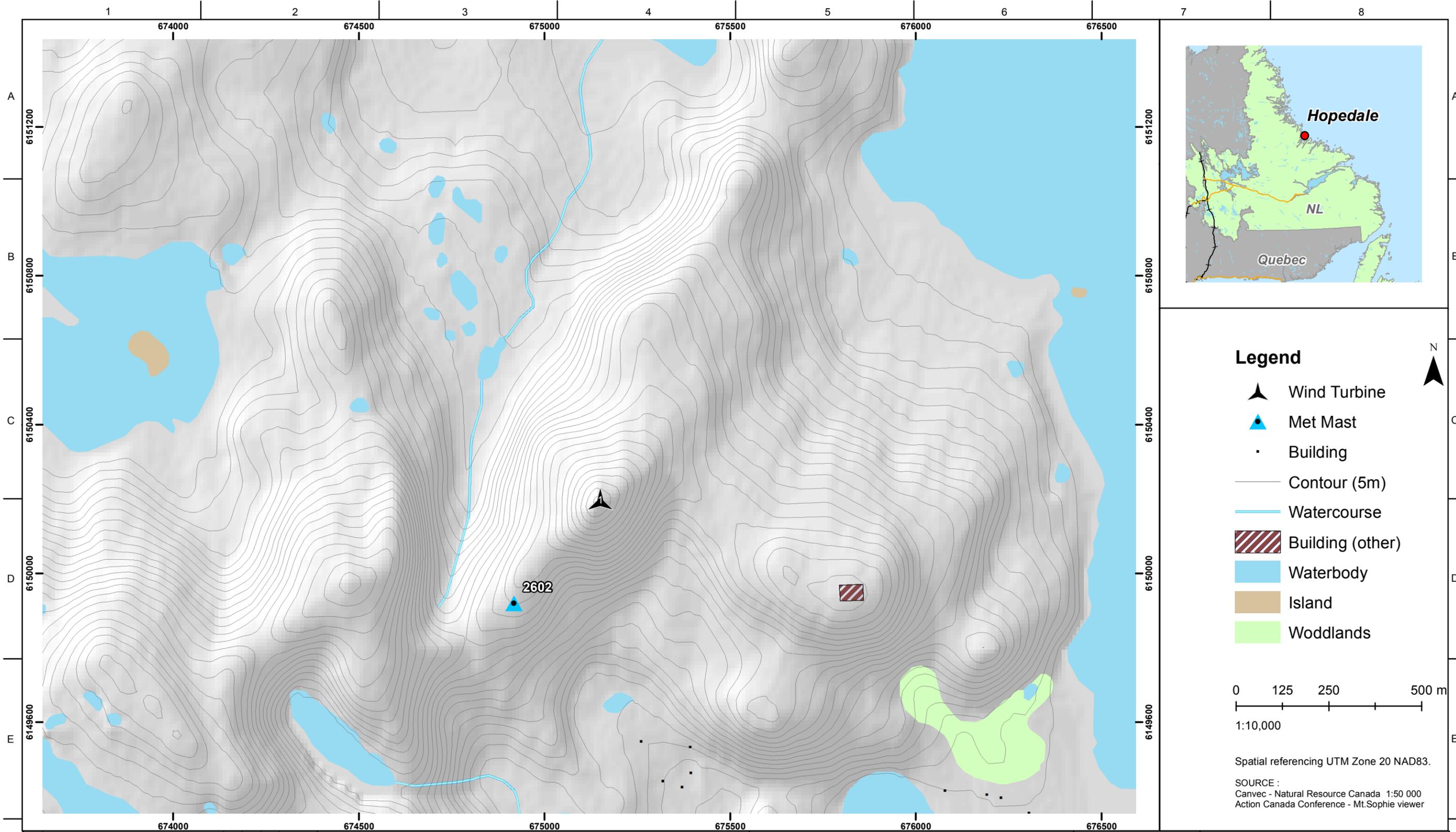
\* Includes topographic effect and wake losses

**Table 5-7: Forecasted Energy Production at Wind Turbines**

Turbine ID	Easting (m)	Northing (m)	Altitude (m)	Mean Free Wind Speed (m/s)	Gross Energy Production* (MWh / Year)	Wake Losses (%)	Gross Energy - Wake* (MWh / Year)	Turbulence Intensity** (%)
<b>Layout 1 - EWT900</b>								
1	675150	6150200	150	9.1	3,950	0.0	3,950	13.4
<b>Layout 2 - NPS100 Arctic</b>								
1	674551	6149815	130	8.1	396	2.1	388	16.7
2	674510	6149911	142	8.3	411	2.5	401	16.4
3	674441	6149998	146	8.3	413	1.3	408	15.6
4	674532	6149996	146	8.4	419	4.4	401	16.9
5	674569	6150082	136	8.3	414	3.2	400	16.1
6	675150	6150200	150	9.1	459	0.7	456	13.5
7	675300	6150503	99	7.8	381	2.8	371	17.1
8	675265	6150587	95	7.9	385	0.8	382	16.3

\* Gross energy production includes topographic effect; "Gross energy – Wake" includes topographic effect and wake losses.

\*\* Turbulence Intensity includes ambient turbulence and incident turbulence. The values represent true meteorological turbulence; they should not be compared directly with IEC models and consequently should not be used to establish the wind turbine class.



NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

Turbine model: EWT DW52-900  
 Number of turbines: 1  
 Site capacity: 900 KW  
 Turbine rated power: 900 KW  
 Hub height: 40 m  
 File reference: Hopedale\_WF2\_Lay6.txt

**HATCH**

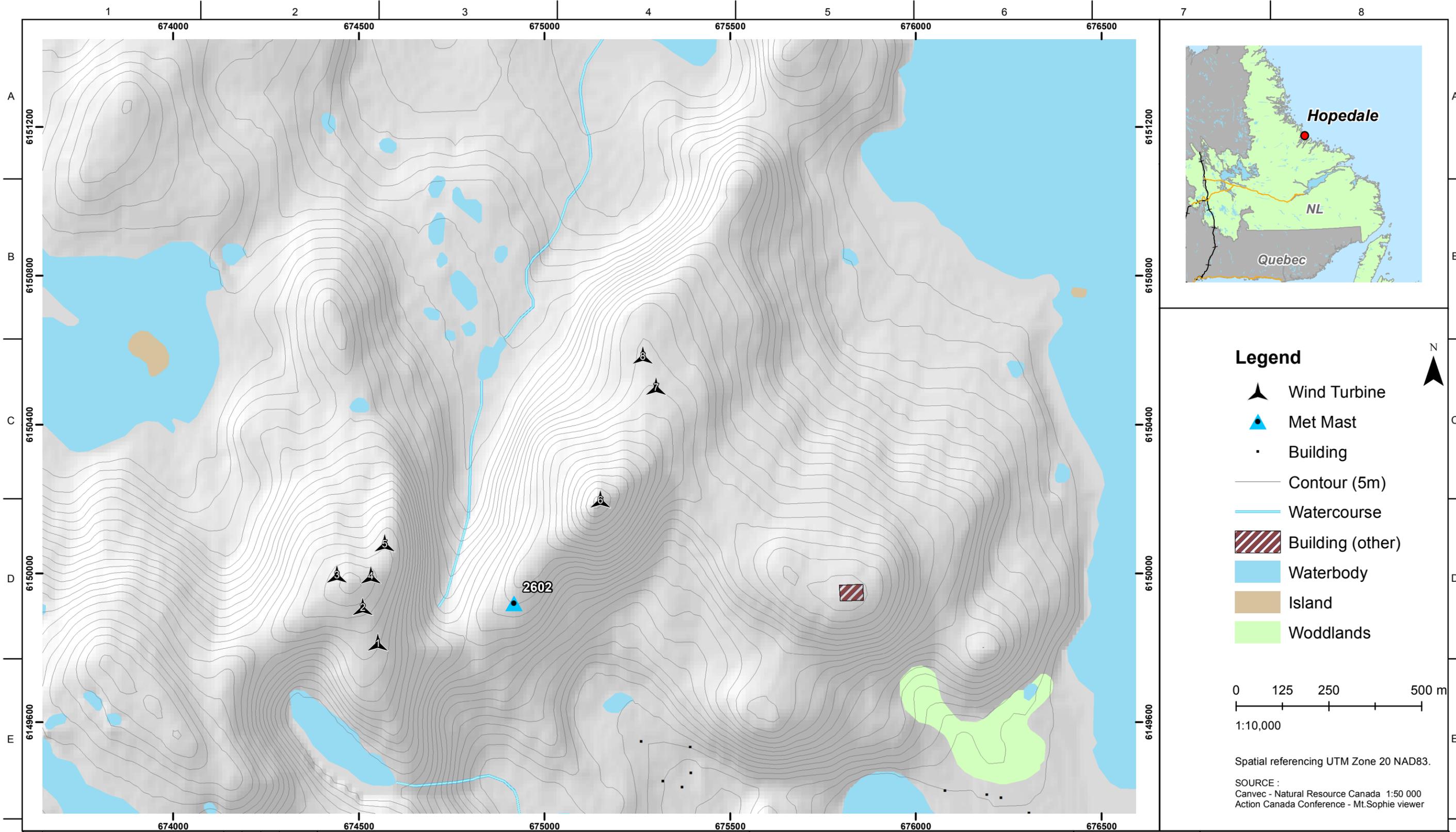
DESIGNED BY DANY AWAD DATE: August 05, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 06, 2015
CHECKED BY DANY AWAD DATE: August 06, 2015	

NALCOR

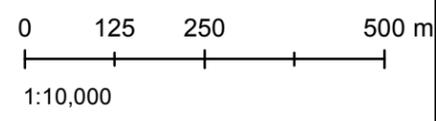
## Hopedale - Layout 1

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- Legend**
- Wind Turbine
  - Met Mast
  - Building
  - Contour (5m)
  - Watercourse
  - Building (other)
  - Waterbody
  - Island
  - Woddlands



Spatial referencing UTM Zone 20 NAD83.  
SOURCE :  
Canvec - Natural Resource Canada 1:50 000  
Action Canada Conference - Mt.Sophie viewer

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

Turbine model: Northern Power 100  
 Number of turbines: 8  
 Site capacity: 800 KW  
 Turbine rated power: 100 KW  
 Hub height: 37 m  
 File reference: Hopedale\_WF2\_Lay7.txt

**HATCH**

DESIGNED BY DANY AWAD DATE: August 05, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 06, 2015
CHECKED BY DANY AWAD DATE: August 06, 2015	

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**Hopedale - Layout 2**

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### 5.3.4 Losses

This section provides a description of the estimated losses included in the P50 estimate. These losses include environmental, electrical, availability, turbine performance losses and wake effects. The P50 is defined as the exceedance probability that denotes the level of annual wind-driven electricity generation that is forecasted to be exceeded 50% of the year. Half of the year's output is expected to surpass this level, and the other half is predicted to fall below it. Loss estimates should be reviewed as more detailed information becomes available.

The losses considered are presented in the following table and described hereafter.

**Table 5-8: Wind Farm Losses**

Loss Category	Loss Type	Losses (%)			
		Layout 1 - EWT900		Layout 2 - NPS100 Arctic	
<b>Environmental</b>	Blade Soiling and Degradation	1.0		1.0	
	High Wind Hysteresis	0.2		0.2	
	Icing	3.0	<b>4.5</b>	3.0	<b>4.2</b>
	Lightning	0.0		0.0	
	Low Temperature Shutdown	0.4		0.0	
<b>Electrical</b>	Collection Network	1.3	<b>3.4</b>	1.3	<b>2.0</b>
	Auxiliary power	2.1		0.7	
<b>Availability</b>	Wind Turbine Availability	5.0		6.5	
	Collection Network Outage	0.6	<b>5.8</b>	0.7	<b>7.3</b>
	Grid Availability	0.2		0.2	
<b>Turbine Performance</b>	Out-of-range Operation	1.0	<b>1.0</b>	1.0	<b>1.0</b>
<b>Wake effects</b>	Internal Wake Effects	0.0	<b>0.0</b>	2.2	<b>2.2</b>
	External Wake Effects	0.0		0.0	
<b>Total*</b>		<b>14.0</b>		<b>15.7</b>	

\* The total is the cumulated effect of the different losses and not their direct summation

**Blade soiling and Degradation** refers to the reduction of the blade's aerodynamic performance due to dust and/or insects. It also takes into account the future blade degradation attributed to wear of the blade's surface. The Hopedale project is not situated in a particularly dusty environment. This value is consistent with what is generally observed within the industry.



**High wind hysteresis** losses are caused by the control loop of the turbine around cut-out wind speed. They depend on the wind turbine design.

These estimations are based on the turbines' control loop specifications and high wind hysteresis simulations. Based on the available wind distribution at the mast, the loss induced by the hysteresis loop is 0.2%.

**Icing** losses happen in different ways: ice accumulation on blades alter their aerodynamic performance, nacelle-mounted instruments affected by ice give inaccurate readings and induce turbine control system errors, asymmetric icing causes mass or aerodynamic imbalance leading to vibrations that may force control systems to shut down the turbine. Icing can have different impact on the production of the turbine and the effect is site-specific. Some areas will be more affected by freezing rain or glaze ice and other regions are more prone to have rime ice or in-cloud icing.

Icing losses are estimated from the detection of icing events during met masts data quality control and translating the icing events into production losses. The level of ice is considered moderate as compared to other northern sites (up to 10% of icing losses).

Values should be taken with caution since no proven methodology is available and because the effect and characteristics of ice are highly site-specific. The uncertainty associated to these aspects is taken into account in the global uncertainty assessment.

**Lightning** has the potential to damage the turbine control system but also the blade integrity. Modern wind turbines have protection devices that most of the time allow continuous operation even after a lightning strike. There is however, a small chance that lightning will impact turbine operation. The lightning losses were estimated according to Environment Canada maps<sup>5</sup>.

**Low temperature shutdown** losses depend on the local climate, the turbine design and the control algorithm. In cold climates, turbine shutdowns can be driven by low temperature detection, even if the wind is blowing. According to the manufacturers' specifications, the wind turbines with cold weather package have an operation threshold of - 40°C. The loss is estimated based on the long-term temperature data measured at Hopedale Environment Canada station.

**Collection network** loss is considered at the interconnection point. It takes into account various elements, including the length of the cables connecting the wind turbines to the substation and the losses in the substation itself. Losses depend on the design of these elements.

These losses have been estimated by Hatch according to previous experiences with similar project size and conditions. They should be confirmed when the design of the collection network is finalized.

**Auxiliary power** losses account for various subsystems of a wind turbine that require electrical power, such as control systems or heaters. All of these losses are not always

<sup>5</sup> <http://ec.gc.ca/foudre-lightning/default.asp?lang=En&n=42ADA306-1>

accounted for in the power curve. For example, cold packages designed for cold climate wind turbines can require energy even when the turbine is stopped.

Based on Hatch's experience, an estimated value is used to account for the consumption of standard auxiliary systems. Specific losses have been added for the Cold Package system delivered with the wind turbines. They have been estimated by simulation according to the Cold Package specifications of the EWT900 and NPS100 Arctic wind turbines.

**Wind turbine availability** losses represent the percentage of time over a year that the turbine is unavailable for power production. Losses include regular maintenance time and unexpected turbine shutdowns. A given availability rate is normally guaranteed by utility-scale wind turbine manufacturers such as EWT (95%), but in the case of smaller wind turbines (NPS100), no availability warranty will be offered by the manufacturer.

Based on Hatch's experience on wind farms in similar conditions and technology for isolated sites, Hatch considers the estimate of 6.5% to be adequate for the Project with NPS100 units. This estimation considers a standard maintenance schedule of 1 day per year per turbine, plus unscheduled repairs and delays due to site accessibility and weather conditions. This is based on information provided by the client that wind turbines will be considered as non-essential grid components and thus deficiencies will be considered as low priority, so that individual units may remain out of service for periods longer than normally considered.

**Collection Network Availability:** The collection network may be out of service, stopping energy delivery from the turbines to the grid. Collection network outage losses include shutdown time for scheduled maintenance and unexpected outages.

Based on the information provided by the client, the Hopedale based operators will manage the site and are expected to have the skills and manpower required to fix any collection system problem in a timely manner. The presence of a support team onsite has a positive impact on the availability of the collection network.

**Grid availability** losses depend on the utility distribution system quality and capacity. It represents the percentage of time over a year when the grid is not able to accept the energy produced by the wind turbines.

The value used assumes the wind turbines will be connected to the grid operated by NLH, which is assumed to be well maintained and operated.

**Out-of-range Operation** losses take into account the aspects usually not covered by the power curve warranty such as turbulence, wind shear and yaw errors. Parameters specific to the Project have been used to perform this loss estimate.

**Wake Effect** corresponds to the deficit in wind speed downstream of a wind turbine. Several models exist to quantify this effect in terms of induced energy losses. Hatch uses the Eddy Viscosity model which corresponds to a CFD calculation representing the development of the velocity deficit field using a solution of the Navier Stokes equations. Because of higher precision as compared to the Park model and recommendations from WindFarmer, the Eddy Viscosity model is used to assess to the wake of the Project. Wake losses are highly



dependent on the layout, especially regarding the distance between the turbine and the layout's compactness.

One of the input in the wake losses calculation is the thrust curve which is provided by the turbine manufacturer for the Project turbine model under consideration.

No other wind farm currently exist in the vicinity of the project. In addition, no future wind farm that may impact the Project in terms of wake is planned. Thus there are no additional wake losses.



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## 6. Conclusions and Recommendations

### 6.1 Objectives of Analysis

The purpose of this report is to present a full wind resource assessment for the Hopedale site, including the estimation of the forecasted annual energy production.

### 6.2 Data Quality and Adjustments

The wind data recovery rates at the monitoring site, for the analysis period, exceed industry standards except for A4, with recovery rates ranging from 85.1% to 98.6% for the primary anemometers and 97.4% for the primary wind vane.

The measured data were adjusted to long-term through correlation with Environment Canada's Hopedale (AUT) station, located 2 km away from the project area. The long-term adjustment method was applied since it was considered to be the best method for producing a representative dataset for the expected life of the project.

### 6.3 Wind Resource

The annual average wind speed at the met mast is a result of the measurements and the long-term adjustment. These wind speeds are summarised in the table below for top anemometer and hub heights.

**Table 6-1: Estimated Long-term Wind Speeds**

Mast (Measurement Height)	Estimated Long-term Wind Speed at Measurement Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2602 (35 m)	7.1	7.2	7.3

The long-term dataset at the met mast was used to build the wind flow across the project area.

The complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 6.4 Forecasted Energy Production

The preliminary turbine selection analysis specified two suitable turbine models: EWT900 and NPS100 Arctic. These models were proven to be best in class for cold and icy environments and suitable for wind-diesel generation in remote community.

The main results of the energy production modeling are summarised in the table below.

**Table 6-2: Forecasted Annual Energy Production**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
Number of Wind Turbines	1	8
Wind Farm Capacity (kW)	900	800
Annual Net Energy Production (MWh/yr)	<b>3,398</b>	<b>2,765</b>
Net Capacity Factor (P50) (%)	<b>43.1</b>	<b>39.4</b>

There remains some uncertainty regarding loss estimates, which should be reassessed as more information becomes available, particularly in relation to warranty contracts and maintenance schedules. Note that the Annual Net Energy Production represents the total forecasted energy production by the wind turbines. The effective energy production used to displace fuel will be a bit lower and vary depending on the chosen layout scenario (type and number of wind turbines), timewise power load and wind resource.

## 6.5 Recommendation

It should be noted that a number of additional studies and more detailed analysis will be required to refine and validate the turbine selected, the turbine position, the energy and losses.

The integration optimization report will show which turbine model is considered optimal for the Hopedale site based on energy cost, control capabilities and logistics and provide recommendations for further analysis and studies prior to implementation.

## References

- [1] International Energy Agency Programme, *Recommended practices for wind turbine testing and evaluation – Task 11: Wind Speed Measurement and Use of Cup Anemometer*, 1999
- [2] National Renewable Energy Laboratory, *Wind Resource Assessment Handbook*, 1999
- [3] International Electrotechnical Commission, *Wind Turbines - Part 1: Design Requirements*, IEC 61400-1, Ed. 3, 2005-08.
- [4] International Electrotechnical Commission, *Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines*, IEC 61400-12-1, Ed. 1, 2005.
- [5] A Practical Guide to Developing a Wind Project, *Wind Resource Assessment*, 2011



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# Appendix A

## Views at Mast Sites



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**View Facing North**



**View Facing East**



**View Facing South**



**View Facing West**

**Figure – A1: Views from Base of Mast 2602**



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# Appendix B

## Wind Turbine Data



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**EWT DW52-900**

The power curve and the thrust curve were provided to Hatch by Emergya Wind Technologies.

**Table – B1: EWT Wind Turbine Performance Curves**

<b>Rotor Diameter:</b> 51.5 m	<b>Hub Height:</b> 40 m	<b>Air Density:</b> 1.225 kg.m <sup>-3</sup>	<b>Turbulence Intensity:</b> N/A
<b>Wind Speed at Hub Height (m/s)</b>	<b>Electrical Power (kW)</b>	<b>Wind Speed at Hub Height (m/s)</b>	<b>Thrust Coefficients</b>
0	0	0	0.000
1	0	1	0.000
2	0	2	0.000
3	7	3	0.866
4	30	4	0.828
5	69	5	0.776
6	124	6	0.776
7	201	7	0.776
8	308	8	0.753
9	439	9	0.722
10	559	10	0.692
11	698	11	0.613
12	797	12	0.516
13	859	13	0.441
14	900	14	0.368
15	900	15	0.296
16	900	16	0.241
17	900	17	0.199
18	900	18	0.168
19	900	19	0.143
20	900	20	0.124
21	900	21	0.109
22	900	22	0.096
23	900	23	0.085
24	900	24	0.075
25	900	25	0.067

**NPS100**

The power curve and the thrust curve were provided to Hatch by Northern Power.

**Table – B2: NPS100 Wind Turbine Performance Curves\***

Rotor Diameter: 20.7 m		Hub Height: 37 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)	Electrical Power (kW)	Wind Speed at Hub Height (m/s)	Thrust Coefficients				
0	0	0	0				
1	0	1	0				
2	0	2	0				
3	0	3	0				
4	3.7	4	1.072				
5	10.5	5	0.963				
6	19.0	6	0.866				
7	29.4	7	0.820				
8	41.0	8	0.754				
9	54.3	9	0.687				
10	66.8	10	0.616				
11	77.7	11	0.548				
12	86.4	12	0.491				
13	92.8	13	0.436				
14	97.3	14	0.391				
15	100.0	15	0.347				
16	100.8	16	0.316				
17	100.6	17	0.286				
18	99.8	18	0.261				
19	99.4	19	0.239				
20	98.6	20	0.222				
21	97.8	21	0.206				
22	97.3	22	0.194				
23	97.3	23	0.184				
24	98.0	24	0.175				
25	99.7	25	0.167				

\* Power curve of the Northern Power 100 – standard model

Patrice Ménard  
PM:pm



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Engineering

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Created by:	JT	Creation Date:	24-07-09
Checked by:	MB	Checked Date:	24-07-09
Approved by:	TY	Approved Date:	05-04-11

Title:

Specification

# **DIRECTWIND 52/54\*900 Technical Specification**

Revision	Date	Author	Approved	Description of changes
02	02-03-12	MB	TY	Format, minor text, blades, options
01	28-11-11	LE	TY	Corrections and drawings
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

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## 1 Introduction

This document provides a technical overview of the *DIRECTWIND* 52/54\*900 Wind Turbine designed for the IEC class II/III application. It is to be read in conjunction with document S-1000921 "Directwind 52/54\*900 Electrical Specification".



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## 2 Technical Description

The *DIRECTWIND* 52/54\*900 is a direct-drive, variable speed, pitch regulated, horizontal axis, three-bladed upwind rotor wind turbine.

The gearless direct-driven synchronous generator operates at variable speed. This is made possible by an actively controlled AC-DC-AC IGBT power converter connected to the grid. Benefits of this design are low maintenance, constant power output at wind speed above rated, and relatively low structural loads compared to constant-speed stall-controlled or constant-speed pitch-controlled wind turbines.

The generator is fully integrated into the structural design of the turbine, which allows for a very compact nacelle design. The drive-train makes use of only one main bearing, whereas classic designs have separately supported main shaft, gearbox and generator. All dynamically loaded interfaces from the blades to the foundation are sturdy flange connections with machined surfaces, and high tensile steel pre-stressed bolt connections are used.

### 2.1 Operation and safety system

The turbine operates automatically under all wind conditions and is controlled by an industrial PLC (Programmable Logic Controller). The cut-in wind speed is approximately 3m/s. When the rotational speed reaches the cut-in threshold, the power converter begins to deliver power to the grid.

The power converter controls the generator power output and is programmed with a power set-point versus rotor speed curve. Below rated wind speed the power output is controlled to optimise rotor speed versus aerodynamic performance (optimum  $\lambda$ -control). Above rated wind speed the power output is kept constant at rated value by PD-controlled active blade pitching.

The dynamic responses of the drive train and power controller are optimised for high yield and negligible electrical power fluctuations. The variable speed rotor acts as a flywheel, absorbing fluctuating aerodynamic power input. The turbine controllers are located in the rotor hub and the tower base (with remote IO in the nacelle) and carry out all control functions and safety condition monitoring. In the case of a fault, or extreme weather conditions, the turbine is stopped by feathering of the blades to vane position (blades swivelled to 90° with respect to rotor's rotational plane). In case of power loss, an independent battery backup system in each blade ensures the blades are feathered.

In the case of less serious faults which have been resolved, or when extreme weather conditions have passed, the turbine restarts automatically to minimise downtime.

### 2.2 Generator

The multiple-pole, direct-drive generator is directly mounted to the hub. The stator is located in the non-moving outer ring and the wound pole, separately excited rotor rotates on the inner ring.

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The generator is designed such that all aerodynamic forces are directly transferred to the nacelle construction without interfering with the generator-induced loads.

## 2.3 Power Converter

The power converter is an AC-DC-AC IGBT active switching converter. It controls the generator to operate in its optimum range, and maintains power quality to the grid. The inverter can produce unity power factor ( $\cos\Phi=1$ ) to the grid under all load conditions. Power factor is also controllable within limits.

## 2.4 Rotor

The rotor is a three bladed construction, mounted up-wind of the tower. Rotational speed is regulated by active blade adjustment towards vane position. Blade pitch is adjusted using an electric servomotor on each of the blades.

Each blade has a complete, fully independent pitch system that is designed to be fail-safe. This construction negates the need for a mechanical rotor brake. The pitch system is the primary method of controlling the aerodynamic power input to the turbine.

At below rated wind speed the blade pitch setting is constant at optimum aerodynamic efficiency. At above rated wind speed the fast-acting control system keeps the average aerodynamic power at the rated level by keeping the rotor speed close to nominal, even in gusty winds.

The rigid rotor hub is a nodular cast iron structure mounted on the main bearing. Each rotor blade is connected to the hub using a pre-stressed ball bearing. It is sufficiently large to provide a comfortable working environment for two service technicians during maintenance of the pitch system, the three pitch bearings and the blade root from inside the structure.

## 2.5 Rotor blade set

The rotor blades are made of fibreglass-reinforced epoxy. The aerodynamic design represents state-of-the-art technology and is based on a pitch-regulated concept. No extenders are used and the aerodynamic design is optimal for this rotor diameter.

## 2.6 Main bearing

The large-diameter main bearing is a specially designed three row cylindrical roller bearing. The inner non-rotating ring is mounted to the generator stator. The outer rotating ring is mounted between the hub and generator rotor. The bearing takes axial and radial loads as well as bending moments. Entrance to the hub is through the inner-bearing ring. The bearing is greased by a fully automatic lubrication system controlled by the turbine PLC.

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## 2.7 Nacelle

The nacelle is a compact welded construction which houses the yaw mechanism, a service hoist and a control cabinet. Both the generator and the tower are flanged to the nacelle. The geometry of the construction assures an ideal transfer of loads to the tower and, with the absence of a shaft and gearbox, results in a simple design ensuring easy personnel access.

## 2.8 Yaw system

The yaw bearing is an internally geared ring with a pre-stressed four point contact ball bearing. Electric planetary gear motors yaw the nacelle. The yaw brake is passive and is based on the friction of brake pads sitting directly on the bearing ring, keeping the yaw system rigid under most loading conditions.

## 2.9 Tower

The nacelle assembly is supported on a tubular steel tower, fully protected against corrosion. The tower allows access to the nacelle via a secure hinged access door at its base. The tower is fitted with an internal ladder with safety wire and optional climb assistance, rest platforms and lighting. Standard hub heights are 35, 40, 50 and 75 metres.

## 2.10 Anchor

The turbine is supported by a concrete foundation. The connection to this foundation is provided by means of a cast-in tube or rod anchor.

## 2.11 Control System

### 2.11.1 Bachmann PLC

The M1 controller perfectly combines the openness of a PC-based controller with the reliability of industrial hardware platforms. Designed to withstand the toughest ambient conditions it guarantees error-free use over long periods of time.

A modern system architecture designed for consistent network-capability permits the easy integration of the M1 into the environment of the controller and system peripherals. Real-time ethernet permits the real-time networking of the controllers, and the support of all standard Fieldbus systems permits the connection of standard external components.

### 2.11.2 DMS

*DIRECTWIND* Monitoring System – EWT’s proprietary HMI featuring local monitoring and control at the turbine, integrated into a remote-access SCADA. DMS offers individual turbine control and total park monitoring and data logging from your Wind Turbine, Wind Park or internet access point.

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## 2.12 Earthing and lightning protection

The complete earthing system of the wind turbine incorporates:

1. Protective earthing:

A PE connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

2. Functional earthing:

Earthing system to minimize and/or remove the source of electrical interference that can adversely affect operation of sensitive electrical and control equipment.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, the functional earth connection may carry electric current during the normal operation of the turbine.

3. Lightning protection:

To provide predictable conductive path for the over-currents in case of a lightning strike and electromagnetic induction caused by lightning strike and to minimize and/or remove dangerous situations for humans and sensitive electrical equipment.

Since the mechanical construction is made of metal (steel), all earthing systems are combined.

## 2.13 Options

The following options are available:

- Cold climate operation (rated for operation down to -40°C)
- Ice detection and/or prevention system
- Aviation lights
- Shadow flicker prevention
- Low Voltage Ride-through (LVRT)
- Service lift (75m tower only)
- G59 protection relay

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### 3 Technical Data

Where data are separated by "/" this refers to the respective rotor diameter (52 / 54 m).

#### 3.1 Wind and Site Data

Wind class	II / III according to IEC 61400 – 1
Max 50-year extreme	59.5 / 52.5 m/s
Turbulence class	A ( $I_{15} = 0.16$ )
Maximum flow inclination (terrain slope)	8°
Max ann. mean wind speed at hub height	8.5 / 7.5 m/s
Nominal air density	1.225 kg/m <sup>3</sup>

#### 3.2 Operating Temperature

	Standard	Cold Climate
Min ambient operating	-20°C	-40°C
Max ambient operating	+40°C	+40°C

#### 3.3 Cooling

Generator cooling	Air cooled
Converter cooling	Water or air cooled (configuration-dependent)

#### 3.4 Operational Data

Cut in wind speed	3 m/s
Cut out wind speed	25 m/s
Rated wind speed	14 / 13.5 m/s
Rated rotor speed	26 rpm
Rotor speed range	12 to 33 rpm
Power output	900kW
Power factor	1.0 (adjustable 0.95 lagging to 0.95 leading) Measured at LV terminals

#### 3.5 Rotor

Diameter	52 / 54 m
Type	3-Bladed, horizontal axis
Position	Up-wind
Swept area	2,083 / 2,290 m <sup>2</sup>
Power regulation	Pitch control; Rotor field excitation
Rotor tilt angle	5°

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### 3.6 Blade Set

Type	PMC 24.5 / 25.8
Blade length	24.5 / 25.8 m
Chord at 22.0 m	0.879 m (90% of 24.5m blade radius)
Chord at 23.5 m	0.723 m (90% of 25.8m blade radius)
Chord Max at 5.5 m	2.402 m
Aerodynamic profile	DU 91, DU 98 and NACA 64618
Material	Glass reinforced epoxy
Leading edge protection	PU coating
Surface colour	Light grey RAL 7035
Twist Distribution	11.5° from root to 5.5m then decreases linearly to 0.29°, then non-linearly to 0°

### 3.7 Transmission System

Type	Direct drive
Couplings	Flange connections only

### 3.8 Controller

Type	Bachmann PLC
Remote monitoring	DIRECTWIND Monitoring System, proprietary SCADA

### 3.9 Pitch Control and Safety System

Type	Independent blade pitch control
Activation	Variable speed DC motor drive
Safety	Redundant electrical backup

### 3.10 Yaw System

Type	Active
Yaw bearing	4 point ball bearing
Yaw drive	3 x constant speed electric geared motors
Yaw brake	Passive friction brake

### 3.11 Tower

Type	Tapered tubular steel tower
Hub height options	HH = 35, 40, 50, 75 m
Surface colour	Interior: White RAL 9001, Exterior: Light grey RAL 7035

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### 3.12 Mass Data

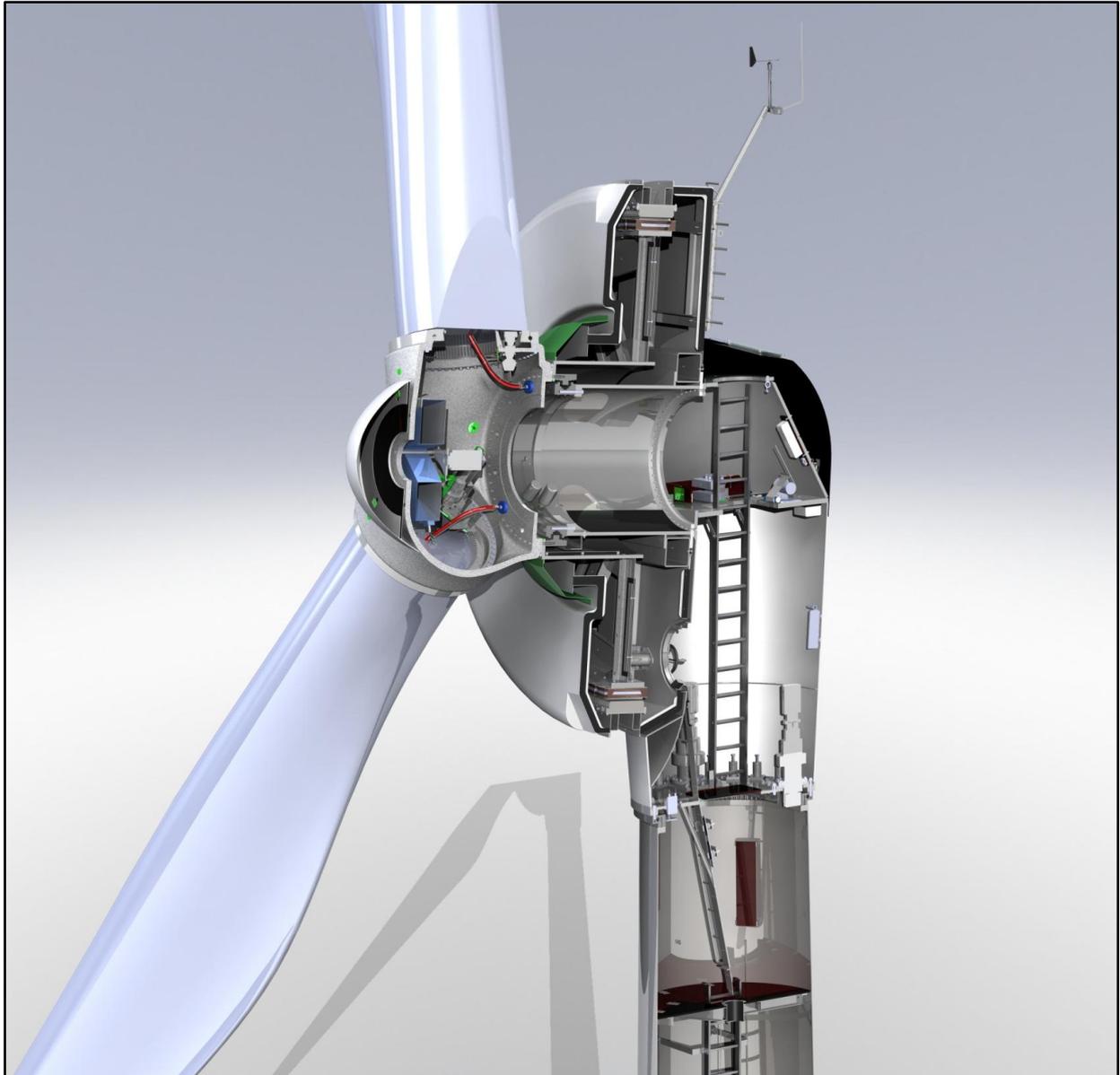
Hub	9,303 kg
Blade – each	1,919 / 1,931 kg
Rotor assembly	15,060 / 15,096 kg
Generator	30,000 kg
Nacelle assembly	10,000 kg
Tower HH35	28,300 kg
Tower HH40	34,000 kg
Tower HH50	46,000 kg
Tower HH75	86,500 kg

### 3.13 Service Brake

Type	Maintenance brake
Position	At hub flange
Calipers	Hydraulic 1-piece

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## APPENDIX 1: 3D image of main turbine components

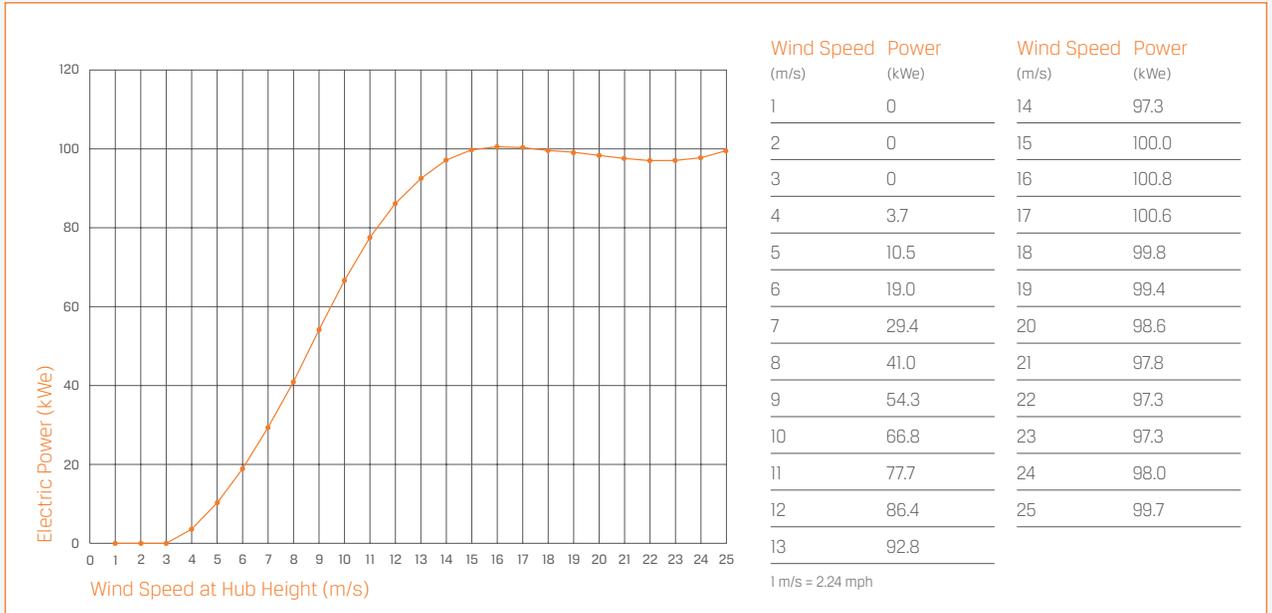


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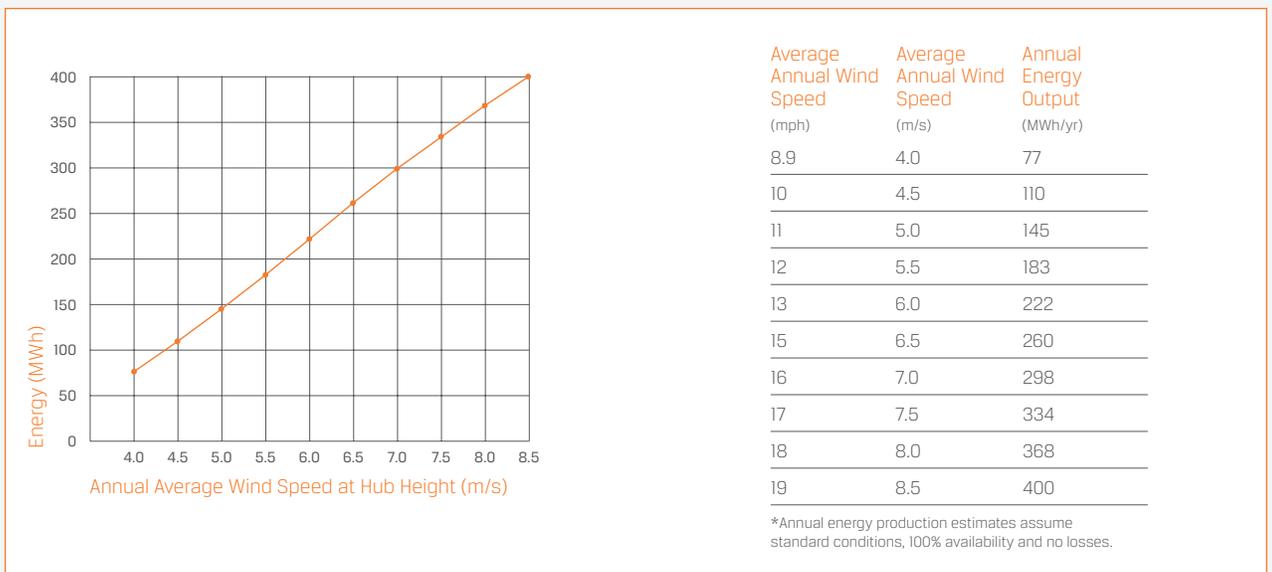


# Northern Power<sup>®</sup> 100

Power Curve: 21-Meter Rotor Standard Air Density (1.225 kg/m<sup>3</sup>)



Annual Energy Production\*: 21-Meter Rotor Standard Air Density, Rayleigh Wind Speed Distribution



## Specifications



GENERAL CONFIGURATION	DESCRIPTION
Model	Northern Power® 100
Design Class	IEC IIA (air density 1.225 kg/m <sup>3</sup> , average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 years
Hub Height	37 m (121 ft) / 30 m (98 ft)
Tower Type	Tubular steel monopole
Orientation	Upwind
Rotor Diameter	21 m (69 ft)
Power Regulation	Variable speed, stall control
Certifications	UL1741, UL1004-4, CSA C22.2 No.107.1-01, CSA C22.2 No. 100.04, and CE compliant
PERFORMANCE	DESCRIPTION
Rated Electrical Power	(standard conditions: air density of 1.225 kg/m <sup>3</sup> , equivalent to 15°C (59°F) at sea level) 100 kW, 3 Phase, 480 VAC, 60/50 Hz
Rated Wind Speed	14.5 m/s (32.4 mph)
Maximum Rotation Speed	59 rpm
Cut-In Wind Speed	3.5 m/s (7.8 mph)
Cut-Out Wind Speed	25 m/s (56 mph)
Extreme Wind Speed	59.5 m/s (133 mph)
WEIGHT	DESCRIPTION
Rotor (21-meter) & Nacelle (standard)	7,200 kg (16,100 lbs)
Tower (37-meter)	13,800 kg (30,000 lbs)
DRIVE TRAIN	DESCRIPTION
Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet, passively cooled
BRAKING SYSTEM	DESCRIPTION
Service Brake Type	Two motor-controlled calipers
Normal Shutdown Brake	Generator dynamic brake and two motor-controlled calipers
Emergency Shutdown Brake	Generator dynamic brake and two spring-applied calipers
YAW SYSTEM	DESCRIPTION
Controls	Active, electromechanically driven with wind direction/speed sensors and automatic cable unwind
CONTROL/ELECTRICAL SYSTEM	DESCRIPTION
Controller Type	DSP-based multiprocessor embedded platform
Converter Type	Pulse-width modulated IGBT frequency converter
Monitoring System	SmartView remote monitoring system, ModBus TCP over ethernet
Power Factor	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive Power	+/- 45 kVAR
NOISE	DESCRIPTION
Apparent Noise Level	55 dBA at 30 meters (98 ft)
ENVIRONMENTAL SPECIFICATIONS	DESCRIPTION
Temperature Range: Operational	-20°C to 50°C (-4°F to 122°F)
Temperature Range: Storage	-40°C to 55°C (-40°F to 131°F)
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection
Icing Protection	Turbine designed in accordance with Germanischer Lloyd Wind Guidelines Edition 2003

All Specifications subject to change without notice.

NPS100SS-2222011-US

# Appendix C: Wind Resource Assessment Report – Makkovik



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H340923-0000-05-124-0012, Rev. B

Project Report

November 15, 2015

## **Newfoundland and Labrador Hydro Makkovik Wind Project**

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## **Final Wind Resource Assessment Report**



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H340923-0000-05-124-0003, Rev. 2  
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## DOCUMENT HISTORY

Revision	Date	Description
1	September 3, 2015	Final Version
2	November 15, 2015	Few edits based on comments from NLH on October 30, 2015 – Final Version



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## EXECUTIVE SUMMARY

In order to assess the potential of Makkovik site for wind power development, a wind resource assessment (WRA) was completed. The site is located near the community of Makkovik, Newfoundland and Labrador, Canada. The site was equipped with one met mast that is described in the table below.

Met Mast	Installation Date	Top Anemometer Height (m)	Elevation (m)	Data Collection* Starts...	Data Collection* Ends...
2603	October 25, 2013	35.0	81	October 25, 2013	April 30, 2015

\* A 12 month period is selected to estimate the annual energy production

In the analysis, the quality control process demonstrated that the data recovery rates exceeded 93.5 % on all instruments which meets industry standards for wind measurement campaign. Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements.

The **wind speed** measured at the mast is **7.7 m/s** on average. The **winds are dominant from southwest and west-southwest** across the site.

The wind **turbulence intensity** observed at the site is generally **moderate**.

Given the land cover and topography at the mast, the **wind shear exponent**, equal to **0.12** is consistent with the expected value.

Met Mast	Period	Annual Average of Measured Wind Speed* (m/s)	Annual Average of Measured Turbulence Intensity* (%)	Annual Wind Shear
2603	November 1, 2013 to October 31, 2014	7.7	12.0	0.12

\* at Top Anemometer Height

During the data quality control process, icing events were detected on anemometers and wind vanes. **Icing occurred 1.7% of the time** at the site. Given the site elevation and the temperatures associated with these events, it is likely that about 77% of these events were caused by freezing rain and about 23% were caused by rime ice. Icing events mainly occurred during the months of April and November.

Temperature data were collected at the mast. The monthly averages range from **-16.8°C** in February and December to **14.1°C** in August, with an **annual average** of **-1.8°C** for the analysis period. The coldest 10-minute temperature recording during the data collection period was **-32.4°C**.

The **air density** was calculated at the mast according to the elevation and the local temperature. The annual value is **1.31 kg/m<sup>3</sup>**.



The annual average power density is **637 W/m<sup>2</sup>**. The most powerful winds come from west-southwest to northwest across the site.

In order to estimate the **long-term wind regime** at the site, several potential **reference stations** with historical data were selected.

The **Hopedale (AUT) station** monitored by Environment Canada, located 77 km away from the potential wind farm site, was selected as the reference station for the long-term extrapolation of the data. The reference station data were then correlated to met mast 2603 and used to translate the short-term data into long-term estimates.

The long-term estimates were then extrapolated from measurement height to hub heights.

Met Mast	Period	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s) at 37 m / 40 m
2603	November 1, 2013 to October 31, 2014	7.6	7.6 / 7.7

The wind resource estimated at the mast was used to compute the wind flow across the project area. The wind flow was calculated with WAsP 11.01.0016 software, which is an appropriate model for the Makkovik project area which exhibits a moderate terrain complexity.

This wind flow was used to optimise the layout of the potential wind farm and to estimate the energy production with WindFarmer software.

A preliminary turbine selection analysis was completed and two turbine models were selected: Emergya Wind Technologies 900 kW (EWT900) and Northern power 100 (NPS100 Arctic). These models have proven technology in cold and icy environments and are suitable for wind-diesel generation in remote community.

A wind farm layout optimisation was completed taking in consideration energy production, information from the preliminary environmental screening and turbine extreme operating condition.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.

Layout	Wind Farm Capacity (kW)	Net Energy Production (MWh/year)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)
Layout 1 - EWT900	900	3,102	39.3	0.0	14.1
Layout 2 - NPS100 Arctic	500	1,728	39.4	1.1	13.6

Other energy production scenarios will be covered under separate portion of the wind penetration report.



## 1. Introduction

Hatch has been mandated by Newfoundland and Labrador Hydro (NLH) to carry out a wind resource assessment (WRA) for a potential wind project, located near the community of Makkovik, Newfoundland and Labrador, Canada.

The site was instrumented with one meteorological (“met”) mast. The installation was completed on October 25, 2013. The mast was equipped with sensors at several heights to measure wind speed, wind direction and temperature. The analysed data cover a total measurement period of one year.

The second section of this report presents an overview of the site and the measurement campaign.

The third section presents the main characteristics of the wind climate.

The fourth section details the process used to translate the measured short-term data into long-term data.

The fifth section presents the methodology used to obtain the wind flow map over the project area. The wind flow map optimises the wind farm layout and helps determine monthly and annual energy production estimates. The key resulting values of these estimations are provided, including a description of the losses considered in the net energy calculation.

## 2. General Information

This section summarises general information about the site, the meteorological (met) mast installed and the measurement campaign.

### 2.1 Site Description

#### 2.1.1 Site Overview

The community of Makkovik is located in an inlet on the Labrador east coast, approximately 200 km Northeast of Goose Bay. The surroundings of the community consists mainly of bare rock hills with an average elevation of 100 m above sea level.





**Figure 2-1: Typical Landscape at the Makkovik Area**

### 2.1.2 Mast Location

The location of met mast 2603 was chosen with agreement between Hatch and NLH. Hatch proceeded with the installation of the mast and followed industry standards [1].

Table 2-1 provides a description of the mast, including the exact coordinates and the elevation.

The location of the mast is shown on the map provided on next page.

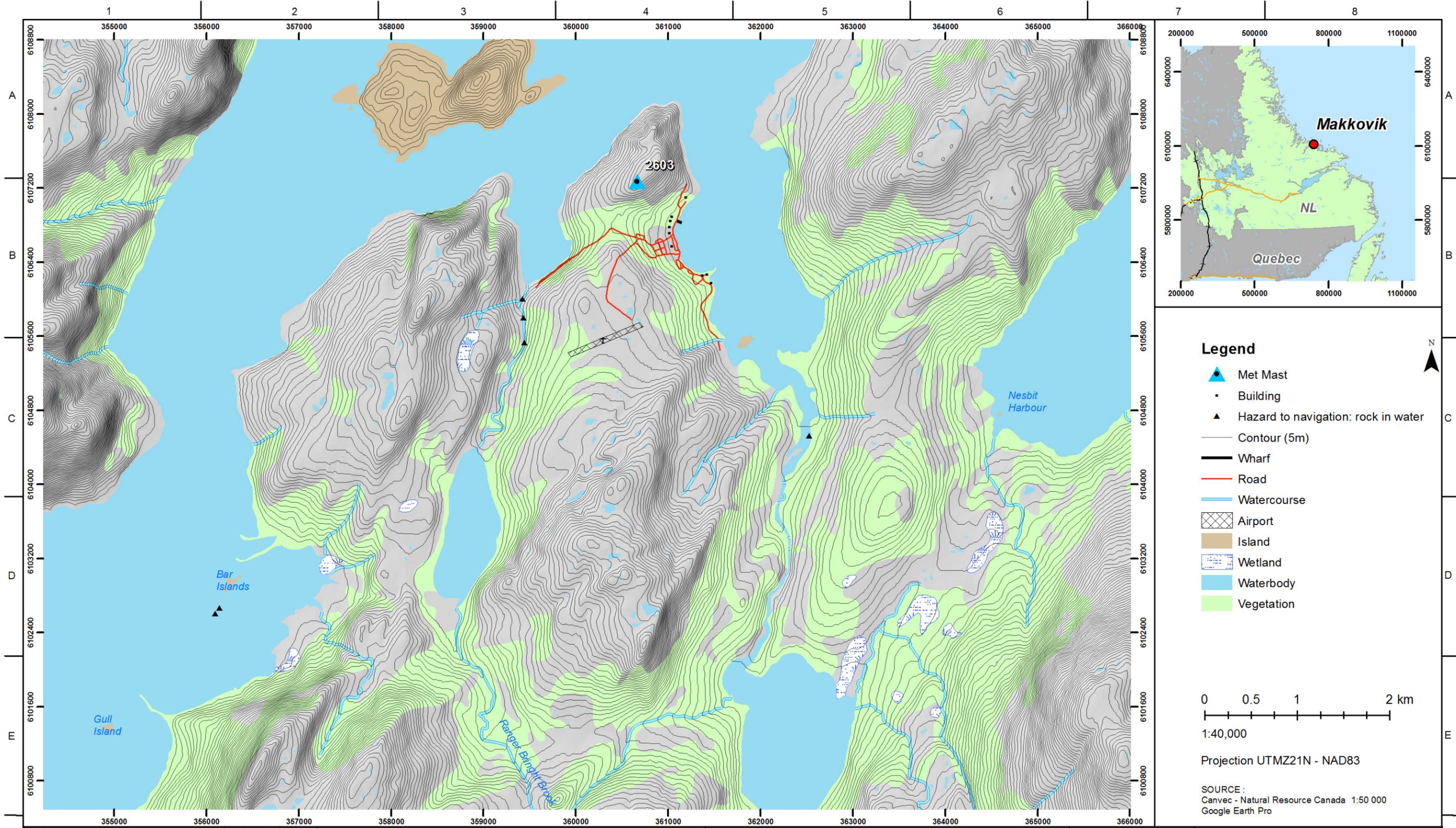
**Table 2-1: Met Mast Characteristics (Coordinate System: NAD83)**

ID	Type	Side Length (m)	Height (m)	Latitude	Longitude	Elevation (m)
2603	Square Lattice	0.404	36	N 55° 05' 33.3"	W 59° 11' 00.1"	81

The Makkovik met mast (#2603) is located north of the community on a rocky hill of approximately 100 m elevation. The site consists in smooth bed rock covered in moss.

Pictures have been provided in Appendix A with views in the four main geographical directions at the met mast.





NO.	DESCRIPTION	BY	CHKD	APP'D	DATE
REVISIONS					


<b>HATCH</b>		NALCOR
DESIGNED BY DANY AWAD DATE: July 06, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: July 06, 2015	<b>Makkovik - Overview Map</b>
CHECKED BY DANY AWAD DATE: July 06, 2015		DISCLAIMER Hatch will not be responsible for any claim, damage, financial or other loss of any kind whatsoever, direct or indirect, as a result of or arising from conclusions obtained or derived from the information contained or referred to in this document. No information, whether oral or written, obtained by you from Hatch shall create any warranty not expressly stated herein.
	SCALE BAR	REV 2

## 2.2 Measurement Campaigns

The mast characteristics, instrumentation, installation dates and periods of data collection are provided in this section.

### 2.2.1 Installation and Collection Dates

The following table provides the date of mast installation and the period of data collection used in the analysis.

**Table 2-2: Installation Date and Period of Relevant Data Collection**

ID	Installation date	Date and time of first data used	Date and time of last data used
2603	October 25, 2013	November 1, 2013, 00:00 AM	October 31, 2014, 11:50 PM

### 2.2.2 Instrumentation

#### 2.2.2.1 Sensors Mounting

The met mast was equipped with anemometers and wind vanes mounted on booms at several heights. The dimensions of the booms, their heights and orientations on the mast, were designed to comply with the best practices in wind resource assessment as specified in [1] and [2].

For the met mast, the instrument and installation parameters are provided in the table below. All instruments and met mast underwent regular maintenance checks.

Heated anemometers and wind vanes were installed to increase the data recovery rate during icing periods. An Autonomous Power System (A.P.S.) developed by Hatch was installed to power supply the heating instruments. The A.P.S. consists of a set of batteries charged by a small wind turbine through a controller.

**Table 2-3: Installation Parameters of Instruments at the met Mast**

Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
<b>Mast 2603</b>							
<b>Data Acquisition System</b>							
N/A	N/A	N/A	NRG Symphonie PLUS3	Oct 25, 2013	July 24, 2015	N/A	N/A
<b>Anemometers</b>							
#1	A1	35.0	NRG #40C	Oct 25, 2013	July 24, 2015	Yes / No	P
#2	A2	35.0	NRG Icefree III	Oct 25, 2013	July 24, 2015	Yes / Yes	R
#3	A3	26.0	NRG #40C	Oct 25, 2013	July 24, 2015	Yes / No	P



Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
#4	A5	26.0	RMYoung 5103-AP	Oct 25, 2013	July 24, 2015	Yes / No	R
#13	A4	17.0	NRG #40C	Oct 25, 2013	July 24, 2015	Yes / No	P
<b>Wind Vanes</b>							
<b>#7</b>	<b>V1</b>	<b>33.0</b>	<b>NRG Icefree III</b>	<b>Oct 25, 2013</b>	<b>July 24, 2015</b>	<b>No / Yes</b>	<b>P</b>
#8	V2	26.0	RMYoung 5103-AP	Oct 25, 2013	July 24, 2015	No / No	R
#9	V3	15.0	NRG #200P	Oct 25, 2013	July 24, 2015	No / No	R
<b>Temperature Sensor</b>							
#10	T	34.0	NRG #110S	Oct 25, 2013	July 24, 2015	No / No	P

*Note: Lines in bold font correspond to the anemometer and wind vane considered as the principal instruments for wind characterisation at the mast location.*

#### 2.2.2.2 Data Acquisition System

For met mast 2603, the instruments were connected to a data acquisition system which stored the data on a memory card. The data were then sent to Hatch computer network by a satellite communication system every 3 days.



### 3. Meteorological Data Analysis

This section presents a comprehensive analysis of the data collected. In the first section, the quality of the data is reviewed. The characteristics of the wind measured at the mast are then presented in Section 3.2 through a number of relevant parameters:

- monthly and annual average wind speeds;
- wind speed distribution;
- wind direction distribution;
- wind shear;
- turbulence intensity;
- 50-year recurrence wind speed.

In the final section, other climatic information such as measured temperature, calculated air density, wind power density and icing events is presented and discussed.

#### 3.1 Quality Control

The quality and completeness of the data are key factors that determine the reliability of the wind resource assessment.

Data are collected periodically from the met masts and the quality of the data is analysed. This is done by applying a variety of logical and statistical tests, observing the concurrent readings from different instruments and relating these observations to the physical conditions at the site (e.g. wind shading, freezing potential, etc.). The process is semi-automated: the tests are implemented in a computer program developed by Hatch, but the expertise of quality analysts are required to accept, reject or replace data. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, data logger malfunction, damaged mounting hardware, sensor calibration drift, icing events and different causes of shading (e.g. shading from the mast or from any obstacles at the site). A list of the possible error categories used during quality control is presented in Table 3-1. Data points that are deemed erroneous or unreliable are replaced by redundant data when available, or removed from the dataset.

The data recovery rate for the analysis period is then calculated for each of the instruments using the following equation:

$$\text{Data recovery rate (\%)} = \frac{\text{Number of valid observations}}{\text{Number of potential observations}} * 100$$

The “Number of valid observations” is evaluated once erroneous or unreliable data are replaced with available redundant data. The “Number of potential observations” is the theoretical maximum number of measurements that could be recorded during the analysis period. A high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.



**Table 3-1: Quality Control Table**

Error Categories
Unknown event
Icing or wet snow event
Static voltage discharge
Wind shading from tower
Wind shading from building
Wind vane deadband
Operator error
Equipment malfunction
Equipment service
Missing data (no value possible)

### 3.1.1 **Data Replacement Policy**

Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements. Replacements were done directly or by using a linear regression equation. Direct replacement is applied to anemometers when the replaced and replacing instruments are of the same model, calibrated, at the same height, and well correlated. Direct replacement is also applied to wind vanes as long as they are well correlated.

A relatively small percentage of the dataset (3%) is replaced by equivalent instruments and it is considered to have a negligible impact on the uncertainty of the measurements.

### 3.1.2 **Recovery Rates**

The following table presents the recovery rates calculated for each instrument after quality control and after replacements have been completed according to the replacement policy.

**Table 3-2: Instruments Data Recovery Rates**

Mast ID	A1	A3	A4	V1	T
2603	93.8%	99.3%	93.5%	98.0%	100.0%

Note that the recovery rates for the following instruments are identical, given the replacement policy:

- A1 and A2; A3 and A5
- V1, V2 and V3

### 3.1.3 **Data History**

The data recovery rates exceed industry standards [5]. A number of data were affected for short periods of time by usual effects, such as shading effect and short period of icing



events, and were removed. Other events resulted in data removal; these included the following:

- A2 became out of order as of January 2014;
- The temperature sensor was damaged after a high wind event on November 08, 2014, resulting in a data loss.

### 3.2 Wind Characteristics

#### 3.2.1 Annual and Monthly Wind Speed

The monthly wind speeds measured at each anemometer are shown in the following figures for mast 2603. The data are presented in two formats (see Figure 3-1 and Figure 3-2):

- for all instruments, the averaged monthly wind speed measured;
- for A1, all monthly wind speeds also reported.

Although the results for anemometers A2 and A5 are presented, they will not be considered in further calculations as these sensors were used primarily for quality control and replacement purposes.

As expected, the data confirm that wind speeds increase with height above ground level (see section 3.2.4 for a description of wind shear). Furthermore, the graphs show the seasonal pattern of wind, which decreases towards summer months and increases towards winter months.

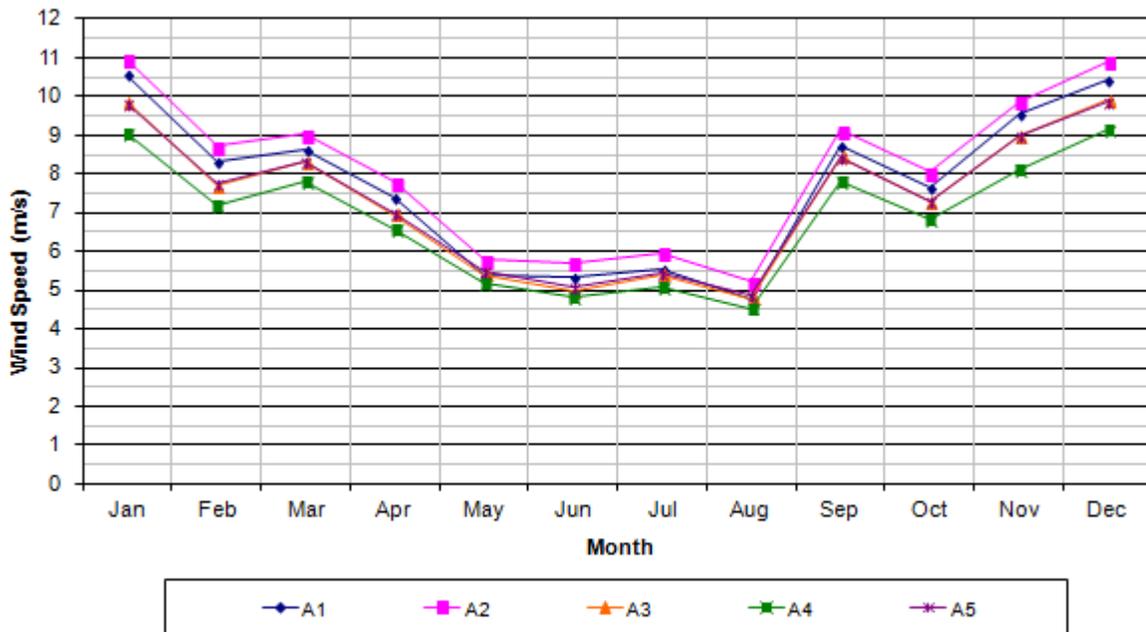
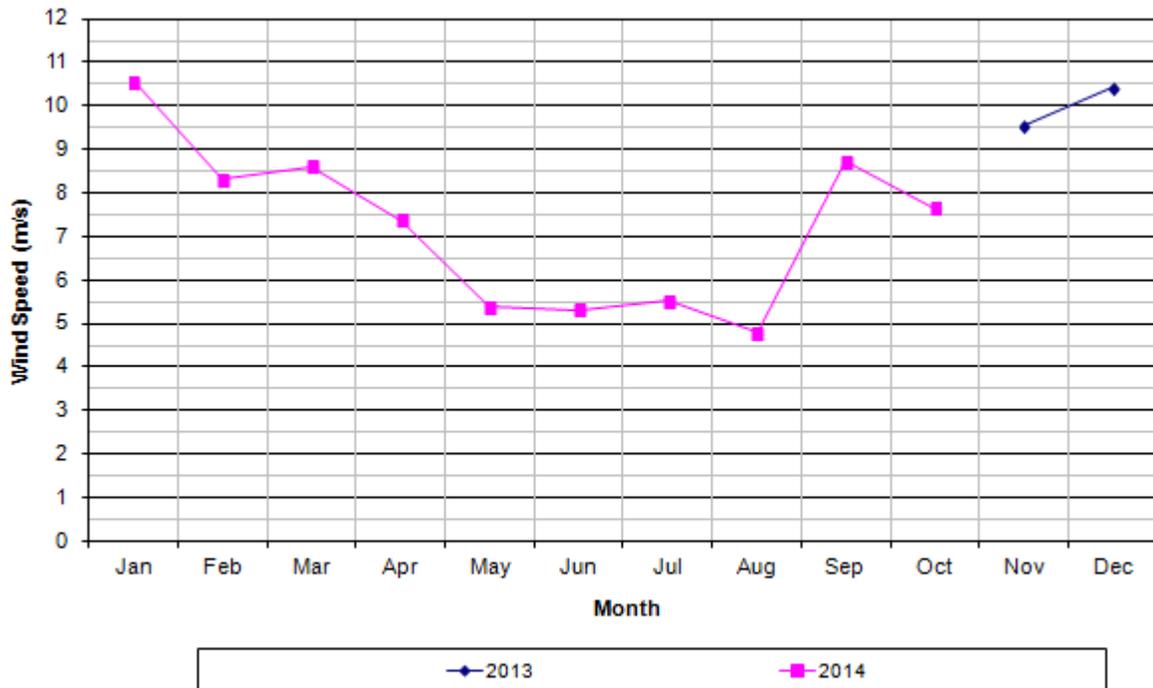


Figure 3-1: Averaged Monthly Wind Speeds for Each Anemometer at Mast 2603, November 1, 2013 to October 31, 2014



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**Figure 3-2: Monthly Wind Speeds Measured at the Top Anemometer at Mast 2603, November 1, 2013 to October 31, 2014**

The following table provides, the average wind speed and the maximum 1-second gust observed, and specifies the averaging method used and the period of data considered. The averaging method varies as it depends upon the available dataset:

- Annual: average of the wind speed recorded over one or more full years.
- Annualised: the annualised wind speed is a weighted wind speed that is calculated from all available monthly average wind speeds—e.g. if 2 values are available for January and only one is available for February, the February value will have twice the weight of each January value in the final average.
- Average: due to insufficient data collection, the annual average wind speed was not calculated. The value given is the average of all available data.

**Table 3-3: Wind Speed Characteristics at the Mast**

Mast	Top Anemometer Height (m)	Period	Average Wind Speed (m/s)	Maximum 1-second gust (m/s)	Method
2603	35.0	November 1, 2013 to October 31, 2014	7.7	42.0	Annual



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### 3.2.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds helps to evaluate how much power is contained in the wind (power is proportional to the cube of the wind speed). Wind turbines will produce more power as the wind speed increases (until reaching the “rated” value). Thus, as the frequency of higher wind speeds increases, more power can be produced.

Annual frequency distributions generally exhibit a Weibull shape that is controlled by its “scale factor” (closely linked to the average wind speed) and its shape factor.

The wind speed frequency distribution graph is presented below for the mast<sup>1</sup>.

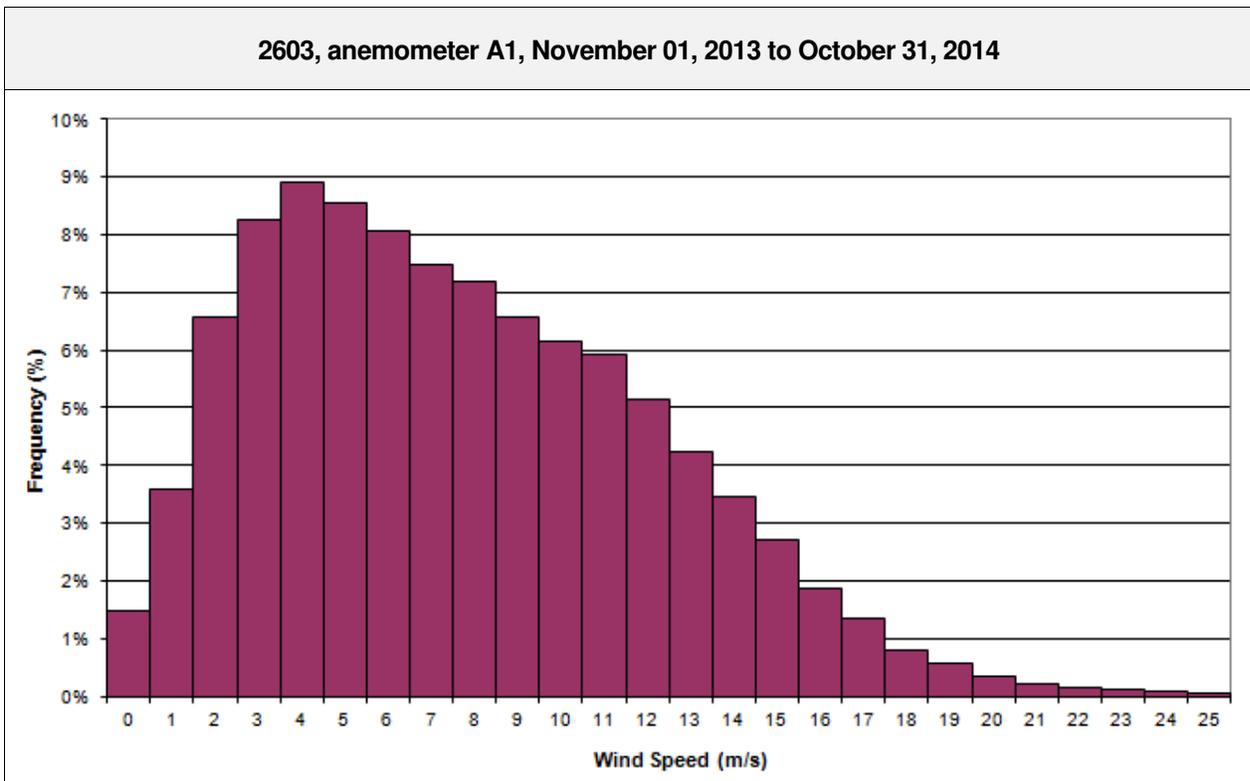


Figure 3-3: Wind Speed Frequency Distribution Graph

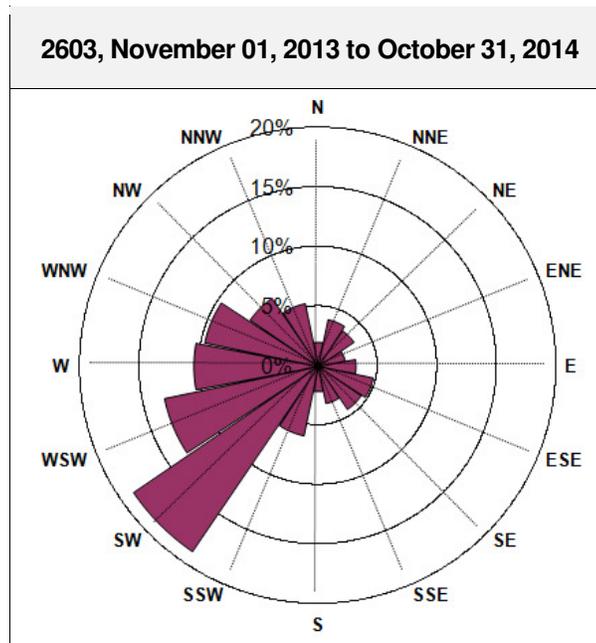
### 3.2.3 Wind Rose

The wind rose graph is presented below. The wind rose is divided into the conventional 16 compass sectors (22.5° wide sectors). Note that all compass orientations referenced in this report are based on the true geographic north, rather than the magnetic north.

<sup>1</sup> The 0 m/s wind speed bin indicates the fraction of the total number of measurements with a wind speed between 0 to 0.5 m/s. The other bins are 1 m/s wide and centered on the integer value (e.g.: the 1 m/s wind speed bin indicates the fraction with a wind speed between 0.5 to 1.5 m/s).



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**Figure 3-4: Wind Rose Graph**

The wind rose indicates that a significant proportion of the wind blows from southwest and west-southwest, across the project area.

Note that wind roses are not adjusted to the long-term. Moreover, differences in wind directions between the levels of measurement are small enough to be neglected. As a consequence, the present wind rose will be considered as representative of the long-term wind rose at hub height.

### 3.2.4 Wind Shear

Wind speeds typically increase with height above the ground, because the frictional drag decreases with altitude. The increase in wind speed with height is referred to as wind shear and is commonly modeled either by a logarithmic law or by a power law.

When the power law is used, the wind shear can be quantified by a wind shear exponent. “Rough” surfaces, such as forested lands and urban areas, have a more pronounced frictional drag than “smooth” surfaces, such as a snow covered field or grasslands—the former will be associated with higher wind shear exponents. Over a smooth, level, grass-covered terrain, the wind shear exponent is typically around 0.14; over snow or calm sea it may be as low as 0.10; and over urban areas or tall buildings it may be as high as 0.40.

The roughness is not the only surface property that has a direct effect on the wind shear. When there is dense vegetation, the vertical wind speed profile is displaced vertically above the canopy, thereby displacing the level of zero wind speed to a certain fraction of the vegetation height above the ground. The “displacement height” is defined as the height at which the zero wind speed level is displaced above the ground. The displacement height is taken into account in all wind shear estimations.



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Finally, large topographic variations over short distances may also impact the wind vertical profile and thus affect the wind shear.

Hatch recommends using the log law to estimate the wind shear at mast locations. Internal studies have shown that the accuracy of the wind shear estimate is slightly improved with the log law when compared to the power law. When available, three wind speed measurements, each at a different height, are used and a log law curve is fitted through the average wind speeds at these heights. With the log law, the parameter that reflects roughness is called the roughness length, instead of the wind shear exponent. However, an equivalent wind shear exponent is calculated between the top anemometer height on a mast and the hub height for easier interpretation.

The equivalent wind shear exponent presented in this report was calculated between the top anemometer height of the mast and hub heights of 37.0 m and 40.0m. The calculation was based on the measured wind speed at the anemometer height and the wind speed extrapolated to hub height by the log law method. The log law parameters were determined by fitting a logarithmic curve through the average measured wind speeds at the three measurement heights.

The average equivalent wind shear exponent is reported in the following table.

Based on our knowledge about the vegetation in the area of the mast, this value conforms to expected results.

**Table 3-4: Average Wind Shear at the Mast**

Mast	Period	Wind Shear
2603	November 01, 2013 to October 31, 2014	0.12

### 3.2.5 *Turbulence Intensity*

Turbulence characterises the gustiness of wind or high frequency changes in wind speed and direction (high turbulence is typical of very irregular wind flows, contaminated by whirls or vortices). Turbulence increases in areas with very uneven terrain and behind obstacles, such as buildings. In wind farms, it interferes with the effective operation of the wind turbines and increases their wear and tear.

The measurement of turbulence is expressed in terms of turbulence intensity, which is the standard deviation of the wind speed divided by the mean wind speed, over a given period. Turbulence intensity is expressed as a percentage. In the present study, the standard deviation and mean speed values are calculated from 1 second wind speed data averaged over a 10 minute period.

Turbulence intensity is more erratic and more difficult to quantify at low wind speeds. As a consequence, only wind speeds in excess of 4 m/s are used to calculate of the turbulence intensity. This threshold is consistent with IEC standards for wind turbine power performance measurements [4].

The turbulence intensity value was calculated with the top anemometer data.



The average turbulence intensity is reported in the next table. This value is considered moderate according to the reference values defined in reference [2]<sup>2</sup>. It is expected that turbulence will decrease with height, as the effect of obstacles and surface roughness will diminish.

**Table 3-5: Average Turbulence Intensity at the Mast**

Mast	Anemometer used	Period	Turbulence Intensity (%)
2603	A1	November 01, 2013 to October 31, 2014	12.0

### 3.2.6 50-year recurrence wind speed

The selected wind turbines Northern power 100 (NPS100) and Emergya Wind Technologies 900 kW (EWT900) are designed to survive a certain level of loading caused by an extreme wind event. Based on the specification provided by the manufacturers, the extreme survival wind speed at hub height is 59.5 m/s (see Appendix B).

At least 7 years of data at the met mast location or a nearby reference station are required. The Gumbel distribution was used to predict the once-in-fifty-year extreme wind speed. The data were extrapolated to hub heights of 37 m (NPS100) and 40 m (EWT900) with a power law exponent of 0.11 suggested for gusts as per Wind Energy Handbook [2] and IEC 61400-1 standard.

In the case of Makkovik project, the met mast has only 18 months of data. Thus, data from Hopedale (AUT) Environment Canada station were used and based on hourly data at 10 metres height. The data cover the period from 2005 to 2014. The 50-year recurrence maximum wind speeds were estimated to be 48.3 m/s at 37 m and 48.7 m/s at 40 m which respect the turbines' specifications.

## 3.3 Other Climatic Data

### 3.3.1 Temperature

Temperature was measured at a height of 34 m. The following table presents the average monthly and annual temperature measured. The coldest 10-minute temperature recording measured during the data collection period was -32.4°C in the morning of January 2, 2014.

**Table 3-6: Average Monthly and Annual Temperatures**

Mast ID	Monthly Air Temperature (°C)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2603	-15.6	-16.8	-14.3	-4.5	1.0	8.9	13.0	14.1	7.2	4.7	-3.5	-16.8	-1.8

<sup>2</sup> Low levels of turbulence intensity are defined as values less than or equal to 0.10, moderate levels are between 0.10 and 0.25, and high levels are greater than 0.25. This classification is for meteorological turbulence only; it should not be used in comparison with IEC models. Meteorological turbulence should not be used to establish the wind turbine class.



### 3.3.2 Air Density

Wind energy is directly proportional to the air density. Consequently, the amount of energy produced by a wind turbine will also be directly proportional to the air density at the turbine location. Air density decreases with increasing temperature, decreasing pressure and increasing altitude.

Based on the measured temperatures and the standard barometric pressure of 101.3 kPa at sea level, the monthly average air densities were calculated. Note that to correct for changes in atmospheric pressure with height, the calculations account for the site elevation. The values were calculated over the entire analysis period reported in Table 2-2.

**Table 3-7: Monthly and Annual Average Air Density**

Mast ID	Monthly Air Density (kg/m <sup>3</sup> )												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2603	1.35	1.36	1.34	1.30	1.27	1.23	1.22	1.21	1.24	1.25	1.29	1.36	1.31

### 3.3.3 Power density

Wind speed, wind direction and air density data can be combined to provide information about the average power density at mast location. Wind power density indicates how much energy is available at a given instant for conversion by a wind turbine<sup>3</sup>. For example, strong winds in the winter, when the air is colder and denser, will have a higher power density (i.e. carry more energy) than the same strong winds in the summer. Though power is an instantaneous value, it is calculated as an average over a given period of time.

Tables of the power density distribution per direction and per month were produced at the top anemometer height and are presented below.

At mast 2603, the most powerful winds come from west-southwest to northwest, and appear in winter months. The annual average power density is 637 W/m<sup>2</sup> at 35 m.

**Table 3-8: Table of Wind Power Density per Direction, November 1, 2013 to October 31, 2014**

Wind Power Density per Direction (W/m <sup>2</sup> )															
N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
417	299	260	397	470	695	354	199	148	287	656	954	886	626	937	585

**Table 3-9: Table of Wind Power Density per Month, November 1, 2013 to October 31, 2014**

Wind Power Density per Month (W/m <sup>2</sup> )													Annual Average
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1339	735	905	610	212	177	249	178	751	547	1011	1106	637	

<sup>3</sup> Note that the units "W/m<sup>2</sup>" refer to m<sup>2</sup> of rotor swept area.



### 3.3.4 Icing Events

Icing affects the operation of wind turbines. Icing on any exposed part of the turbine can occur in the form of wet snow (generally associated with temperatures between 0°C to 1°C), super-cooled rain or drizzle (that can occur at temperatures between 0°C to -8°C, but mostly in the upper part of this range), or in-cloud icing (that can occur below - 2°C). Losses during production due to ice occur in several ways:

- Ice accumulation on the blades alters their aerodynamic profile, reducing the power output.
- Nacelle-mounted instruments accumulate ice and give inaccurate readings. The turbine control system may detect a fault condition due to the turbine output being much greater than expected. This expectation is based on the wind speed. As a result, the turbine will be shut down until the ice is removed from the instruments and the turbine is reset.
- Asymmetric icing causes mass or aerodynamic imbalance leading to vibrations. Control systems that sense vibrations will normally shut down when these vibrations occur.

Icing is a complex phenomenon and predicting icing from meteorological conditions is notoriously difficult, requires a good set of observations from a number of meteorology variables, and can be misleading. As no reliable instrument is presently available to detect and quantify icing events for the purpose of estimating their impact on wind energy production, Hatch uses several tests during data quality control to detect icing events: detection of unusual standard deviations or changes with time of wind speeds and directions, comparison of measurements from a heated anemometer and a standard anemometer at the same level, in parallel with the measurement of temperature.

These tests cannot distinguish between the different types of icing, but a rough approximation can be done by utilising the temperature ranges measured during icing events. Therefore, in the following estimate, we will consider two categories: “glaze”, which is assumed to include wet snow, super-cooled rain and drizzle, and “rime ice”, which is assumed to include in-cloud icing and the very low temperature part of super-cooled rain or drizzle. The threshold of -5°C is used to differentiate between rime ice (below -5°C) and glaze (above -5°C).

The following table presents the estimated number of icing events in a month and the type of event assumed to occur in the project area. This estimate is based on the average of icing events detected on the mast during the measurement campaign.

**Table 3-10: Estimated Hours of Icing Events, October 25, 2013 to April 30, 2015**

	January	February	March	April	May	June	
<b>Hours</b>	6	11	2	52	11	0	
<b>Rime</b>	100%	100%	100%	20%	10%	-	
<b>Glaze</b>	0%	0%	0%	80%	90%	-	
	July	August	September	October	November	December	Annual Average
<b>Hours</b>	0	0	0	4	60	0	146
<b>Rime</b>	-	-	-	0%	10%	-	23%
<b>Glaze</b>	-	-	-	100%	90%	-	77%



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## 4. Long-term Wind Speed at Hub Height

The previous section presented the analysis of the wind regime as it was measured by the met mast installed on the project site. However, to forecast the energy production of a wind power plant, wind data that represent the historical wind conditions at the site are required. Unfortunately, wind resource assessments are generally conducted for a limited number of years, often no more than one or two years, which is not sufficient to capture the year-to-year variability of wind. For example, in North America, the annual average wind speed exhibits a standard deviation of about 6% (or  $1\sigma$  from a normal distribution) of the long-term average wind speed. Hence, the maximum deviation from the average wind speeds could reach as much as 20% (or  $3.3\sigma$ ). Consequently, it is necessary to translate the measured short-term data into long-term data. This is done through a correlation/adjustment process that makes reference to a meteorological station where historical data are available.

Moreover, when the top anemometers of the met masts are mounted at a lower height than the expected hub height of the wind turbines, the long-term data must also be extrapolated from these anemometer heights to the wind turbine's hub height.

The long-term projection process is presented in the next section and is followed by the extrapolation to hub height.

### 4.1 Long-term Projection

When required, selecting a reference dataset to perform a long-term correlation and adjustment is determined by the following process:

- A quality assessment of the potential long-term reference stations for the site (history, similarity of the local climate with regards to the meteorology mast climate, etc.);
- A quality assessment of the correlation equations obtained with acceptable long-term reference stations and the measured data for the concurrent period;
- A comparison of the long-term correlation results obtained with all acceptable reference stations;
- A crosscheck of the resulting long-term adjustments with the measured data and the long-term trends at nearby reference stations or at a regional level;

Once the reference dataset is selected, it is used to adjust the met mast data to long-term conditions. This can be achieved either by synthesizing non existing years of data at the met mast site or by applying an adjustment factor to the measured data in order to better reflect the reference period. The process is as follows:

- The measured data from the met mast is correlated with the reference dataset;
- If the correlation parameters meet the synthesis criteria, then data are synthesized at the measurement mast for the complete reference data period; this method is referred to as the Measure-Correlate-Predict (MCP);
- If the criteria are not met but a good correlation can still be obtained with hourly or daily intervals, then the measured dataset is scaled up (or down) to long-term using the reference long-term average wind speed and the correlation equation obtained; this method is referred to as the Long-term Adjustment;
- If no correlation can be clearly established between a reference site and the met mast site, the measured data stay unchanged.



#### 4.1.1 Selection of reference dataset

The present section summarises the results of the analysis.

Among the possible set of reference stations, one station was selected and considered suitable for the long-term projection of the data at the met mast. This station is Hopedale monitored by Environment Canada (EC). The location of this station is given in the table below.

**Table 4-1: Identification of the Long-term Reference**

Name	ID	Instruments Height (m)	Latitude	Longitude	Elevation (m)
Hopedale (AUT)	8502400	10.0	N 55° 27' 00.0"	W 60° 13' 00.0"	11.9

#### 4.1.2 Long-term Adjustment

The long-term adjustment consists of:

- Correlating short term data at the met mast with short term data at the reference station;
- Using the obtained linear regression equation,  $Y = m X + b$ , where  $X$  represents the long-term average wind speed at the reference station and  $Y$  is the estimated long-term average at the met mast;
- Applying an adjustment factor (to speed up or scale down) to the met mast short term data in order to obtain an average wind speed equal to the estimated long-term average at met mast (i.e.  $Y$ ).

For mast 2603, which only displayed 18 months of data recorded, the long-term adjustment method was used for the long-term projection.

The wind speed data of the met mast were correlated to the concurrent wind speed data at the long-term reference station Hopedale. Good correlation results were obtained with daily average values ( $R^2$  greater than or equal to 0.7 is good correlation, above 0.85 is excellent). The results of the correlations are given in the following table. Linear regression equations were used to compare the data, where  $m$  is the slope of the equation,  $b$  is the intercept, and  $R^2$  is the coefficient of determination.

**Table 4-2: Correlations between Reference Station and met mast Wind Speeds**

Reference Station	Met Mast	Correlation Period		Daily Wind Speed Correlations		
		Beginning	End	$m$	$b$	$R^2$
EC Hopedale	2603	November 1, 2013	October 31, 2014	1.245	0.9	0.69

The regression equations were then used to estimate the long-term average wind speed at the mast as a function of the long-term wind speed at the reference station. The estimated



long-term average at the Hopedale station is 5.4 m/s. It was estimated by averaging all annual averages over the period 2005 to 2014 (except 2011 having a low recovery rate). The results are presented in the following table.

**Table 4-3: Long-term Adjustment factor at the met mast**

Met Mast	Wind Speed over Correlation Period (m/s)	Long-term Annual Wind Speed (m/s)	Adjustment Factor (%)
2603	7.7	7.6	-1.9%

Finally, the 10-minute measured data recorded at the met mast were scaled by the adjustment factor to reflect the long-term value. In terms of the wind direction data, the one-year dataset for the met mast remained untouched. As a result, the mast has a set of wind speeds and wind directions that are the best estimate of the long-term wind regime.

## 4.2 Extrapolation to Hub Height

The wind shear exponent, calculated with the measured data, was used to adjust the dataset to hub heights. The results are presented in the following table.

**Table 4-4: Estimated Long-term Wind Speed at Hub Heights\***

Met Mast	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2603	7.6	7.6	7.7

\* Estimated using the calculated wind shear



## 5. Wind Resource Mapping and Projected Energy Production

Met masts provide a local estimate of the wind resource. Met mast locations are chosen based on how representative they are of the project site and in particular for potential wind turbine locations. However, since the number of met masts is usually limited compared to the expected number of wind turbines, it is necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area.

Wind modeling software, such as MS-Micro and WAsP, are known to produce erroneous wind flows over complex terrain. In this case, Hatch applies a method based on the Ruggedness Index (RIX) to calculate the wind flow for each mast dataset while correcting errors on wind speed<sup>4</sup>. All produced wind flows are then merged by a distance-weighting process. When the RIX correction is not applicable, wind flows are calculated with each mast dataset and simply merged together by a distance-weighting process, without a RIX correction.

Once the wind flow map is built, it is possible to optimise the size and layout of the foreseen wind farm for the project, and then to calculate the projected energy production. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow (see section 3.2.4). These corrections result in an effective hub height for each wind turbine.

The wind flow and energy production are calculated with specialised software that require, apart from the met masts long-term data, background maps that contain the information on topography, elevation, roughness lengths (related to the land cover) and potential obstacles. This is also used in conjunction with the wind turbine characteristics. Finally, wind farm losses must be estimated in order to complete the energy estimate.

The first part of this section introduces the information and the methodology used to calculate the wind flow.

The next part will present the optimisation process and the results in terms of energy production.

The software used to map the wind resource and to calculate the energy production include:

- WAsP Issue 11.01.0016 from Risø for wind resource mapping;
- Wind Farmer Issue 4.2.2 from Garrad Hassan for layout optimisation and energy production calculations.

### 5.1 Background Data

#### 5.1.1 Topography and elevation

The topographic and elevation data come from files provided by the National Topographic Data Base (NTDB).

The contour line interval is 5 m within the project area and 20 m outside.

<sup>4</sup> Bowen, A.J. and N.G. Mortensen (2004). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.

### 5.1.2 *Roughness*

The base map for roughness lengths was determined from land cover information included in the NTDB files. This map was then checked and corrected using satellite imagery from Google Earth. Around mast location and wind turbines, pictures and information noted during site visits were also used to check and modify the land cover information. The spatial resolution considered for the roughness lengths is 30 m.

The following table details the roughness lengths used by land cover category.

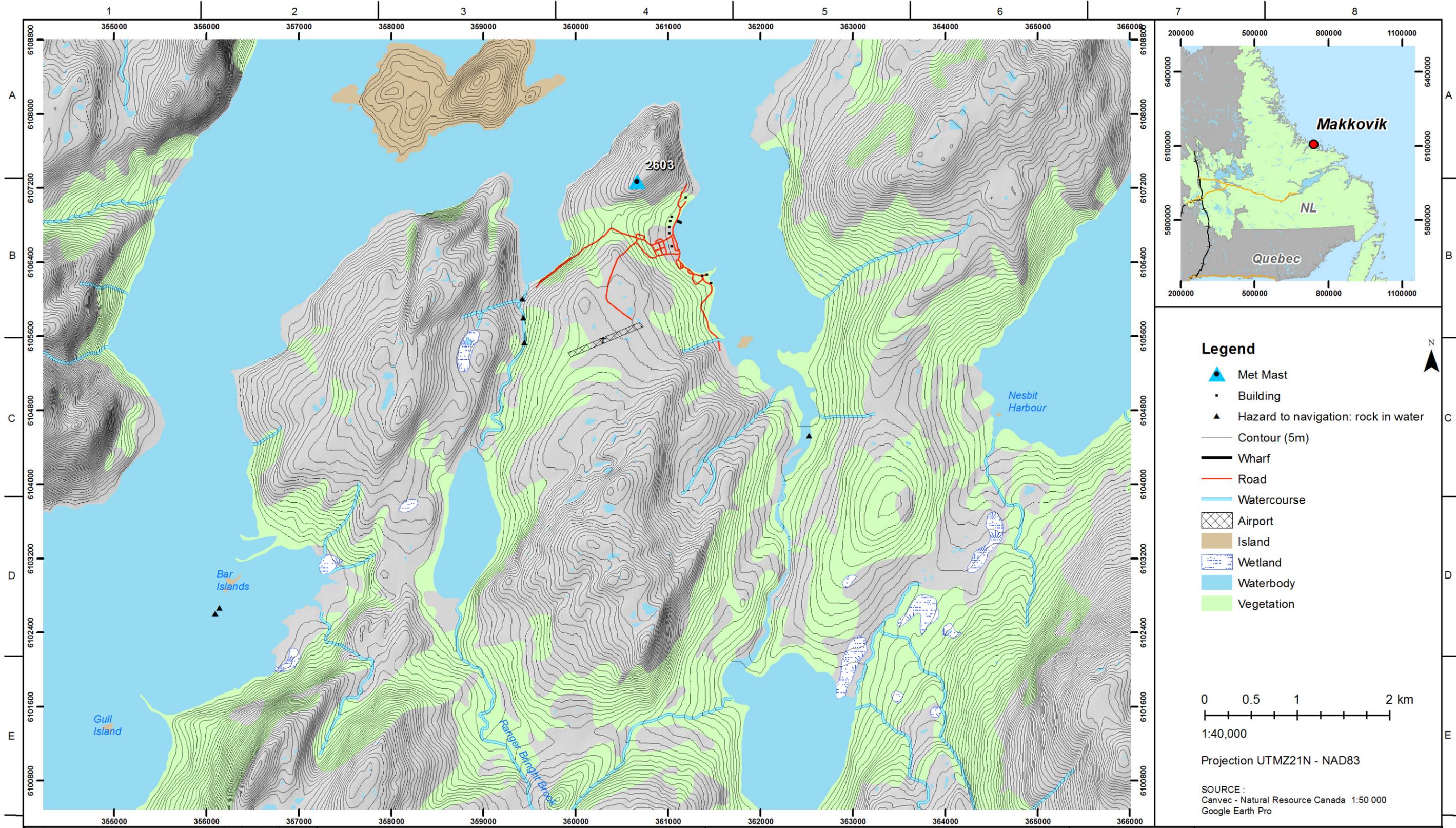
**Table 5-1: Roughness Lengths Categories**

Land Cover Type	Roughness Length (m)
Open farmland, high grass	0.04
Forest	0.5
Water	0
Building	0.5

### 5.1.3 *Background Map*

The background map, showing topography and contour lines is provided on the next page.





NO.	DESCRIPTION	BY	CHKD	APP'D	DATE
REVISIONS					

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DESIGNED BY DANY AWAD DATE: July 06, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: July 06, 2015
CHECKED BY DANY AWAD DATE: July 06, 2015	

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## Makkovik - Overview Map

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## 5.2 Wind Flow Calculation

### 5.2.1 *Terrain Complexity*

The wind flow is produced over semi-complex terrain. Wind modeling software, such as MS-Micro (used in Windfarm) and WAsP, are known to produce erroneous wind flows over complex terrain. Depending on the topography, predicted wind speeds can be over or underestimated at a given location. Errors can reach more than 20% in very complex areas.

In the present case, the complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 5.2.2 *Parameters*

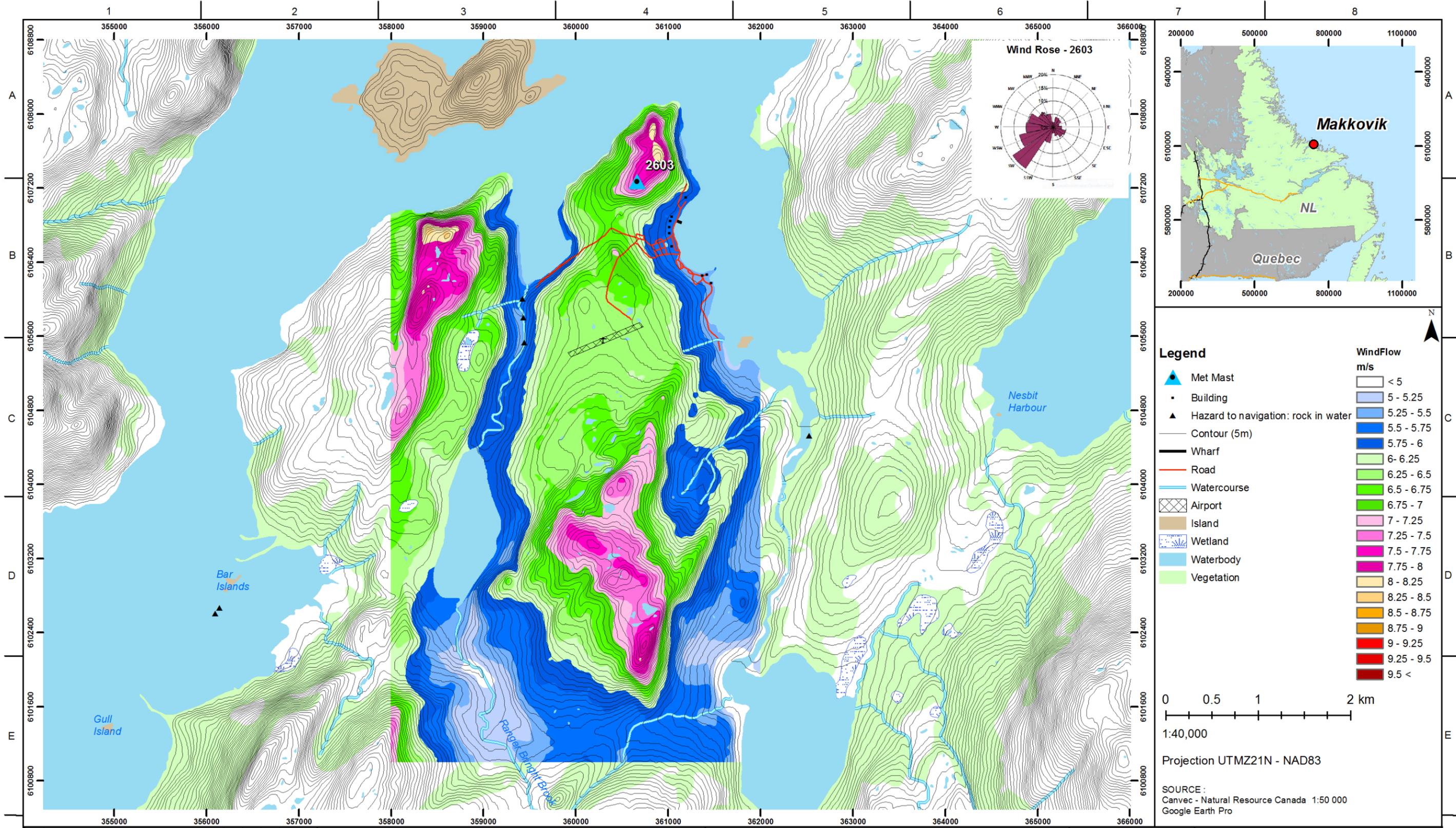
The following parameters were used to calculate the wind flow map.

**Table 5-2: Wind Flow Calculation Parameters**

Parameter	Value
<b>Wind Resource Grid Spatial Resolution</b>	50 m
<b>Calculation Area</b>	4 km by 7 km
<b>Reference Mast</b>	2603
<b>Reference Height</b>	Top Anemometer Height
<b>Calculation height</b>	37 m
<b>Vertical Extrapolation Method</b>	Based on measured wind shear
<b>Roughness Change Model</b>	WAsP Standard Model

### 5.2.3 *Results*

The wind flow map used for layout optimisation and energy production estimates is presented on the next page.



NO.	DESCRIPTION	BY	CHKD	APP'D	DATE
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Wind resource map created by Hatch with WASP 11.01.0016  
 Height of calculation: 37 m  
 Spatial resolution of wind resource grid: 50 m  
 Source file: Makkovik\_WF2\_2603\_GridWRG\_37m.asc  
 Source of data used to create the wind flow:  
 Topographic data are provided by the Center for Topographic Information (NRCan).  
 Meteorological data were collected from mast 2603, located 2.5 km on average from  
 the center of the map, between 01/11/2013 and 31/10/2014. Data were controlled by  
 Hatch. Met data were adjusted for long term with reference to station Environment  
 Canada Hopedale (AUT) # 8502400 (reference period 2005-2014).  
 It is believed that the present map gives a reliable overall picture of the wind resource.  
 However, it is advised to confirm any information obtained from this map at any location  
 by on-site measurements.

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DESIGNED BY DANY AWAD DATE: July 06, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: July 06, 2015
CHECKED BY DANY AWAD DATE: July 06, 2015	

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## Makkovik - Windflow 2

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SCALE: BAR      REV: 2

Projection UTMZ21N - NAD83

SOURCE:  
Canvec - Natural Resource Canada 1:50 000  
Google Earth Pro

### 5.3 Forecasting Energy Production

The layout was initially designed in order to maximise energy production. Turbines were spread out inside the project boundaries to minimise wake effects. The preliminary environmental screening and turbine extreme operating conditions also contributed to set the turbine locations.

#### 5.3.1 Preliminary Turbine Selection

A preliminary turbine selection was performed using Windographer software by comparing the performance of different turbines at the location of the met mast, where the dataset was recorded. The main parameters used for the comparison were the capacity factor of the wind turbine for the site specific conditions as well as the turbine purchase cost. Only turbines that meet the following criteria were considered:

- Site's turbine and turbulence class (IEC class II)
- Extreme wind and weather conditions (operation down to -40°C) The minimum 10-minute temperature recording of -32.4°C during the monitoring campaign confirms the site conditions are within the operating range of the turbine.
- Turbine capacity ranges from 100 kW to 1,000 kW to meet the community load
- Wind turbine's dimensions and weight versus crane capacity and accessibility

Hub heights of about 40 m to 50 m were used for this preliminary analysis.

Standard losses considered include: 12.5% technical losses and 2% wake losses.

The following table provides a summary of the turbine comparison.

**Table 5-3: Windographer Results at the Mast Location**

Turbine type	Turbine Class	Hub height (m)	Turbine Capacity (kW)	Mean Energy Output (MWh/yr)	Capacity Factor (%)	Turbine purchase cost (\$)
Northern Power NPS100 Arctic	IIA	37	100	296	33.8	325,000
Aeronautica AW/Siva29-250	IIA/IIIA	37	250	668	30.5	656,000
Aeronautica AW/Siva47-500	IB/IIA	47	500	1,671	38.2	1,632,000
EWT DW52-250 (EWT250)	IIA	37	250	1,124	51.3	1,980,000
EWT DW52-500 (EWT500)	IIA	37	500	1,857	42.4	1,990,000
EWT DW52-900 (EWT900)	IIA	40	900	2,566	32.5	2,000,000

The capacity factors listed above in table 5-3 are taken from Windographer and may change as a function of the site's optimized layout and should only be used for turbine comparison.

Due the lack of proven experience in remote arctic conditions, the Aeronautica wind turbine models were discarded from the analysis. Northern Power and EWT wind turbines have



been installed and are operating in similar site conditions in Nome, Alaska for EWT or in Kasigluk, Alaska for Northern Power and were thus further compared as part of the analysis.

The average community load at Makkovik during the project lifetime is around 500 kW. The following table shows the results of the WindFarmer optimization models using the required number of turbines to meet that load. The turbines were ranked based on their capacity factor, energy output and simple payback.

**Table 5-4: Preliminary Turbine Selection Results**

Turbine type	Number of wind turbine required	Total Capacity (kW)	Gross Energy Output (MWh/yr)	Gross Capacity Factor (%)	Total purchase cost (Million \$)	Ranking
<b>Northern Power NPS100 Arctic</b>	<b>5</b>	<b>500</b>	<b>2,000</b>	<b>45.6</b>	<b>1.625</b>	<b>2</b>
EWT250	2	500	2,957	67.5	3.960	4
EWT500	1	500	2,519	57.5	1.990	3
<b>EWT900</b>	<b>1</b>	<b>900</b>	<b>3,610</b>	<b>45.8</b>	<b>2.000</b>	<b>1</b>

\* Based on the gross energy output at 30 cents/kWh and the turbine purchase cost only.

Based on information provided by EWT, the 250 kW wind turbine has the same foundation design as the 500 kW and 900 kW machines and nearly the same price (\$10,000 difference). Because of the similar turbine costs of the three EWT models, from a financial point of view, the EWT900 becomes the most suitable having the lowest simple payback, and would also benefit from potential lower constructability and BOP cost.

The Northern power NPS100 Arctic can also be considered as potential candidates for the Makkovik project since it is a proven turbine in arctic conditions, and would provide for more redundancy due to number of turbines. The NPS100 has the advantage of being a smaller turbine and would be less difficult from a logistic and crane accessibility stand point.

The NPS100 and EWT900 turbines are two models that meet the wind class of the site and have proven technology for cold and icy environments.

Even though a more detailed turbine selection exercise will be required in later phase of the project, the NPS100 and EWT900 are considered suitable candidate turbines in order to complete the preliminary energy estimates for the potential Makkovik project.

### 5.3.2 *Layout Optimization*

The following section shows the WindFarmer modeling results which further refines the energy estimates for the turbines selected at the potential turbine positions and to confirm the capacity factor values. The table below outlines the parameters and constraints assumed to influence optimisation.



**Table 5-5: Layout Optimisation Parameters and Constraints**

Parameter / Constraint	Value	
<b>Annual Air Density</b>	1.31 kg.m <sup>-3</sup> at 115 m.a.s.l.	
<b>Turbulence Intensity</b>	12.0% at mast 2603 <i>Note: average value for information, the turbulence intensity is actually entered by wind-speed bins and by direction for energy prediction calculation</i>	
<b>Exclusion areas</b>	Due to the lack of information in regard to setbacks for wind energy projects in Newfoundland and Labrador, general restriction rules were used: - 500 m from habitations - 100 m from public roads - 50 m from lakes and rivers - 2 km by 1 km buffer zone from the airport track	
<b>WTG Minimum Separation Distance</b>	Elliptical separation: Minimum of 6 rotor diameters on long axis Minimum of 3 rotor diameters on short axis Bearing of long axis: 225 degrees	
<b>WTG Model</b>	EWT900	NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>WTG Power Curve</b>	See Appendix B	
<b>WTG Thrust Curve</b>	See Appendix B	
<b>Number of WTG's</b>	1	5
<b>Wind Farm Capacity (kW)</b>	900	500
<b>Wake Model</b>	Modified Park Model used for optimisation and Eddy Viscosity Model for final energy calculation as recommended by Garrad Hassan	
<b>Maximum Slope</b>	10 degrees	
<b>Optimization Strategy</b>	Layout designed in order to maximise energy production.	

The project layouts are presented at the end of this section.

The layouts are still considered preliminary. Land restrictions, communication corridors, noise and visual impacts, and other site-specific matters need to be evaluated through a detailed environmental assessment. Available land, road and collection system costs are also issues that will need to be addressed before the site layout can be finalized.



### 5.3.3 Energy production

Once the optimised layout has been produced, the energy production for each wind turbine is calculated. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow. These corrections result in an effective hub height for each wind turbine.

The calculation was executed with the power curves and thrust curves used for the optimisation and presented in Appendix B. The additional losses are described in the next section.

Note that air density is corrected by the software for each turbine location according to its elevation.

The following table is a summary of the estimated energy production. Detailed energy figures are presented per wind turbine on the next page.

**Table 5-6: Wind Farm Energy Production Summary**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
WTG Rotor Diameter (m)	51.5	20.7
WTG Hub Height (m)	40.0	37.0
Number of Wind Turbines	1	5
Wind Farm Capacity (kW)	900	500
Mean Free Wind Speed across Wind Farm (m/s)	8.4	8.1
Average Wake Losses (%)	0.0	1.1
Energy Production Before Additional Losses* (MWh/yr)	3,610	2,000
Capacity Factor Before Additional Losses* (%)	45.8	45.6
Additional Losses (%)	14.1	13.6
Net Energy Production (P50) (MWh/yr)	<b>3,102</b>	<b>1,728</b>
Net Capacity Factor (%)	<b>39.3</b>	<b>39.4</b>

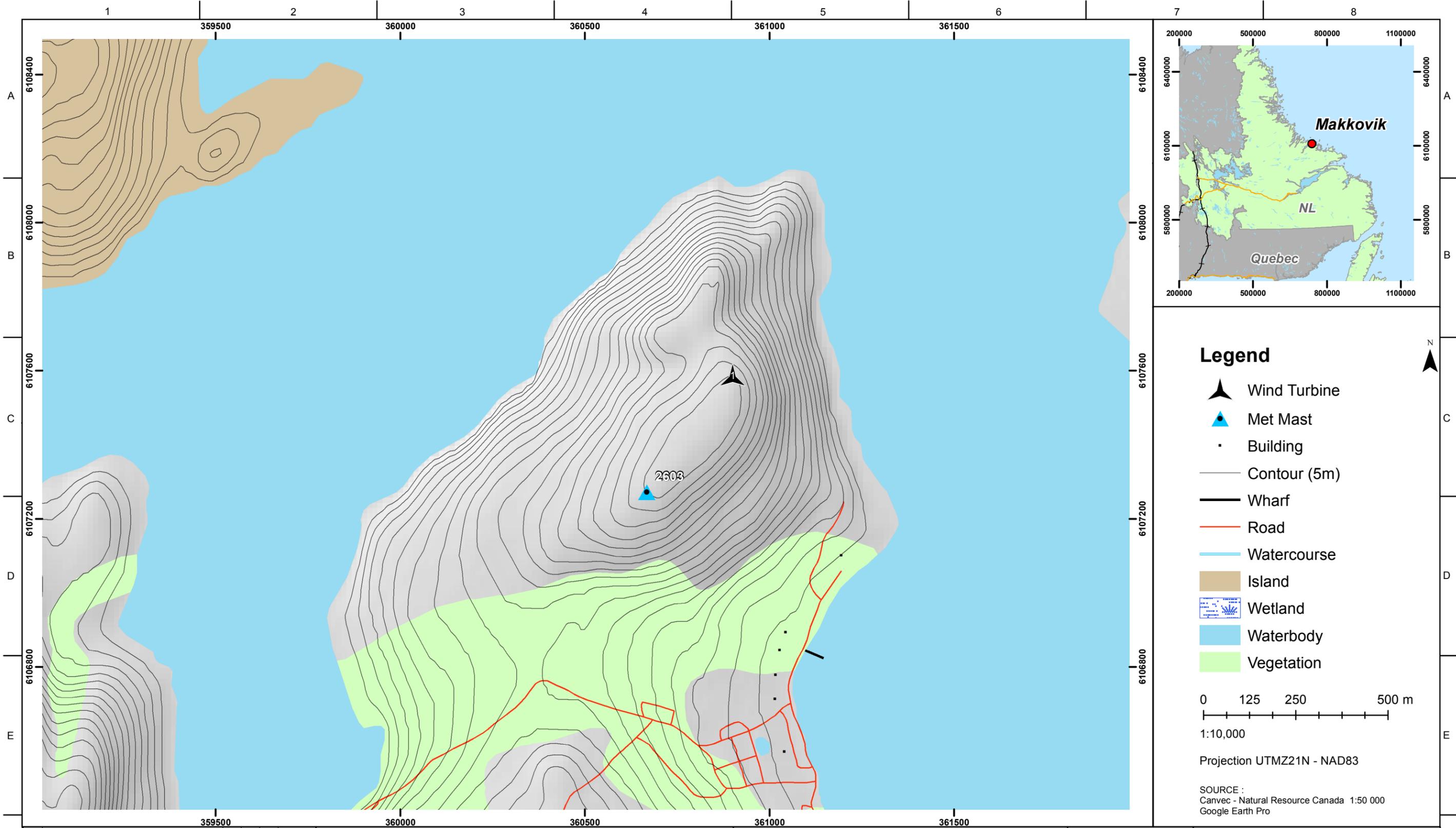
\* Includes topographic effect and wake losses

**Table 5-7: Forecasted Energy Production at Wind Turbines**

Turbine ID	Easting (m)	Northing (m)	Altitude (m)	Mean Free Wind Speed (m/s)	Gross Energy Production* (MWh / Year)	Wake Losses (%)	Gross Energy - Wake* (MWh / Year)	Turbulence Intensity** (%)
<b>Layout 1 - EWT900</b>								
1	360900	6107589	89	8.4	3,610	0.0	3,610	15.2
<b>Layout 2 - NPS100 Arctic</b>								
1	360901	6107480	89	8.1	403	0.6	400	15.9
2	360904	6107561	88	8.3	412	2.6	402	17.0
3	360859	6107604	85	8.2	408	1.8	400	16.8
4	360833	6107669	78	8.0	400	0.6	398	16.4
5	360818	6107763	75	8.1	400	0.1	400	15.8

\* Gross energy production includes topographic effect; "Gross energy – Wake" includes topographic effect and wake losses.

\*\* Turbulence Intensity includes ambient turbulence and incident turbulence. The values represent true meteorological turbulence; they should not be compared directly with IEC models and consequently should not be used to establish the wind turbine class.



NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

Turbine model: EWT DW52-900  
 Number of turbines: 1  
 Site capacity: 900 KW  
 Turbine rated power: 900 KW  
 Hub height: 40 m  
 File reference: Makkovik\_WF2\_Lay3.txt

**HATCH**

DESIGNED BY DANY AWAD DATE: August 5, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 5, 2015
CHECKED BY DANY AWAD DATE: August 5, 2015	

NALCOR

## Makkovik - Layout 1

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### 5.3.4 Losses

This section provides a description of the estimated losses included in the P50 estimate. These losses include environmental, electrical, availability, turbine performance losses and wake effects. The P50 is defined as the exceedance probability that denotes the level of annual wind-driven electricity generation that is forecasted to be exceeded 50% of the year. Half of the year's output is expected to surpass this level, and the other half is predicted to fall below it. Loss estimates should be reviewed as more detailed information becomes available.

The losses considered are presented in the following table and described hereafter.

**Table 5-8: Wind Farm Losses**

Loss Category	Loss Type	Losses (%)			
		Layout 1 - EWT900		Layout 2 - NPS100 Arctic	
<b>Environmental</b>	Blade Soiling and Degradation	1.0		1.0	
	High Wind Hysteresis	0.2		0.2	
	Icing	2.8	<b>4.3</b>	2.6	<b>3.8</b>
	Lightning	0.0		0.0	
	Low Temperature Shutdown	0.4		0.0	
<b>Electrical</b>	Collection Network	1.3	<b>3.7</b>	1.3	<b>2.2</b>
	Auxiliary power	2.4		0.9	
<b>Availability</b>	Wind Turbine Availability	5.0		6.5	
	Collection Network Outage	0.6	<b>5.8</b>	0.7	<b>7.3</b>
	Grid Availability	0.2		0.2	
<b>Turbine Performance</b>	Out-of-range Operation	1.0	<b>1.0</b>	1.0	<b>1.0</b>
<b>Wake effects</b>	Internal Wake Effects	0.0	<b>0.0</b>	1.1	<b>1.1</b>
	External Wake Effects	0.0		0.0	
<b>Total*</b>		<b>14.1</b>		<b>14.6</b>	

\* The total is the cumulated effect of the different losses and not their direct summation

**Blade soiling and Degradation** refers to the reduction of the blade's aerodynamic performance due to dust and/or insects. It also takes into account the future blade degradation attributed to wear of the blade's surface. The Makkovik project is not situated in a particularly dusty environment. This value is consistent with what is generally observed within the industry.



**High wind hysteresis** losses are caused by the control loop of the turbine around cut-out wind speed. They depend on the wind turbine design.

These estimations are based on the turbines' control loop specifications and high wind hysteresis simulations. Based on the available wind distribution at the mast, the loss induced by the hysteresis loop is 0.2%.

**Icing** losses happen in different ways: ice accumulation on blades alter their aerodynamic performance, nacelle-mounted instruments affected by ice give inaccurate readings and induce turbine control system errors, asymmetric icing causes mass or aerodynamic imbalance leading to vibrations that may force control systems to shut down the turbine. Icing can have different impact on the production of the turbine and the effect is site-specific. Some areas will be more affected by freezing rain or glaze ice and other regions are more prone to have rime ice or in-cloud icing.

Icing losses are estimated from the detection of icing events during met masts data quality control and translating the icing events into production losses. The level of ice is considered moderate as compared to other northern sites (up to 10% of icing losses).

Values should be taken with caution since no proven methodology is available and because the effect and characteristics of ice are highly site-specific. The uncertainty associated to these aspects is taken into account in the global uncertainty assessment.

**Lightning** has the potential to damage the turbine control system but also the blade integrity. Modern wind turbines have protection devices that most of the time allow continuous operation even after a lightning strike. There is however, a small chance that lightning will impact turbine operation. The lightning losses were estimated according to Environment Canada maps<sup>5</sup>.

**Low temperature shutdown** losses depend on the local climate, the turbine design and the control algorithm. In cold climates, turbine shutdowns can be driven by low temperature detection, even if the wind is blowing. According to the manufacturers' specifications, the wind turbines with cold weather package have an operation threshold of - 40°C. The loss is estimated based on the long-term temperature data measured at Hopedale Environment Canada station.

**Collection network** loss is considered at the interconnection point. It takes into account various elements, including the length of the cables connecting the wind turbines to the substation and the losses in the substation itself. Losses depend on the design of these elements.

These losses have been estimated by Hatch according to previous experiences with similar project size and conditions. They should be confirmed when the design of the collection network is finalized.

**Auxiliary power** losses account for various subsystems of a wind turbine that require electrical power, such as control systems or heaters. All of these losses are not always

<sup>5</sup> <http://ec.gc.ca/foudre-lightning/default.asp?lang=En&n=42ADA306-1>

accounted for in the power curve. For example, cold packages designed for cold climate wind turbines can require energy even when the turbine is stopped.

Based on Hatch's experience, an estimated value is used to account for the consumption of standard auxiliary systems. Specific losses have been added for the Cold Package system delivered with the wind turbines. They have been estimated by simulation according to the Cold Package specifications of the EWT900 and NPS100 Arctic wind turbines.

**Wind turbine availability** losses represent the percentage of time over a year that the turbine is unavailable for power production. Losses include regular maintenance time and unexpected turbine shutdowns. A given availability rate is normally guaranteed by utility-scale wind turbine manufacturers such as EWT (95%), but in the case of smaller wind turbines (NPS100), no availability warranty will be offered by the manufacturer.

Based on Hatch's experience on wind farms in similar conditions and technology for isolated sites, Hatch considers the estimate of 6.5% to be adequate for the Project with NPS100 units. This estimation considers a standard maintenance schedule of 1 day per year per turbine, plus unscheduled repairs and delays due to site accessibility and weather conditions. This is based on information provided by the client that wind turbines will be considered as non-essential grid components and thus deficiencies will be considered as low priority, so that individual units may remain out of service for periods longer than normally considered.

**Collection Network Availability:** The collection network may be out of service, stopping energy delivery from the turbines to the grid. Collection network outage losses include shutdown time for scheduled maintenance and unexpected outages.

Based on the information provided by the client, the Makkovik based operators will manage the site and are expected to have the skills and manpower required to fix any collection system problem in a timely manner. The presence of a support team onsite has a positive impact on the availability of the collection network.

**Grid availability** losses depend on the utility distribution system quality and capacity. It represents the percentage of time in a year when the grid is not able to accept the energy produced by the wind turbines.

The value used assumes the wind turbines will be connected to the grid operated by NLH, which is assumed to be well maintained and operated.

**Out-of-range Operation** losses take into account the aspects usually not covered by the power curve warranty such as turbulence, wind shear and yaw errors. Parameters specific to the Project have been used to perform this loss estimate.

**Wake Effect** corresponds to the deficit in wind speed downstream of a wind turbine. Several models exist to quantify this effect in terms of induced energy losses. Hatch uses the Eddy Viscosity model which corresponds to a CFD calculation representing the development of the velocity deficit field using a solution of the Navier Stokes equations. Because of higher precision as compared to the Park model and recommendations from WindFarmer, the Eddy Viscosity model is used to assess to the wake of the Project. Wake losses are highly



dependent on the layout, especially regarding the distance between the turbine and the layout's compactness.

One of the input in the wake losses calculation is the thrust curve provided by the turbine manufacturer for the Project turbine model under consideration.

No other wind farm currently exists in the vicinity of the project. In addition, no future wind farm that may impact the Project in terms of wake is planned. Thus, there are no additional wake losses.



## 6. Conclusions and Recommendations

### 6.1 Objectives of Analysis

The purpose of this report is to present a full wind resource assessment for the Makkovik site, including the estimation of the forecasted annual energy production.

### 6.2 Data Quality and Adjustments

The wind data recovery rates at the monitoring site, for the analysis period, exceed industry standards, with recovery rates ranging from 93.5% to 99.3% for the primary anemometers and 98.0% for the primary wind vane.

The measured data were adjusted to long-term through correlation with Environment Canada's Hopedale station, located 77 km away from the project area. The long-term adjustment method was applied since it was considered to be the best method for producing a representative dataset for the expected life of the project.

### 6.3 Wind Resource

The annual average wind speed at the met mast is a result of the measurements and the long-term adjustment. These wind speeds are summarised in the table below for top anemometer and hub heights.

**Table 6-1: Estimated Long-term Wind Speeds**

Mast (Measurement Height)	Estimated Long-term Wind Speed at Measurement Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2603 (35 m)	7.6	7.6	7.7

The long-term dataset at the met mast was used to build the wind flow across the project area.

The complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 6.4 Forecasted Energy Production

The preliminary turbine selection analysis specified two suitable turbine models: EWT900 and NPS100 Arctic. These models were proven to be best in class for cold and icy environments and suitable for wind-diesel generation in remote community.

The main results of the energy production modeling are summarised in the table below.

**Table 6-2: Forecasted Annual Energy Production**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
Number of Wind Turbines	1	5
Wind Farm Capacity (kW)	900	500
Annual Net Energy Production (MWh/yr)	<b>3,102</b>	<b>1,728</b>
Net Capacity Factor (P50) (%)	<b>39.3</b>	<b>39.4</b>

There remains some uncertainty regarding loss estimates, which should be reassessed as more information becomes available, particularly in relation to warranty contracts and maintenance schedules. Note that the Annual Net Energy Production represents the total forecasted energy production by the wind turbines. The effective energy production used to displace fuel will be a bit lower and vary depending on the chosen layout scenario (type and number of wind turbines), timewise power load and wind resource.

## 6.5 Recommendation

It should be noted that a number of additional studies and more detailed analysis will be required to refine and validate the turbine selected, the turbine position, the energy and losses.

The integration optimization report will show which turbine model is considered optimal for the Makkovik site based on energy cost, control capabilities and logistics and provide recommendations for further analysis and studies prior to implementation.

## References

- [1] International Energy Agency Programme, *Recommended practices for wind turbine testing and evaluation – Task 11: Wind Speed Measurement and Use of Cup Anemometer*, 1999
- [2] National Renewable Energy Laboratory, *Wind Resource Assessment Handbook*, 1999
- [3] International Electrotechnical Commission, *Wind Turbines - Part 1: Design Requirements*, IEC 61400-1, Ed. 3, 2005-08.
- [4] International Electrotechnical Commission, *Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines*, IEC 61400-12-1, Ed. 1, 2005.
- [5] A Practical Guide to Developing a Wind Project, *Wind Resource Assessment*, 2011



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# Appendix A

## Views at Mast Site



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**View Facing North**



**View Facing East**



**View Facing South**



**View Facing West**

**Figure – A1: Views from Base of Mast 2603**

# Appendix B

## Wind Turbine Data



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**EWT DW52-900**

The power curve and the thrust curve were provided to Hatch by Emergya Wind Technologies.

**Table – B1: EWT Wind Turbine Performance Curves**

Rotor Diameter: 51.5 m		Hub Height: 40.0 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0	0	0	0	0	0.000	0	0.000
1	0	0	0	1	0.000	1	0.000
2	0	0	0	2	0.000	2	0.000
3	7	7	0.866	3	0.866	3	0.866
4	30	30	0.828	4	0.828	4	0.828
5	69	69	0.776	5	0.776	5	0.776
6	124	124	0.776	6	0.776	6	0.776
7	201	201	0.776	7	0.776	7	0.776
8	308	308	0.753	8	0.753	8	0.753
9	439	439	0.722	9	0.722	9	0.722
10	559	559	0.692	10	0.692	10	0.692
11	698	698	0.613	11	0.613	11	0.613
12	797	797	0.516	12	0.516	12	0.516
13	859	859	0.441	13	0.441	13	0.441
14	900	900	0.368	14	0.368	14	0.368
15	900	900	0.296	15	0.296	15	0.296
16	900	900	0.241	16	0.241	16	0.241
17	900	900	0.199	17	0.199	17	0.199
18	900	900	0.168	18	0.168	18	0.168
19	900	900	0.143	19	0.143	19	0.143
20	900	900	0.124	20	0.124	20	0.124
21	900	900	0.109	21	0.109	21	0.109
22	900	900	0.096	22	0.096	22	0.096
23	900	900	0.085	23	0.085	23	0.085
24	900	900	0.075	24	0.075	24	0.075
25	900	900	0.067	25	0.067	25	0.067



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**NPS100**

The power curve and the thrust curve were provided to Hatch by Northern Power.

**Table – B2: NPS100 Wind Turbine Performance Curves\***

Rotor Diameter: 20.7 m		Hub Height: 37.0 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0		0		0		0	
1		0		1		0	
2		0		2		0	
3		0		3		0	
4		3.7		4		1.072	
5		10.5		5		0.963	
6		19.0		6		0.866	
7		29.4		7		0.820	
8		41.0		8		0.754	
9		54.3		9		0.687	
10		66.8		10		0.616	
11		77.7		11		0.548	
12		86.4		12		0.491	
13		92.8		13		0.436	
14		97.3		14		0.391	
15		100.0		15		0.347	
16		100.8		16		0.316	
17		100.6		17		0.286	
18		99.8		18		0.261	
19		99.4		19		0.239	
20		98.6		20		0.222	
21		97.8		21		0.206	
22		97.3		22		0.194	
23		97.3		23		0.184	
24		98.0		24		0.175	
25		99.7		25		0.167	

\* Power curve of the Northern Power 100 – standard model

Gilles Boesch  
GB:gb



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Emergya Wind Technologies BV

Engineering

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Created by:	JT	Creation Date:	24-07-09
Checked by:	MB	Checked Date:	24-07-09
Approved by:	TY	Approved Date:	05-04-11

Title:

Specification

# **DIRECTWIND 52/54\*900 Technical Specification**

Revision	Date	Author	Approved	Description of changes
02	02-03-12	MB	TY	Format, minor text, blades, options
01	28-11-11	LE	TY	Corrections and drawings
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

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## 1 Introduction

This document provides a technical overview of the *DIRECTWIND 52/54\*900* Wind Turbine designed for the IEC class II/III application. It is to be read in conjunction with document S-1000921 "Directwind 52/54\*900 Electrical Specification".



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## 2 Technical Description

The *DIRECTWIND* 52/54\*900 is a direct-drive, variable speed, pitch regulated, horizontal axis, three-bladed upwind rotor wind turbine.

The gearless direct-driven synchronous generator operates at variable speed. This is made possible by an actively controlled AC-DC-AC IGBT power converter connected to the grid. Benefits of this design are low maintenance, constant power output at wind speed above rated, and relatively low structural loads compared to constant-speed stall-controlled or constant-speed pitch-controlled wind turbines.

The generator is fully integrated into the structural design of the turbine, which allows for a very compact nacelle design. The drive-train makes use of only one main bearing, whereas classic designs have separately supported main shaft, gearbox and generator. All dynamically loaded interfaces from the blades to the foundation are sturdy flange connections with machined surfaces, and high tensile steel pre-stressed bolt connections are used.

### 2.1 Operation and safety system

The turbine operates automatically under all wind conditions and is controlled by an industrial PLC (Programmable Logic Controller). The cut-in wind speed is approximately 3m/s. When the rotational speed reaches the cut-in threshold, the power converter begins to deliver power to the grid.

The power converter controls the generator power output and is programmed with a power set-point versus rotor speed curve. Below rated wind speed the power output is controlled to optimise rotor speed versus aerodynamic performance (optimum  $\lambda$ -control). Above rated wind speed the power output is kept constant at rated value by PD-controlled active blade pitching.

The dynamic responses of the drive train and power controller are optimised for high yield and negligible electrical power fluctuations. The variable speed rotor acts as a flywheel, absorbing fluctuating aerodynamic power input. The turbine controllers are located in the rotor hub and the tower base (with remote IO in the nacelle) and carry out all control functions and safety condition monitoring. In the case of a fault, or extreme weather conditions, the turbine is stopped by feathering of the blades to vane position (blades swivelled to 90° with respect to rotor's rotational plane). In case of power loss, an independent battery backup system in each blade ensures the blades are feathered.

In the case of less serious faults which have been resolved, or when extreme weather conditions have passed, the turbine restarts automatically to minimise downtime.

### 2.2 Generator

The multiple-pole, direct-drive generator is directly mounted to the hub. The stator is located in the non-moving outer ring and the wound pole, separately excited rotor rotates on the inner ring.

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The generator is designed such that all aerodynamic forces are directly transferred to the nacelle construction without interfering with the generator-induced loads.

## 2.3 Power Converter

The power converter is an AC-DC-AC IGBT active switching converter. It controls the generator to operate in its optimum range, and maintains power quality to the grid. The inverter can produce unity power factor ( $\cos\Phi=1$ ) to the grid under all load conditions. Power factor is also controllable within limits.

## 2.4 Rotor

The rotor is a three bladed construction, mounted up-wind of the tower. Rotational speed is regulated by active blade adjustment towards vane position. Blade pitch is adjusted using an electric servomotor on each of the blades.

Each blade has a complete, fully independent pitch system that is designed to be fail-safe. This construction negates the need for a mechanical rotor brake. The pitch system is the primary method of controlling the aerodynamic power input to the turbine.

At below rated wind speed the blade pitch setting is constant at optimum aerodynamic efficiency. At above rated wind speed the fast-acting control system keeps the average aerodynamic power at the rated level by keeping the rotor speed close to nominal, even in gusty winds.

The rigid rotor hub is a nodular cast iron structure mounted on the main bearing. Each rotor blade is connected to the hub using a pre-stressed ball bearing. It is sufficiently large to provide a comfortable working environment for two service technicians during maintenance of the pitch system, the three pitch bearings and the blade root from inside the structure.

## 2.5 Rotor blade set

The rotor blades are made of fibreglass-reinforced epoxy. The aerodynamic design represents state-of-the-art technology and is based on a pitch-regulated concept. No extenders are used and the aerodynamic design is optimal for this rotor diameter.

## 2.6 Main bearing

The large-diameter main bearing is a specially designed three row cylindrical roller bearing. The inner non-rotating ring is mounted to the generator stator. The outer rotating ring is mounted between the hub and generator rotor. The bearing takes axial and radial loads as well as bending moments. Entrance to the hub is through the inner-bearing ring. The bearing is greased by a fully automatic lubrication system controlled by the turbine PLC.

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## 2.7 Nacelle

The nacelle is a compact welded construction which houses the yaw mechanism, a service hoist and a control cabinet. Both the generator and the tower are flanged to the nacelle. The geometry of the construction assures an ideal transfer of loads to the tower and, with the absence of a shaft and gearbox, results in a simple design ensuring easy personnel access.

## 2.8 Yaw system

The yaw bearing is an internally geared ring with a pre-stressed four point contact ball bearing. Electric planetary gear motors yaw the nacelle. The yaw brake is passive and is based on the friction of brake pads sitting directly on the bearing ring, keeping the yaw system rigid under most loading conditions.

## 2.9 Tower

The nacelle assembly is supported on a tubular steel tower, fully protected against corrosion. The tower allows access to the nacelle via a secure hinged access door at its base. The tower is fitted with an internal ladder with safety wire and optional climb assistance, rest platforms and lighting. Standard hub heights are 35, 40, 50 and 75 metres.

## 2.10 Anchor

The turbine is supported by a concrete foundation. The connection to this foundation is provided by means of a cast-in tube or rod anchor.

## 2.11 Control System

### 2.11.1 Bachmann PLC

The M1 controller perfectly combines the openness of a PC-based controller with the reliability of industrial hardware platforms. Designed to withstand the toughest ambient conditions it guarantees error-free use over long periods of time.

A modern system architecture designed for consistent network-capability permits the easy integration of the M1 into the environment of the controller and system peripherals. Real-time ethernet permits the real-time networking of the controllers, and the support of all standard Fieldbus systems permits the connection of standard external components.

### 2.11.2 DMS

*DIRECTWIND* Monitoring System – EWT’s proprietary HMI featuring local monitoring and control at the turbine, integrated into a remote-access SCADA. DMS offers individual turbine control and total park monitoring and data logging from your Wind Turbine, Wind Park or internet access point.

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## 2.12 Earthing and lightning protection

The complete earthing system of the wind turbine incorporates:

1. Protective earthing:

A PE connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

2. Functional earthing:

Earthing system to minimize and/or remove the source of electrical interference that can adversely affect operation of sensitive electrical and control equipment.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, the functional earth connection may carry electric current during the normal operation of the turbine.

3. Lightning protection:

To provide predictable conductive path for the over-currents in case of a lightning strike and electromagnetic induction caused by lightning strike and to minimize and/or remove dangerous situations for humans and sensitive electrical equipment.

Since the mechanical construction is made of metal (steel), all earthing systems are combined.

## 2.13 Options

The following options are available:

- Cold climate operation (rated for operation down to -40°C)
- Ice detection and/or prevention system
- Aviation lights
- Shadow flicker prevention
- Low Voltage Ride-through (LVRT)
- Service lift (75m tower only)
- G59 protection relay

	Category:	Specification	Revision: 02
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### 3 Technical Data

Where data are separated by "/" this refers to the respective rotor diameter (52 / 54 m).

#### 3.1 Wind and Site Data

Wind class	II / III according to IEC 61400 – 1
Max 50-year extreme	59.5 / 52.5 m/s
Turbulence class	A ( $I_{15} = 0.16$ )
Maximum flow inclination (terrain slope)	8°
Max ann. mean wind speed at hub height	8.5 / 7.5 m/s
Nominal air density	1.225 kg/m <sup>3</sup>

#### 3.2 Operating Temperature

	Standard	Cold Climate
Min ambient operating	-20°C	-40°C
Max ambient operating	+40°C	+40°C

#### 3.3 Cooling

Generator cooling	Air cooled
Converter cooling	Water or air cooled (configuration-dependent)

#### 3.4 Operational Data

Cut in wind speed	3 m/s
Cut out wind speed	25 m/s
Rated wind speed	14 / 13.5 m/s
Rated rotor speed	26 rpm
Rotor speed range	12 to 33 rpm
Power output	900kW
Power factor	1.0 (adjustable 0.95 lagging to 0.95 leading) Measured at LV terminals

#### 3.5 Rotor

Diameter	52 / 54 m
Type	3-Bladed, horizontal axis
Position	Up-wind
Swept area	2,083 / 2,290 m <sup>2</sup>
Power regulation	Pitch control; Rotor field excitation
Rotor tilt angle	5°

	Category:	Specification	Revision: 02
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### 3.6 Blade Set

Type	PMC 24.5 / 25.8
Blade length	24.5 / 25.8 m
Chord at 22.0 m	0.879 m (90% of 24.5m blade radius)
Chord at 23.5 m	0.723 m (90% of 25.8m blade radius)
Chord Max at 5.5 m	2.402 m
Aerodynamic profile	DU 91, DU 98 and NACA 64618
Material	Glass reinforced epoxy
Leading edge protection	PU coating
Surface colour	Light grey RAL 7035
Twist Distribution	11.5° from root to 5.5m then decreases linearly to 0.29°, then non-linearly to 0°

### 3.7 Transmission System

Type	Direct drive
Couplings	Flange connections only

### 3.8 Controller

Type	Bachmann PLC
Remote monitoring	DIRECTWIND Monitoring System, proprietary SCADA

### 3.9 Pitch Control and Safety System

Type	Independent blade pitch control
Activation	Variable speed DC motor drive
Safety	Redundant electrical backup

### 3.10 Yaw System

Type	Active
Yaw bearing	4 point ball bearing
Yaw drive	3 x constant speed electric geared motors
Yaw brake	Passive friction brake

### 3.11 Tower

Type	Tapered tubular steel tower
Hub height options	HH = 35, 40, 50, 75 m
Surface colour	Interior: White RAL 9001, Exterior: Light grey RAL 7035

	Category:	Specification	Revision: 02
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### 3.12 Mass Data

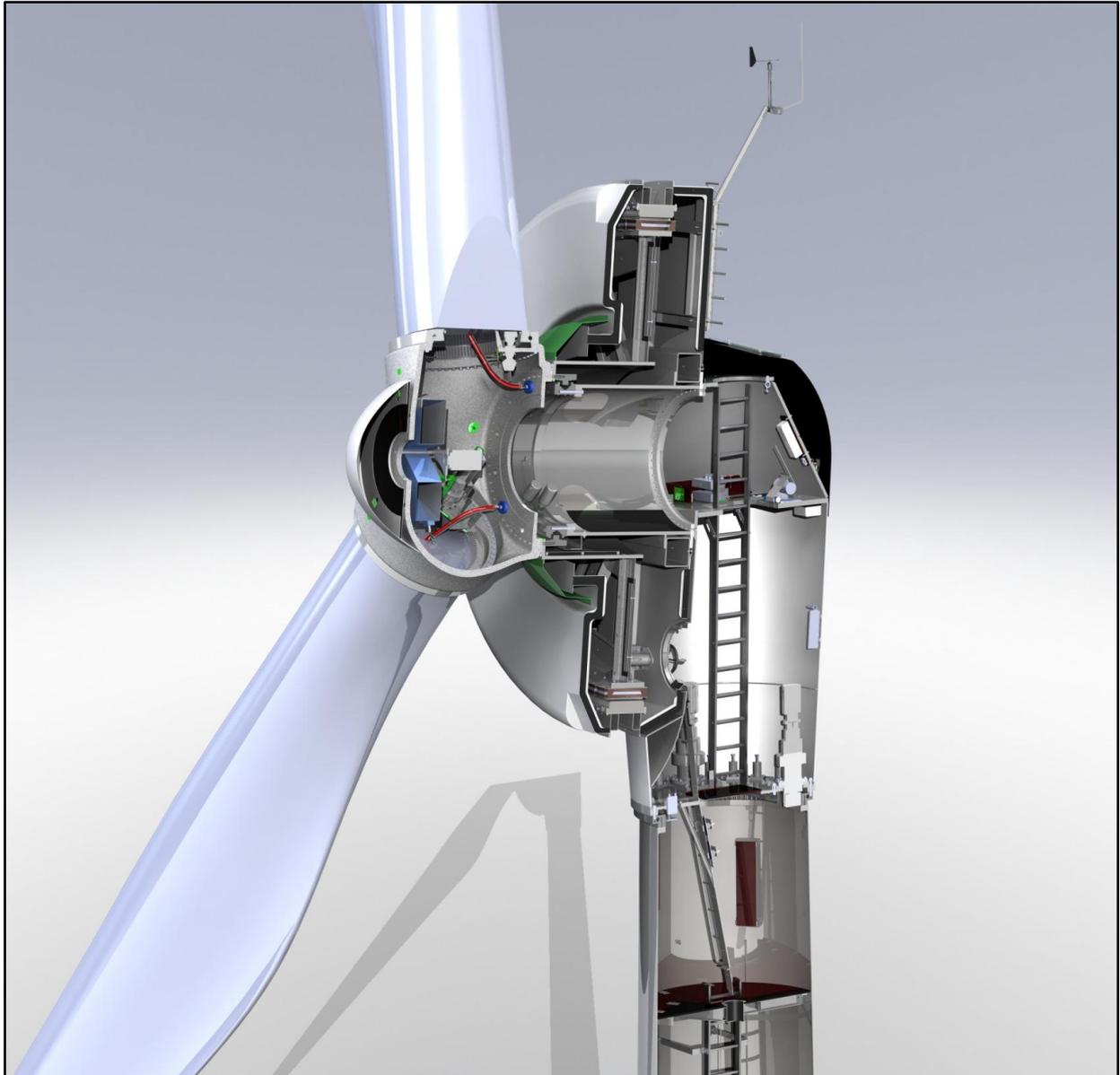
Hub	9,303 kg
Blade – each	1,919 / 1,931 kg
Rotor assembly	15,060 / 15,096 kg
Generator	30,000 kg
Nacelle assembly	10,000 kg
Tower HH35	28,300 kg
Tower HH40	34,000 kg
Tower HH50	46,000 kg
Tower HH75	86,500 kg

### 3.13 Service Brake

Type	Maintenance brake
Position	At hub flange
Calipers	Hydraulic 1-piece

	Category:	Specification	Revision: 02
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## APPENDIX 1: 3D image of main turbine components

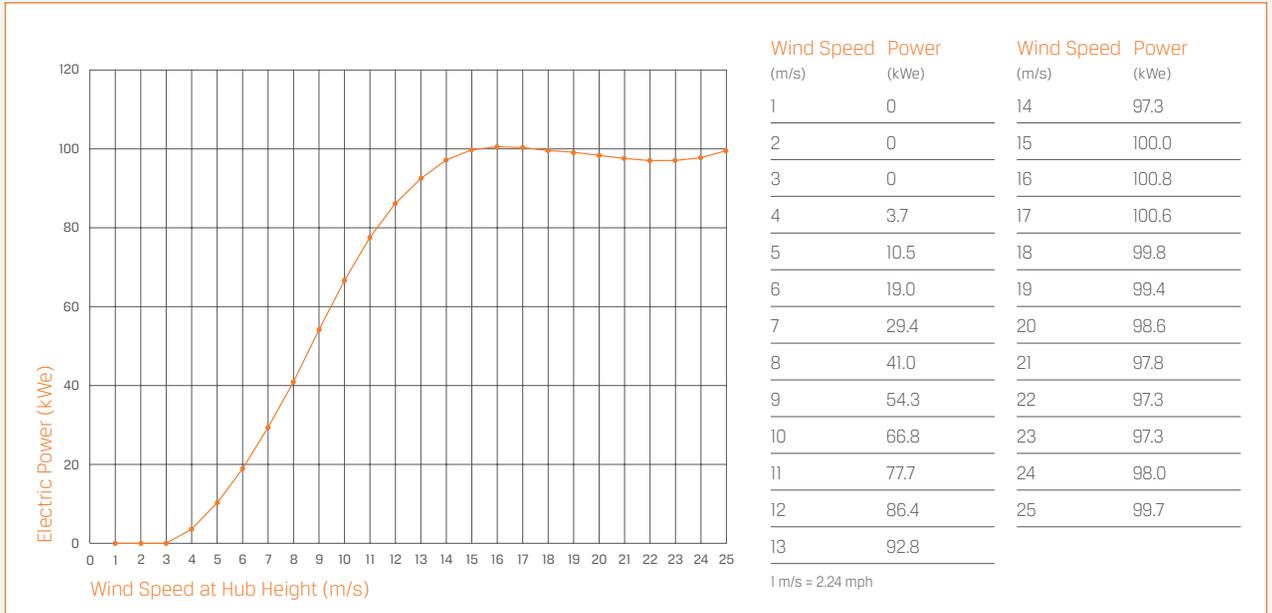


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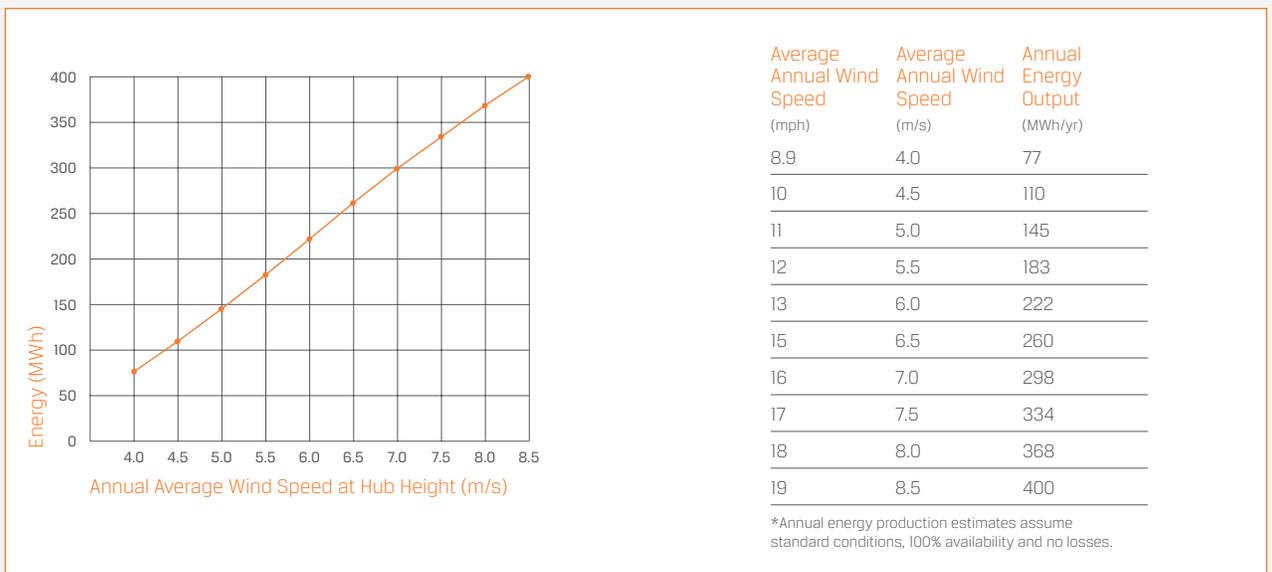


# Northern Power<sup>®</sup> 100

Power Curve: 21-Meter Rotor Standard Air Density (1.225 kg/m<sup>3</sup>)



Annual Energy Production\*: 21-Meter Rotor Standard Air Density, Rayleigh Wind Speed Distribution



## Specifications



GENERAL CONFIGURATION	DESCRIPTION
Model	Northern Power® 100
Design Class	IEC IIA (air density 1.225 kg/m <sup>3</sup> , average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 years
Hub Height	37 m (121 ft) / 30 m (98 ft)
Tower Type	Tubular steel monopole
Orientation	Upwind
Rotor Diameter	21 m (69 ft)
Power Regulation	Variable speed, stall control
Certifications	UL1741, UL1004-4, CSA C22.2 No.107.1-01, CSA C22.2 No. 100.04, and CE compliant
PERFORMANCE	DESCRIPTION
Rated Electrical Power	(standard conditions: air density of 1.225 kg/m <sup>3</sup> , equivalent to 15°C (59°F) at sea level) 100 kW, 3 Phase, 480 VAC, 60/50 Hz
Rated Wind Speed	14.5 m/s (32.4 mph)
Maximum Rotation Speed	59 rpm
Cut-In Wind Speed	3.5 m/s (7.8 mph)
Cut-Out Wind Speed	25 m/s (56 mph)
Extreme Wind Speed	59.5 m/s (133 mph)
WEIGHT	DESCRIPTION
Rotor (21-meter) & Nacelle (standard)	7,200 kg (16,100 lbs)
Tower (37-meter)	13,800 kg (30,000 lbs)
DRIVE TRAIN	DESCRIPTION
Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet, passively cooled
BRAKING SYSTEM	DESCRIPTION
Service Brake Type	Two motor-controlled calipers
Normal Shutdown Brake	Generator dynamic brake and two motor-controlled calipers
Emergency Shutdown Brake	Generator dynamic brake and two spring-applied calipers
YAW SYSTEM	DESCRIPTION
Controls	Active, electromechanically driven with wind direction/speed sensors and automatic cable unwind
CONTROL/ELECTRICAL SYSTEM	DESCRIPTION
Controller Type	DSP-based multiprocessor embedded platform
Converter Type	Pulse-width modulated IGBT frequency converter
Monitoring System	SmartView remote monitoring system, ModBus TCP over ethernet
Power Factor	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive Power	+/- 45 kVAR
NOISE	DESCRIPTION
Apparent Noise Level	55 dBA at 30 meters (98 ft)
ENVIRONMENTAL SPECIFICATIONS	DESCRIPTION
Temperature Range: Operational	-20°C to 50°C (-4°F to 122°F)
Temperature Range: Storage	-40°C to 55°C (-40°F to 131°F)
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection
Icing Protection	Turbine designed in accordance with Germanischer Lloyd Wind Guidelines Edition 2003

All Specifications subject to change without notice.

NPS100SS-2222011-US

# Appendix D: Wind Resource Assessment Report – Cartwright



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H340923-0000-05-124-0012, Rev. B

Project Report

November 15, 2015

## Newfoundland and Labrador Hydro Cartwright Wind Project

### Distribution

Trevor Andrew – NLH  
Asim Haldar – NLH  
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## Final Wind Resource Assessment Report



Safety • Quality • Sustainability • Innovation

H340923-0000-05-124-0005, Rev. 2  
Page i

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## DOCUMENT HISTORY

Revision	Date	Description
1	August 31, 2015	Final Version
2	November 15, 2015	Few edits based on comments from NLH on October 30, 2015 – Final Version



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## EXECUTIVE SUMMARY

In order to assess the potential of Cartwright site for wind power development, a wind resource assessment (WRA) was completed. The site is located near the community of Cartwright, Newfoundland and Labrador, Canada. The site was equipped with one met mast that is described in the table below.

Met Mast	Installation Date	Top Anemometer Height (m)	Elevation (m)	Data Collection* Starts...	Data Collection* Ends...
2605	November 5, 2013	35.0	57	November 5, 2013	April 30, 2015

\* A 12 month period is selected to estimate the annual energy production

In the analysis, the quality control process demonstrated that the data recovery rates exceeded 95 % on all instruments which meets industry standards for wind measurement campaign. Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements.

The **wind speed** measured at the mast is **6.5 m/s** in average. The **winds are dominant from southwest** across the site.

The wind **turbulence intensity** observed at the site is generally **moderate**.

Given the land cover and topography at the mast the **wind shear exponent**, equal to **0.11**, is consistent with the expected value.

Met Mast	Period	Annual Average of Measured Wind Speed* (m/s)	Annual Average of Measured Turbulence Intensity* (%)	Annual Wind Shear
2605	December 1, 2013 to November 30, 2014	6.5	14.4	0.11

\* at Top Anemometer Height

During the data quality control process, icing events were detected on anemometers and wind vanes. **Icing occurred 3.1% of the time** at the site. Given the site elevation and the temperatures associated with these events, it is likely that about 82% of these events were caused by freezing rain and about 18% were caused by rime ice. Icing events mainly occurred during the month of November.

Temperature data were collected at the mast. The monthly averages range from **-15.0°C** in December to **15.1°C** in July, with an **annual average of -0.6°C**. The coldest 10-minute temperature recording during the data collection period was **-30.0°C**.

The **air density** was calculated at the mast according to the elevation and the local temperature. The annual value is **1.30 kg/m<sup>3</sup>**.



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The annual average power density is **467 W/m<sup>2</sup>**. The most powerful winds come from southwest to west-northwest across the site.

In order to estimate the **long-term wind regime** at the site, several potential **reference stations** with historical data were selected.

The **Cartwright station** monitored by Environment Canada, located 4 km away from the potential wind farm site, was selected as the reference station for the long-term extrapolation of the data. The reference station data were then correlated to met mast 2605 and used to translate the short-term data into long-term estimates.

The long-term estimates were then extrapolated from measurement height to hub heights.

Met Mast	Period	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s) at 37 m / 40 m
2605	December 1, 2013 to November 30, 2014	7.0	7.3 / 7.3

The wind resource estimated at the mast was used to compute the wind flow across the project area. The wind flow was calculated with WAsP 11.01.0016 software, which is an appropriate model for the Cartwright project area which exhibits a moderate terrain complexity.

This wind flow was used to optimise the layout of the potential wind farm and to estimate the energy production with WindFarmer software.

A preliminary turbine selection analysis was completed and two turbine models were selected: Emergya Wind Technologies 900 kW (EWT900) and Northern power 100 (NPS100 Arctic). These models have proven technology in cold and icy environments and are suitable for wind-diesel generation in remote community.

A wind farm layout optimisation was completed taking in consideration energy production, information from the preliminary environmental screening and turbine extreme operating condition.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.



Layout	Wind Farm Capacity (kW)	Net Energy Production (MWh/year)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)
Layout 1 - EWT900	900	2,898	36.7	0.0	14.2
Layout 2 - NPS100 Arctic	500	1,559	35.6	4.0	14.0

Other energy production scenarios will be covered under separate portion of the wind penetration report.



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## 1. Introduction

Hatch has been mandated by Newfoundland and Labrador Hydro (NLH) to carry out a wind resource assessment (WRA) for a potential wind farm project, located 3 kilometres east of the community of Cartwright, Newfoundland and Labrador, Canada.

The site was instrumented with one meteorological (“met”) mast. The installation was completed on November 5, 2013. The mast was equipped with sensors at several heights to measure wind speed, wind direction and temperature. The analysed data cover a total measurement period of one year.

The second section of this report presents an overview of the site and the measurement campaign.

The third section presents the main characteristics of the wind climate.

The fourth section details the process used to translate the measured short-term data into long-term data.

The fifth section presents the methodology used to obtain the wind flow map over the project area. The wind flow map optimises the wind farm layout and helps determine monthly and annual energy production estimates. The key resulting values of these estimations are provided, including a description of the losses considered in the net energy calculation.

## 2. General Information

This section summarises general information about the site, the meteorological (met) mast installed and the measurement campaign.

### 2.1 Site Description

#### 2.1.1 Site Overview

The community of Cartwright is located on the eastern side of the entrance to Sandwich Bay along the southern coast of Labrador. The surroundings of the community consists mainly of gently rolling hills with an average elevation of 120 m above sea level.





**Figure 2-1: Typical Landscape at the Cartwright Area**

### 2.1.2 Mast Location

The location of met mast 2605 was chosen with agreement between Hatch and NLH. Hatch proceeded with the installation of the mast and followed industry standards [1].

Table 2-1 provides a description of the mast, including the exact coordinates and the elevation.

The location of the mast is shown on the map provided on next page.

**Table 2-1: Met Mast Characteristics (Coordinate System: NAD83)**

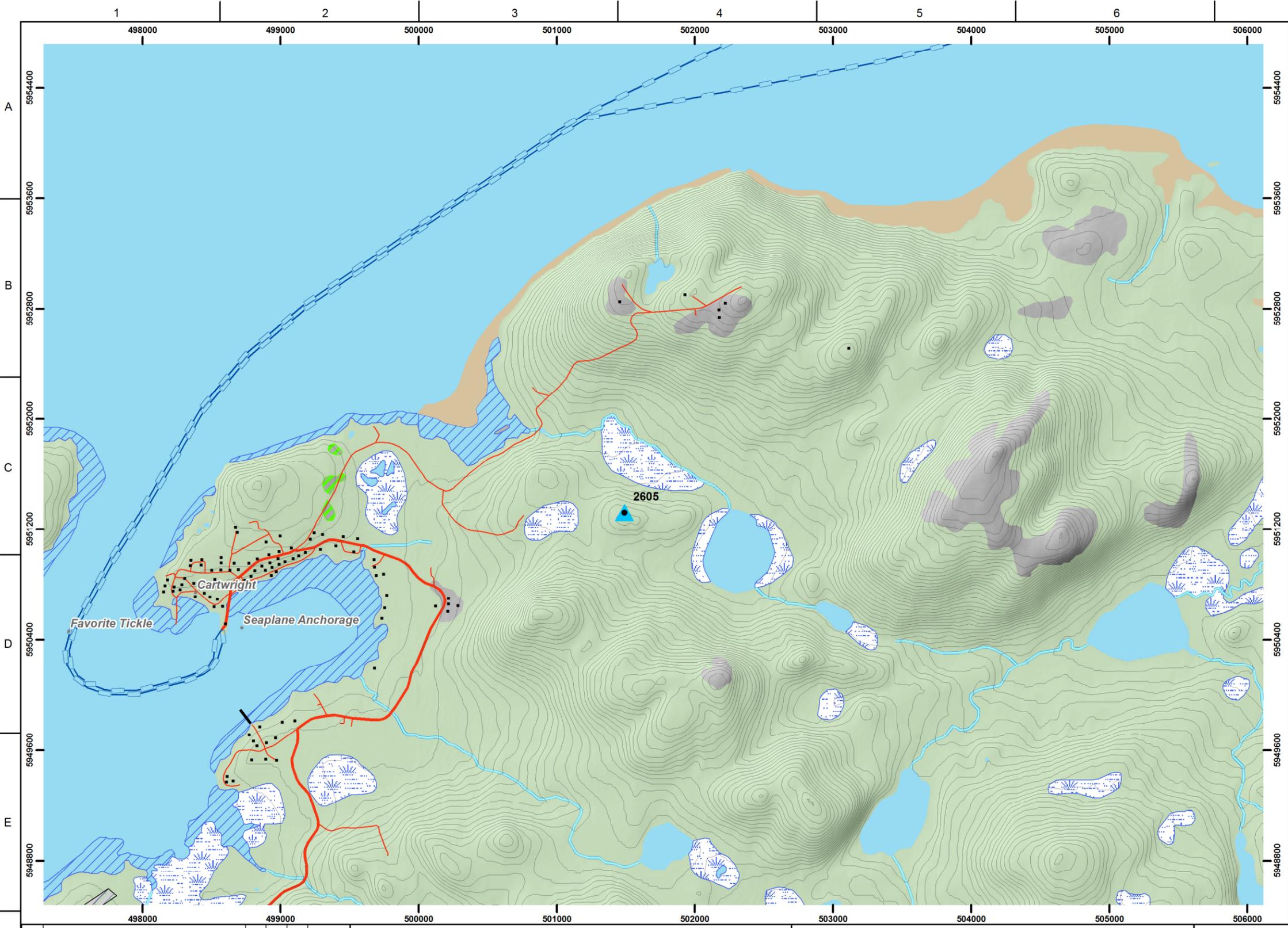
ID	Type	Diameter (m)	Height (m)	Latitude	Longitude	Elevation (m)
2605	Square Lattice	0.404	36	N 53° 42' 38.1"	W 56° 58' 38.7"	57

The Cartwright met mast (#2605) is located east of the community on a gently rocky hill of approximately 50m elevation. The site consists in smooth bed rock with a thin layer of moss.

Pictures have been provided in Appendix A with views in the four main geographical directions at the met mast.

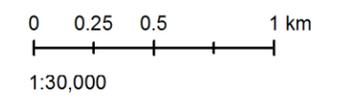


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**Legend**

- Met Mast
- Building
- Contour (5m)
- Wharf
- Watercourse
- Ferry connection segment
- Mining area
- Reef
- Airport
- Wetland
- Waterbody
- Sand
- Vegetation



Spatial referencing UTM Zone 21 NAD83.

SOURCE :  
 Canvec - Natural Resource Canada 1:50 000  
 Action Canada Conference - Mt.Sophie viewer

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

**HATCH**

DESIGNED BY SLADJANA PAVLOVIC DATE: March 10, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: March 10, 2015
CHECKED BY Dany Awad DATE: March 10, 2015	

NALCOR

**Cartwright - Overview Map**

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## 2.2 Measurement Campaigns

The mast characteristics, instrumentation, installation dates and periods of data collection are provided in this section.

### 2.2.1 Installation and Collection Date

The following table provides the date of mast installation and the period of data collection used in the analysis.

**Table 2-2: Installation Date and Period of Relevant Data Collection**

ID	Installation date	Date and time of first data used	Date and time of last data used
2605	November 5, 2013	December 1, 2013, 00:00 AM	November 30, 2014, 11:50 PM

### 2.2.2 Instrumentation

#### 2.2.2.1 Sensors Mounting

The met mast was equipped with anemometers and wind vanes mounted on booms at several heights. The dimensions of the booms, their heights and orientations on the mast, were designed to comply with the best practices in wind resource assessment as specified in [1] and [2].

For the met mast, the instrument and installation parameters are provided in the table below. All instruments and met mast underwent regular maintenance checks.

Heated anemometers and wind vanes were installed to increase the data recovery rate during icing periods. An Autonomous Power System (A.P.S.) developed by Hatch was installed to power supply the heating instruments. The A.P.S. consists of a set of batteries charged by a small wind turbine through a controller.

**Table 2-3: Installation Parameters of Instruments at the Met Mast**

Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
<b>Mast 2605</b>							
<b>Data Acquisition System</b>							
N/A	N/A	N/A	NRG Symphonie PLUS3	Nov 5, 2013	July 15, 2015	N/A	N/A
<b>Anemometers</b>							
#1	A1	35.0	NRG #40C	Nov 5, 2013	July 15, 2015	Yes / No	P
#2	A2	35.0	NRG Icefree III	Nov 5, 2013	July 15, 2015	Yes / Yes	R
#3	A3	26.0	NRG #40C	Nov 5, 2013	July 15, 2015	Yes / No	P



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Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
#4	A5	26.0	RMYoung 5103-AP	Nov 5, 2013	July 15, 2015	Yes / No	R
#13	A4	17.0	NRG #40C	Nov 5, 2013	July 15, 2015	Yes / No	P
<b>Wind Vanes</b>							
<b>#7</b>	<b>V1</b>	<b>33.0</b>	<b>NRG Icefree III</b>	<b>Nov 5, 2013</b>	<b>July 15, 2015</b>	<b>No / Yes</b>	<b>P</b>
#8	V2	26.0	RMYoung 5103-AP	Nov 5, 2013	July 15, 2015	No / No	R
#9	V3	15.0	NRG #200P	Nov 5, 2013	July 15, 2015	No / No	R
<b>Temperature Sensor</b>							
#10	T	34.0	NRG #110S	Nov 5, 2013	July 15, 2015	No / No	P

*Note: Lines in bold font correspond to the anemometer and wind vane considered as the principal instruments for wind characterisation at the mast location.*

#### 2.2.2.2 Data Acquisition System

For met mast 2605, the instruments were connected to a data acquisition system which stored the data on a memory card. The data were then sent to Hatch computer network by a satellite communication system every 3 days.



### 3. Meteorological Data Analysis

This section presents a comprehensive analysis of the data collected. In the first section, the quality of the data is reviewed. The characteristics of the wind measured at the mast are then presented in Section 3.2 through a number of relevant parameters:

- monthly and annual average wind speeds;
- wind speed distribution;
- wind direction distribution;
- wind shear;
- turbulence intensity;
- 50-year recurrence wind speed.

In the final section, other climatic information such as measured temperature, calculated air density, wind power density and icing events is presented and discussed.

#### 3.1 Quality Control

The quality and completeness of the data are key factors that determine the reliability of the wind resource assessment.

Data are collected periodically from the met masts and the quality of the data is analysed. This is done by applying a variety of logical and statistical tests, observing the concurrent readings from different instruments and relating these observations to the physical conditions at the site (e.g. wind shading, freezing potential, etc.). The process is semi-automated: the tests are implemented in a computer program developed by Hatch, but the expertise of quality analysts are required to accept, reject or replace data. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, data logger malfunction, damaged mounting hardware, sensor calibration drift, icing events and different causes of shading (e.g. shading from the mast or from any obstacles at the site). A list of the possible error categories used during quality control is presented in Table 3-1. Data points that are deemed erroneous or unreliable are replaced by redundant data when available, or removed from the dataset.

The data recovery rate for the analysis period is then calculated for each of the instruments using the following equation:

$$\text{Data recovery rate (\%)} = \frac{\text{Number of valid observations}}{\text{Number of potential observations}} * 100$$

The “Number of valid observations” is evaluated once erroneous or unreliable data are replaced with available redundant data. The “Number of potential observations” is the theoretical maximum number of measurements that could be recorded during the analysis period. A high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.



**Table 3-1: Quality Control Table**

Error Categories
Unknown event
Icing or wet snow event
Static voltage discharge
Wind shading from tower
Wind shading from building
Wind vane deadband
Operator error
Equipment malfunction
Equipment service
Missing data (no value possible)

### 3.1.1 Data Replacement Policy

Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements. Replacements were done directly or by using a linear regression equation. Direct replacement is applied to anemometers when the replaced and replacing instruments are of the same model, calibrated, at the same height, and well correlated. Direct replacement is also applied to wind vanes as long as they are well correlated.

An acceptable percentage of the dataset (7%) is replaced by equivalent instruments and it is considered to have a small impact on the uncertainty of the measurements.

### 3.1.2 Recovery Rates

The following table presents the recovery rates calculated for each instrument after quality control and after replacements have been completed according to the replacement policy.

**Table 3-2: Instruments Data Recovery Rates**

Mast ID	A1	A3	A4	V1	T
2605	99.3%	98.9%	95.3%	95.4%	100.0%

Note that the recovery rates for the following instruments are identical, given the replacement policy:

- A1 and A2; A3 and A5
- V1, V2 and V3



### 3.1.3 Data History

The data recovery rates exceed industry standards [5]. A number of data were affected on short periods of time by usual effects, such as shading effect and short period of icing events and were removed.

## 3.2 Wind Characteristics

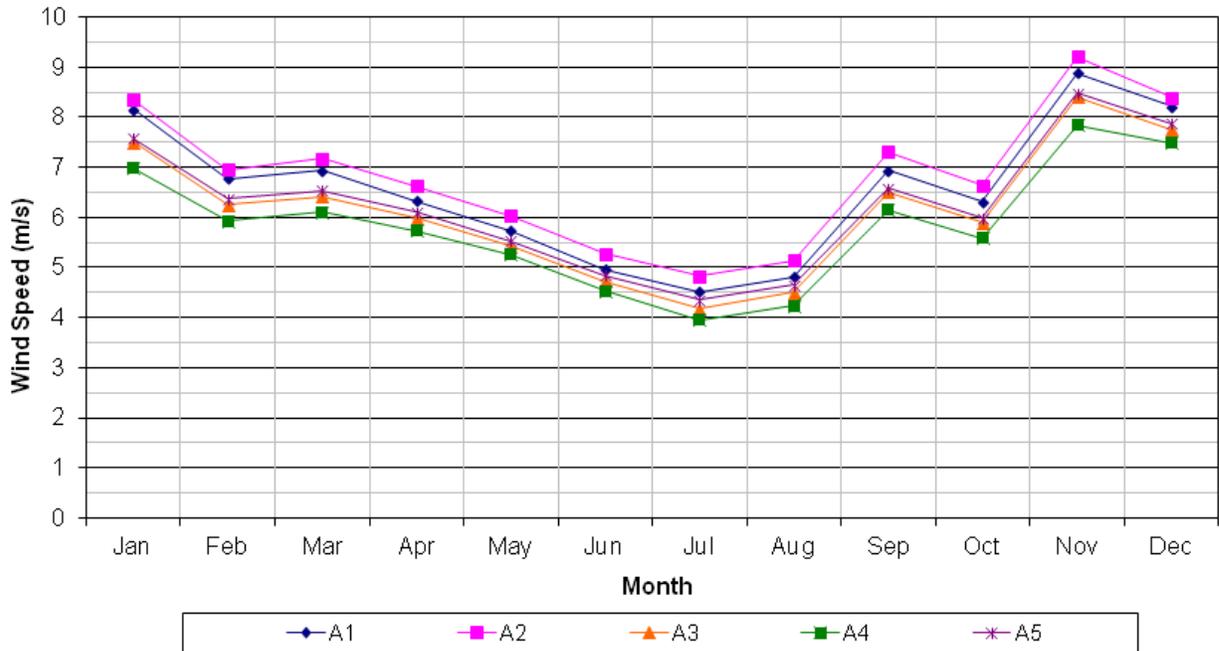
### 3.2.1 Annual and Monthly Wind Speed

The monthly wind speeds measured at each anemometer are shown in the following figures for mast 2605. The data are presented in two formats (see Figure 3-1 and Figure 3-2):

- a) for all instruments, the averaged monthly wind speed measured;
- b) for A1, all monthly wind speeds are also reported.

Although the results for anemometers A2 and A5 are presented, they will not be considered in further calculations as these sensors were used primarily for quality control and replacement purposes.

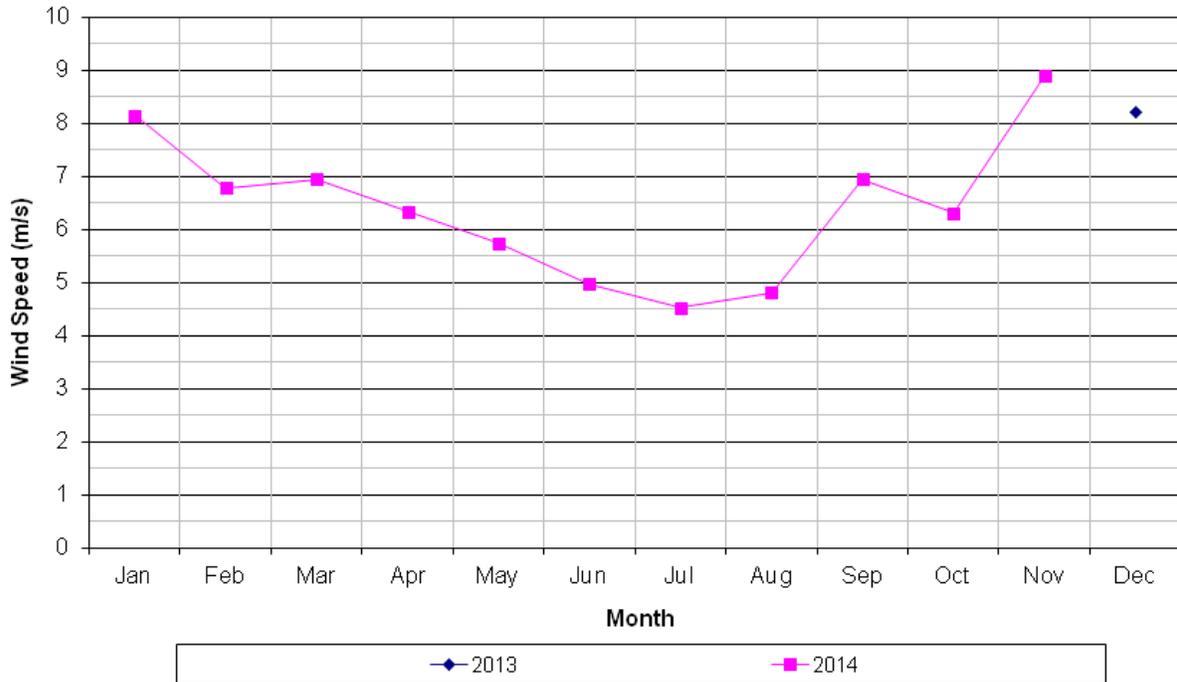
As expected, the data confirm that wind speeds increase with height above ground level (see section 3.2.4 for a description of wind shear). Furthermore, the graphs show the seasonal pattern of wind, which decreases towards summer months and increases towards winter months.



**Figure 3-1: Averaged Monthly Wind Speeds for Each Anemometer at Mast 2605, December 1, 2013 to November 30, 2014**



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**Figure 3-2: Monthly Wind Speeds Measured at the Top Anemometer at Mast 2605, December 1, 2013 to November 30, 2014**

The following table provides, the average wind speed and the maximum 1-second gust observed, and specifies the averaging method used and the period of data considered. The averaging method varies as it depends upon the available dataset:

- Annual: average of the wind speed recorded over one or more full years.
- Annualised: the annualised wind speed is a weighted wind speed that is calculated from all available monthly average wind speeds—e.g. if 2 values are available for January and only one is available for February, the February value will have twice the weight of each January value in the final average.
- Average: due to insufficient data collection, the annual average wind speed was not calculated. The value given is the average of all available data.

**Table 3-3: Wind Speed Characteristics at the Mast**

Mast	Top Anemometer Height (m)	Period	Average Wind Speed (m/s)	Maximum 1-second gust (m/s)	Method
2605	35.0	December 1, 2013 to November 30, 2014	6.5	35.0	Annual



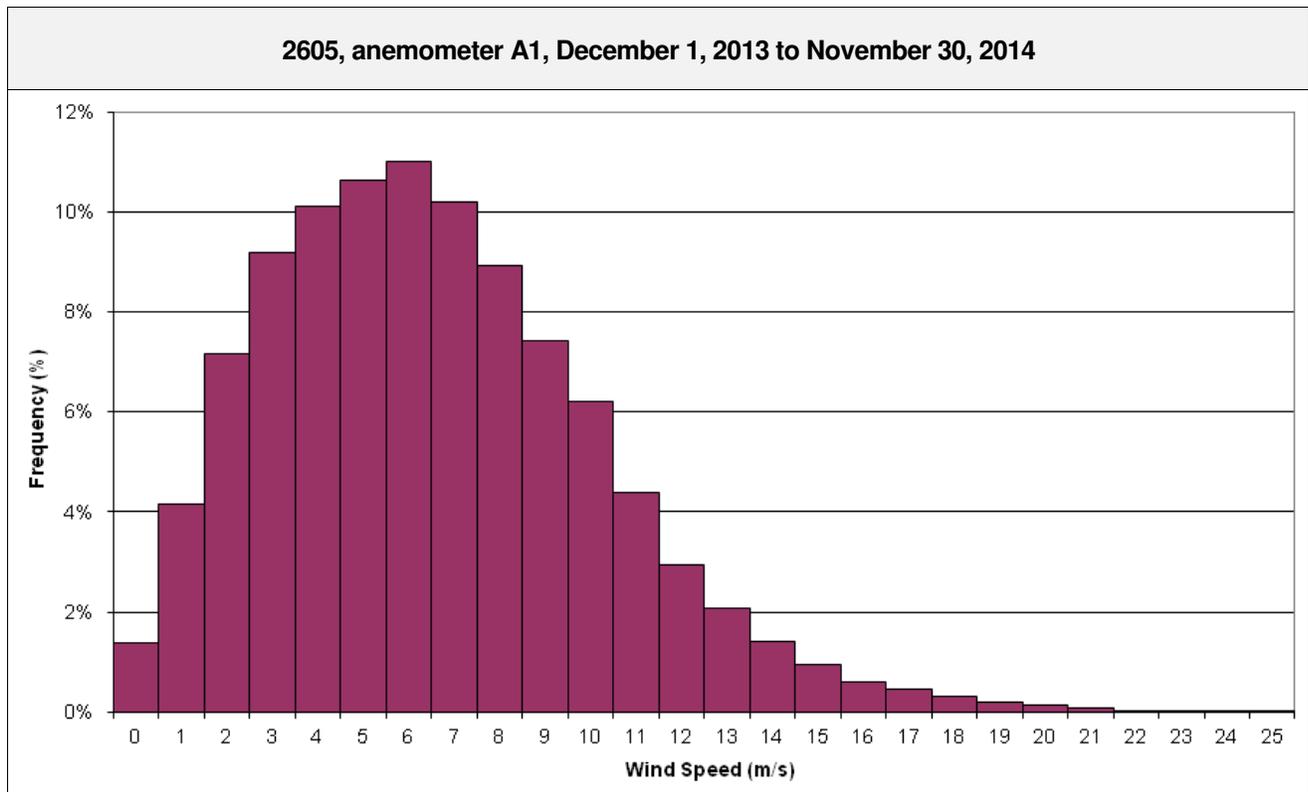
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### 3.2.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds helps to evaluate how much power is contained in the wind (power is proportional to the cube of the wind speed). Wind turbines will produce more power as the wind speed increases (until reaching the “rated” value). Thus, as the frequency of higher wind speeds increases, more power can be produced.

Annual frequency distributions generally exhibit a Weibull shape that is controlled by its “scale factor” (closely linked to the average wind speed) and its shape factor.

The wind speed frequency distribution graph is presented below for the mast<sup>1</sup>.



**Figure 3-3: Wind Speed Frequency Distribution Graph**

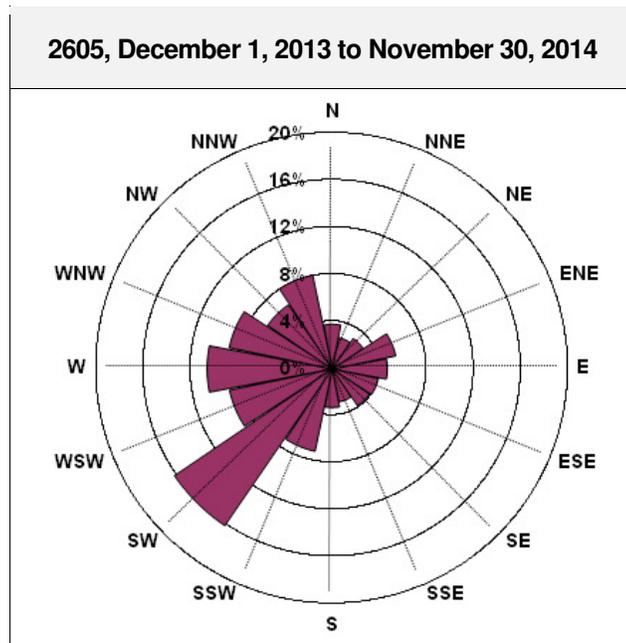
### 3.2.3 Wind Rose

The wind rose graph is presented below. The wind rose is divided into the conventional 16 compass sectors (22.5° wide sectors). Note that all compass orientations referenced in this report are based on the true geographic north, rather than the magnetic north.

<sup>1</sup> The 0 m/s wind speed bin indicates the fraction of the total number of measurements with a wind speed between 0 to 0.5 m/s. The other bins are 1 m/s wide and centered on the integer value (e.g.: the 1 m/s wind speed bin indicates the fraction with a wind speed between 0.5 to 1.5 m/s).



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**Figure 3-4: Wind Rose Graph**

The wind rose indicates that a significant proportion of the wind blows southwest, across the project area.

Note that wind roses are not adjusted to the long-term. Moreover, differences in wind directions between the levels of measurement are small enough to be neglected. As a consequence, the present wind rose will be considered as representative of the long-term wind rose at hub height.

### 3.2.4 *Wind Shear*

Wind speeds typically increase with height above the ground, because the frictional drag decreases with altitude. The increase in wind speed with height is referred to as wind shear and is commonly modeled either by a logarithmic law or by a power law.

When the power law is used, the wind shear can be quantified by a wind shear exponent. “Rough” surfaces, such as forested lands and urban areas, have a more pronounced frictional drag than “smooth” surfaces, such as a snow covered field or grasslands—the former will be associated with higher wind shear exponents. Over a smooth, level, grass-covered terrain, the wind shear exponent is typically around 0.14; over snow or calm sea it may be as low as 0.10; and over urban areas or tall buildings it may be as high as 0.40.

The roughness is not the only surface property that has a direct effect on the wind shear. When there is dense vegetation, the vertical wind speed profile is displaced vertically above the canopy, thereby displacing the level of zero wind speed to a certain fraction of the vegetation height above the ground. The “displacement height” is defined as the height at



which the zero wind speed level is displaced above the ground. The displacement height is taken into account in all wind shear estimations.

Finally, large topographic variations over short distances may also impact the wind vertical profile and thus affect the wind shear.

Hatch recommends using the log law to estimate the wind shear at mast locations. Internal studies have shown that the accuracy of the wind shear estimate is slightly improved with the log law when compared to the power law. When available, three wind speed measurements, each at a different height, are used and a log law curve is fitted through the average wind speeds at these heights. With the log law, the parameter that reflects roughness is called the roughness length, instead of the wind shear exponent. However, an equivalent wind shear exponent is calculated between the top anemometer height on a mast and the hub height for easier interpretation.

The equivalent wind shear exponent presented in this report was calculated between the top anemometer height of the mast and hub heights of 37 m and 40 m. The calculation was based on the measured wind speed at the anemometer height and the wind speed extrapolated to hub height by the log law method. The log law parameters were determined by fitting a logarithmic curve through the average measured wind speeds at the three measurement heights.

The average equivalent wind shear exponent is reported in the following table.

Based on our knowledge about the vegetation in the area of the mast, this value conforms to expected results.

**Table 3-4: Average Wind Shear at the Mast**

Mast	Period	Wind Shear
2605	December 01, 2013 to November 30, 2014	0.11

### 3.2.5 *Turbulence Intensity*

Turbulence characterises the gustiness of wind or high frequency changes in wind speed and direction (high turbulence is typical of very irregular wind flows, contaminated by whirls or vortices). Turbulence increases in areas with very uneven terrain and behind obstacles, such as buildings. In wind farms, it interferes with the effective operation of the wind turbines and increases their wear and tear.

The measurement of turbulence is expressed in terms of turbulence intensity, which is the standard deviation of the wind speed divided by the mean wind speed, over a given period. Turbulence intensity is expressed as a percentage. In the present study, the standard deviation and mean speed values are calculated from 1 second wind speed data averaged over a 10 minute period.

Turbulence intensity is more erratic and more difficult to quantify at low wind speeds. As a consequence, only wind speeds in excess of 4 m/s are used to calculate of the turbulence intensity. This threshold is consistent with IEC standards for wind turbine power performance measurements [4].



The turbulence intensity value was calculated with the top anemometer data.

The average turbulence intensity is reported in the next table. This value is considered moderate according to the reference values defined in reference [2]<sup>2</sup>. It is expected that turbulence will decrease with height, as the effect of obstacles and surface roughness will diminish.

**Table 3-5: Average Turbulence Intensity at the Mast**

Mast	Anemometer used	Period	Turbulence Intensity (%)
2605	A1	December 01, 2013 to November 30, 2014	14.4

### 3.2.6 *50-year recurrence wind speed*

The selected wind turbines Northern power 100 (NPS100) and Emergya Wind Technologies 900 kW (EWT900) are designed to survive a certain level of loading caused by an extreme wind event. Based on the specification provided by the manufacturers, the extreme survival wind speed at hub height is 59.5 m/s (see Appendix B).

At least 7 years of data at the met mast location or a nearby reference station are required. The Gumbel distribution was used to predict the once-in-fifty-year extreme wind speed. The data were extrapolated to hub heights of 37 m (NPS100) and 40 m (EWT900) with a power law exponent of 0.11 suggested for gusts as per Wind Energy Handbook [2] and IEC 61400-1 standard.

In the case of Cartwright project, the met mast has only 18 months of data. Thus, data from Cartwright Environment Canada station were used and based on hourly data at 10 metres height. The data cover the period from 2007 to 2014. The 50-year recurrence maximum wind speeds were estimated to be 49.4 m/s at 37 m and 49.8 m/s at 40 m which respect the turbines' specifications.

## 3.3 Other Climatic Data

### 3.3.1 *Temperature*

Temperature was measured at a height of 34 m. The following table presents the average monthly and annual temperature measured. The coldest 10-minute temperature recording measured during the data collection period was -30.0°C in the morning of January 8, 2015.

<sup>2</sup> Low levels of turbulence intensity are defined as values less than or equal to 0.10, moderate levels are between 0.10 and 0.25, and high levels are greater than 0.25. This classification is for meteorological turbulence only; it should not be used in comparison with IEC models. Meteorological turbulence should not be used to establish the wind turbine class.



**Table 3-6: Average Monthly and Annual Temperatures**

Mast ID	Monthly Air Temperature (°C)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2605	-13.6	-14.6	-12.0	-2.6	1.7	10.0	15.1	13.9	8.4	5.5	-4.3	-15.0	-0.6

### 3.3.2 Air Density

Wind energy is directly proportional to the air density. Consequently, the amount of energy produced by a wind turbine will also be directly proportional to the air density at the turbine location. Air density decreases with increasing temperature, decreasing pressure and increasing altitude.

Based on the measured temperatures and the standard barometric pressure of 101.3 kPa at sea level, the monthly average air densities were calculated. Note that to correct for changes in atmospheric pressure with height, the calculations account for the site elevation. The values were calculated over the entire analysis period reported in Table 2-2.

**Table 3-7: Monthly and Annual Average Air Density**

Mast ID	Monthly Air Density (kg/m <sup>3</sup> )												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2605	1.34	1.35	1.34	1.29	1.27	1.23	1.21	1.22	1.24	1.25	1.30	1.35	1.30

### 3.3.3 Power density

Wind speed, wind direction and air density data can be combined to provide information about the average power density at mast location. Wind power density indicates how much energy is available at a given instant for conversion by a wind turbine<sup>3</sup>. For example, strong winds in the winter, when the air is colder and denser, will have a higher power density (i.e. carry more energy) than the same strong winds in the summer. Though power is an instantaneous value, it is calculated as an average over a given period of time.

Tables of the power density distribution per direction and per month were produced at the top anemometer height and are presented below.

At mast 2605, the most powerful winds come from southwest to west-northwest, and appear in winter months. The annual average power density is 467 W/m<sup>2</sup> at 35 m.

<sup>3</sup> Note that the units "W/m<sup>2</sup>" refer to m<sup>2</sup> of rotor swept area.



**Table 3-8: Table of Wind Power Density per Direction, December 1, 2013 to November 30, 2014**

Wind Power Density per Direction (W/m <sup>2</sup> )															
N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
434	565	365	298	233	297	438	194	153	241	558	487	620	677	603	517

**Table 3-9: Table of Wind Power Density per Month, December 1, 2013 to November 30, 2014**

Wind Power Density per Month (W/m <sup>2</sup> )												Annual Average
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
677	426	436	307	206	151	111	129	342	280	825	579	467

### 3.3.4 Icing Events

Icing affects the operation of wind turbines. Icing on any exposed part of the turbine can occur in the form of wet snow (generally associated with temperatures between 0°C to 1°C), super-cooled rain or drizzle (that can occur at temperatures between 0°C to -8°C, but mostly in the upper part of this range), or in-cloud icing (that can occur below -2°C). Losses during production due to ice occur in several ways:

- Ice accumulation on the blades alters their aerodynamic profile, reducing the power output.
- Nacelle-mounted instruments accumulate ice and give inaccurate readings. The turbine control system may detect a fault condition due to the turbine output being much greater than expected. This expectation is based on the wind speed. As a result, the turbine will be shut down until the ice is removed from the instruments and the turbine is reset.
- Asymmetric icing causes mass or aerodynamic imbalance leading to vibrations. Control systems that sense vibrations will normally shut down when these vibrations occur.

Icing is a complex phenomenon and predicting icing from meteorological conditions is notoriously difficult, requires a good set of observations from a number of meteorology variables, and can be misleading. As no reliable instrument is presently available to detect and quantify icing events for the purpose of estimating their impact on wind energy production, Hatch uses several tests during data quality control to detect icing events: detection of unusual standard deviations or changes with time of wind speeds and directions, comparison of measurements from a heated anemometer and a standard anemometer at the same level, in parallel with the measurement of temperature.

These tests cannot distinguish between the different types of icing, but a rough approximation can be done by utilising the temperature ranges measured during icing events. Therefore, in the following estimate, we will consider two categories: “glaze”, which is assumed to include wet snow, super-cooled rain and drizzle, and “rime ice”, which is assumed to include in-cloud icing and the very low temperature part of super-cooled rain or drizzle. The threshold of -5°C is used to differentiate between rime ice (below -5°C) and glaze (above -5°C).

The following table presents the estimated number of icing events in a month and the type of event assumed to occur in the project area. This estimate is based on the average of icing events detected on the mast during the measurement campaign.



**Table 3-10: Estimated Hours of Icing Events, November 5, 2013 to April 30, 2015**

	January	February	March	April	May	June	
<b>Hours</b>	23	24	31	31	48	2	
<b>Rime</b>	30%	100%	40%	0%	0%	0%	
<b>Glaze</b>	70%	0%	60%	100%	100%	100%	
	July	August	September	October	November	December	Annual
<b>Hours</b>	0	0	0	0	79	38	275
<b>Rime</b>	-	-	-	-	0%	10%	18%
<b>Glaze</b>	-	-	-	-	100%	90%	82%



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## 4. Long-term Wind Speed at Hub Height

The previous section presented the analysis of the wind regime as it was measured by the met mast installed on the project site. However, to forecast the energy production of a wind power plant, wind data that represent the historical wind conditions at the site are required. Unfortunately, wind resource assessments are generally conducted for a limited number of years, often no more than one or two years, which is not sufficient to capture the year-to-year variability of wind. For example, in North America, the annual average wind speed exhibits a standard deviation of about 6% (or  $1\sigma$  from a normal distribution) of the long-term average wind speed. Hence, the maximum deviation from the average wind speeds could reach as much as 20% (or  $3.3\sigma$ ). Consequently, it is necessary to translate the measured short-term data into long-term data. This is done through a correlation/adjustment process that makes reference to a meteorological station where historical data are available.

Moreover, when the top anemometers of the met masts are mounted at a lower height than the expected hub height of the wind turbines, the long-term data must also be extrapolated from these anemometer heights to the wind turbine's hub height.

The long-term projection process is presented in the next section and is followed by the extrapolation to hub height.

### 4.1 Long-term Projection

When required, selecting a reference dataset to perform a long-term correlation and adjustment is determined by the following process:

- A quality assessment of the potential long-term reference stations for the site (history, similarity of the local climate with regards to the meteorology mast climate, etc.);
- A quality assessment of the correlation equations obtained with acceptable long-term reference stations and the measured data for the concurrent period;
- A comparison of the long-term correlation results obtained with all acceptable reference stations;
- A crosscheck of the resulting long-term adjustments with the measured data and the long-term trends at nearby reference stations or at a regional level;

Once the reference dataset is selected, it is used to adjust the met mast data to long-term conditions. This can be achieved either by synthesizing non existing years of data at the met mast site or by applying an adjustment factor to the measured data in order to better reflect the reference period. The process is as follows:

- The measured data from the met mast is correlated with the reference dataset;
- If the correlation parameters meet the synthesis criteria, then data are synthesized at the measurement mast for the complete reference data period; this method is referred to as the Measure-Correlate-Predict (MCP);
- If the criteria are not met but a good correlation can still be obtained with hourly or daily intervals, then the measured dataset is scaled up (or down) to long-term using the reference long-term average wind speed and the correlation equation obtained; this method is referred to as the Long-term Adjustment;



- If no correlation can be clearly established between a reference site and the met mast site, the measured data stay unchanged.

#### 4.1.1 Selection of reference dataset

The present section summarises the results of the analysis.

Among the possible set of reference stations, one station was selected and considered suitable for the long-term projection of the data at the met mast. This station is Cartwright monitored by Environment Canada (EC). The location of this station is given in the table below.

**Table 4-1: Identification of the Long-term Reference**

Name	ID	Instruments Height (m)	Latitude	Longitude	Elevation (m)
Cartwright	8501100	10.0	N 53° 42' 30.0"	W 57° 02' 06.0"	14.3

#### 4.1.2 Long-term Adjustment

The long-term adjustment consists of:

- Correlating short term data at the met mast with short term data at the reference station;
- Using the obtained linear regression equation,  $Y = m X + b$ , where  $X$  represents the long-term average wind speed at the reference station and  $Y$  is the estimated long-term average at the met mast;
- Applying an adjustment factor (to speed up or scale down) to the met mast short term data in order to obtain an average wind speed equal to the estimated long-term average at met mast (i.e.  $Y$ ).

For masts 2605, which displayed 18 months of data recorded, the long-term adjustment method was used for the long-term projection.

The wind speed data of the met mast were correlated to the concurrent wind speed data at the long-term reference station Cartwright. The hourly correlation with the reference data was acceptable ( $R^2$  greater than or equal to 0.7 is good correlation, above 0.85 is excellent), i.e. the hourly values of the reference station are representative of the hourly wind data of the project site. The results of the correlation are given in the following table. Linear regression equations were used to compare the data, where  $m$  is the slope of the equation,  $b$  is the intercept, and  $R^2$  is the coefficient of determination.



**Table 4-2: Correlation between Reference Station and met mast Wind Speeds**

Reference Station	Met Mast	Correlation Period		Hourly Wind Speed Correlations		
		Beginning	End	m	b	R <sup>2</sup>
Cartwright	2605	December 1, 2013	November 30, 2014	0.969	2.1	0.69

The regression equations were then used to estimate the long-term average wind speed at the mast as a function of the long-term wind speed at the reference station. The estimated long-term average at the Cartwright station is 5.0 m/s. It was estimated by averaging all annual averages over the period 2007 to 2014 (except 2012 having a very low recovery rate). The results are presented in the following table.

**Table 4-3: Long-term Adjustment factor at the met mast**

Met Mast	Wind Speed over Correlation Period (m/s)	Long-term Annual Wind Speed (m/s)	Adjustment Factor (%)
2605	6.5	7.0	6.4

The Cartwright EC station is a well maintained station as confirmed by an Environment Canada specialist. Since 2007, the U2A instrument has been replaced every year by new or rebuilt sensors and was changed to Ultrasonic sensor in November 2014. This modification should not affect the annual average wind speed of 2014 which is 4.5 m/s. The wind speed of 2014 is 0.5 m/s less compare to the long-term annual wind speeds measured at Cartwright station covering the period 2007 to 2014. It seems 2014 was a less windy year than previous years, which explain the high adjustment factor of 6.4% of the mast data.

Finally, the 10-minute measured data recorded at the met mast were scaled by the adjustment factor to reflect the long-term value. In terms of the wind direction data, the one-year dataset for the met mast remained untouched. As a result, the mast has a set of wind speeds and wind directions that are the best estimate of the long-term wind regime.

## 4.2 Extrapolation to Hub Height

The wind shear exponent, calculated with the measured data, was used to adjust the dataset to hub heights. The results are presented in the following table.

**Table 4-4: Estimated Long-term Wind Speed at Hub Heights\***

Met Mast	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2605	7.0	7.3	7.3

\* Estimated using the calculated wind shear



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## 5. Wind Resource Mapping and Projected Energy Production

Met masts provide a local estimate of the wind resource. Met mast locations are chosen based on how representative they are of the project site and in particular for potential wind turbine locations. However, since the number of met masts is usually limited compared to the expected number of wind turbines, it is necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area.

Wind modeling software, such as MS-Micro and WAsP, are known to produce erroneous wind flows over complex terrain. In this case, Hatch applies a method based on the Ruggedness Index (RIX) to calculate the wind flow for each mast data set while correcting errors on wind speed<sup>4</sup>. All produced wind flows are then merged by a distance-weighting process. When the RIX correction is not applicable, wind flows are calculated with each mast dataset and simply merged together by a distance-weighting process, without a RIX correction.

Once the wind flow map is built, it is possible to optimise the size and layout of the foreseen wind farm for the project, and then to calculate the projected energy production. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow (see section 3.2.4). These corrections result in an effective hub height for each wind turbine.

The wind flow and energy production are calculated with specialised software that require, apart from the met masts long-term data, background maps that contain the information on topography, elevation, roughness lengths (related to the land cover) and potential obstacles. This is also used in conjunction with the wind turbine characteristics. Finally, wind farm losses must be estimated in order to complete the energy estimate.

The first part of this section introduces the information and the methodology used to calculate the wind flow.

The next part will present the optimisation process and the results in terms of energy production.

The software used to map the wind resource and to calculate the energy production include:

- WAsP Issue 11.01.0016 from Risø for wind resource mapping;
- Wind Farmer Issue 4.2.2 from Garrad Hassan for layout optimisation and energy production calculations.

### 5.1 Background Data

#### 5.1.1 Topography and elevation

The topographic and elevation data come from files provided by the National Topographic Data Base (NTDB).

The contour line interval is 5 m within the project area and 20 m outside.

<sup>4</sup> Bowen, A.J. and N.G. Mortensen (2004). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.



### 5.1.2 *Roughness*

The base map for roughness lengths was determined from land cover information included in the NTDB files. This map was then checked and corrected using satellite imagery from Google Earth. Around most locations and wind turbines, pictures and information noted during site visits were also used to check and modify the land cover information. The spatial resolution considered for the roughness lengths is 30m.

The following table details the roughness lengths used by land cover category.

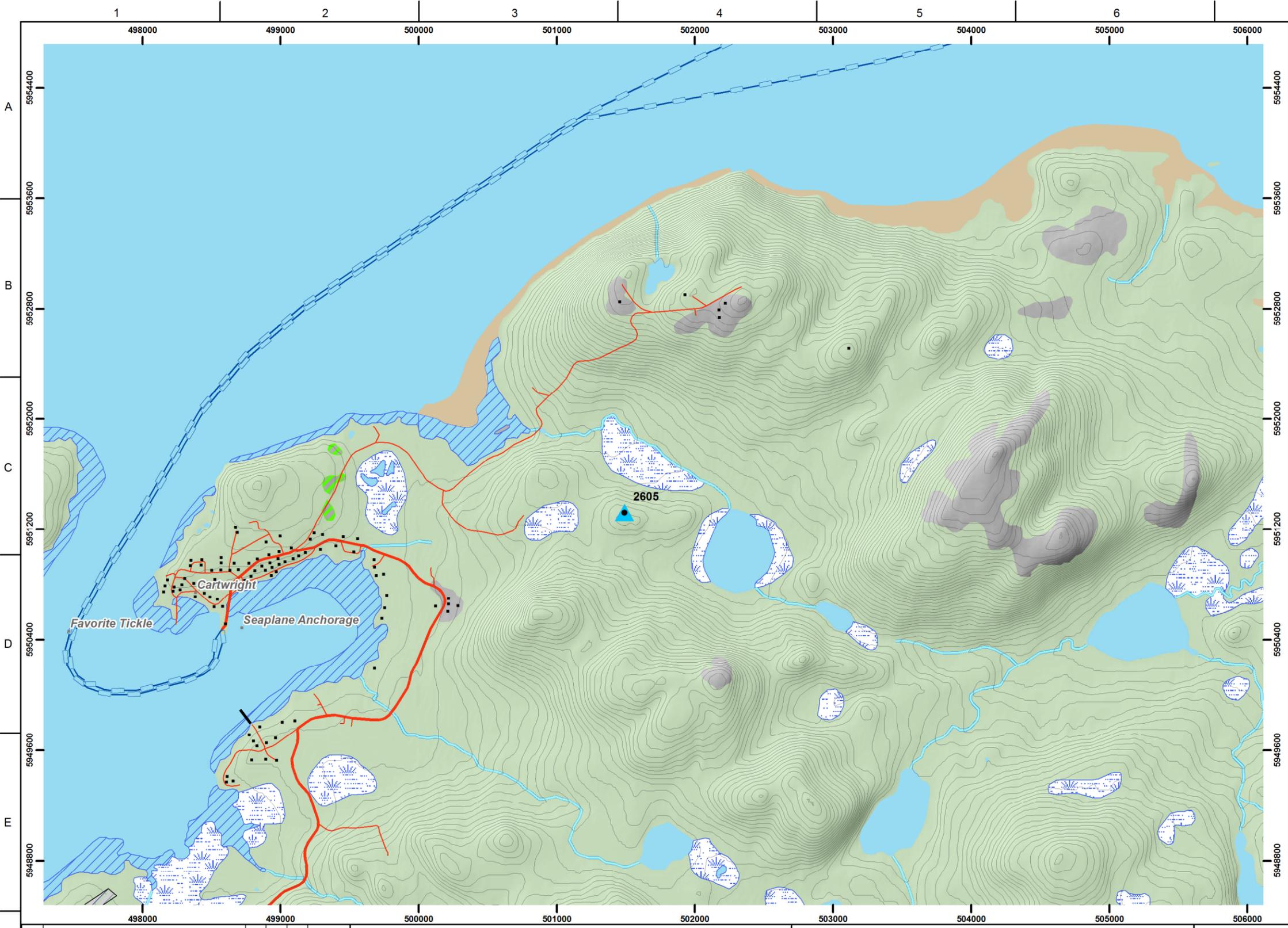
**Table 5-1: Roughness Lengths Categories**

<b>Land Cover Type</b>	<b>Roughness Length (m)</b>
Open farmland, high grass	0.04
Forest	0.8
Water	0
Building	0.5

### 5.1.3 *Background Map*

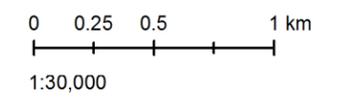
The background map, showing topography and contour lines is provided on the next page.





**Legend**

- Met Mast
- Building
- Contour (5m)
- Wharf
- Watercourse
- Ferry connection segment
- Mining area
- Reef
- Airport
- Wetland
- Waterbody
- Sand
- Vegetation



Spatial referencing UTM Zone 21 NAD83.

SOURCE :  
 Canvec - Natural Resource Canada 1:50 000  
 Action Canada Conference - Mt.Sophie viewer

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

**HATCH**

DESIGNED BY SLADJANA PAVLOVIC DATE: March 10, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: March 10, 2015
CHECKED BY Dany Awad DATE: March 10, 2015	

NALCOR

**Cartwright - Overview Map**

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## 5.2 Wind Flow Calculation

### 5.2.1 *Terrain Complexity*

The wind flow is produced over semi-complex terrain. Wind modeling software, such as MS-Micro (used in Windfarm) and WAsP, are known to produce erroneous wind flows over complex terrain. Depending on the topography, predicted wind speeds can be over or underestimated at a given location. Errors can reach more than 20% in very complex areas.

In the present case, the complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 5.2.2 *Parameters*

The following parameters were used to calculate the wind flow map.

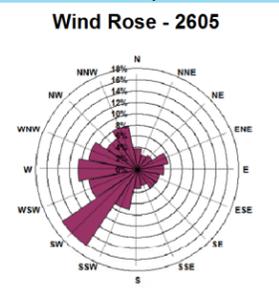
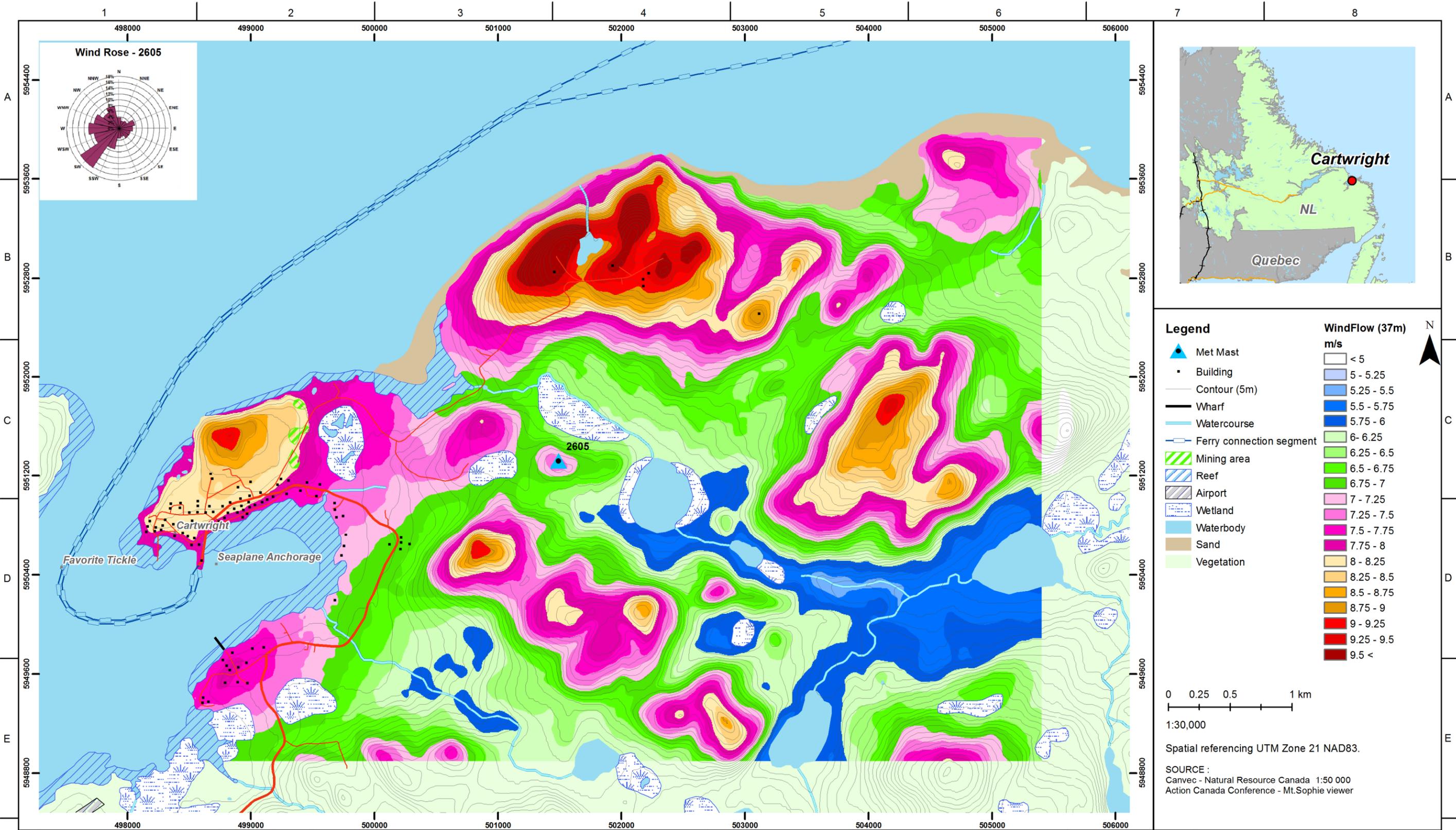
**Table 5-2: Wind Flow Calculation Parameters**

Parameter	Value
Wind Resource Grid Spatial Resolution	50 m
Calculation Area	7.5 km by 5.5 km
Reference Mast	2605
Reference Height	Top Anemometer Height
Calculation height	37 m
Vertical Extrapolation Method	Based on measured wind shear
Roughness Change Model	WAsP Standard Model

### 5.2.3 *Results*

The wind flow map used for layout optimisation and energy production estimates is presented on the next page.



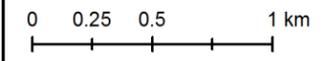


**Legend**

- ▲ Met Mast
- Building
- Contour (5m)
- Wharf
- Watercourse
- Ferry connection segment
- ▨ Mining area
- ▨ Reef
- ▨ Airport
- ▨ Wetland
- ▨ Waterbody
- ▨ Sand
- ▨ Vegetation

**WindFlow (37m) m/s**

- < 5
- 5 - 5.25
- 5.25 - 5.5
- 5.5 - 5.75
- 5.75 - 6
- 6 - 6.25
- 6.25 - 6.5
- 6.5 - 6.75
- 6.75 - 7
- 7 - 7.25
- 7.25 - 7.5
- 7.5 - 7.75
- 7.75 - 8
- 8 - 8.25
- 8.25 - 8.5
- 8.5 - 8.75
- 8.75 - 9
- 9 - 9.25
- 9.25 - 9.5
- 9.5 <



1:30,000

Spatial referencing UTM Zone 21 NAD83.

SOURCE:  
Canvec - Natural Resource Canada 1:50 000  
Action Canada Conference - Mt.Sophie viewer

NO	DESCRIPTION	BY	CHKD	APPD	DATE
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Wind resource map created by Hatch with WAsP 11.01.0016  
 Height of calculation: 37 m  
 Spatial resolution of wind resource grid: 50 m  
 Source file: Cartwright\_2605\_GridWRG\_37m\_WF2.grd  
 Source of data used to create the wind flow:  
 Topographic data are provided by the Center for Topographic Information (NRCan).  
 Meteorological data were collected from mast 2605, located 1 km on average from the center of the map, between 01/12/2013 and 30/11/2014. Data were controlled by Hatch.  
 Met data were adjusted for long term with reference to station Environment Canada Cartwright # 8501100 (reference period 2007-2014). It is believed that the present map gives a reliable overall picture of the wind resource. However, it is advised to confirm any information obtained from this map at any location by on-site measurements.

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DATE: March 10, 2015

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**Cartwright - WindFlow 2**

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### 5.3 Forecasting Energy Production

The layout was initially designed in order to maximise energy production. Turbines were spread out inside the project boundaries to minimise wake effects. The preliminary environmental screening and turbine extreme operating conditions also contributed to set the turbine locations.

#### 5.3.1 Preliminary Turbine Selection

A preliminary turbine selection was performed using Windographer software by comparing the performance of different turbines at the location of the met mast, where the dataset was recorded. The main parameters used for the comparison were the capacity factor of the wind turbine for the site specific conditions as well as the turbine purchase cost. Only turbines that meet the following criteria were considered:

- Site's turbine and turbulence class (IEC class II)
- Extreme wind and weather conditions (operation down to -40°C). The minimum 10-minute temperature recording of -30.0°C during the monitoring campaign confirms the site conditions are within the operating range of the turbine.
- Turbine capacity ranges from 100 kW to 1,000 kW to meet the community load
- Wind turbine's dimensions and weight versus crane capacity and accessibility

Hub heights of about 40 m to 50 m were used for this preliminary analysis.

Standard losses considered include: 12.5% technical losses and 2% wake losses.

The following table provides a summary of the turbine comparison.

**Table 5-3: Windographer Results at the Mast Location**

Turbine type	Turbine Class	Hub height (m)	Turbine Capacity (kW)	Mean Energy Output (MWh/yr)	Capacity Factor (%)	Turbine purchase cost (\$)
Northern Power NPS100 Arctic	IIA	37	100	259	29.5	325,000
Aeronautica AW/Siva29-250	IIA/IIIA	37	250	571	26.1	656,000
Aeronautica AW/Siva47-500	IB/IIA	47	500	1,438	32.8	1,632,000
EWT DW52-250 (EWT250)	IIA	37	250	1,096	50.0	1,980,000
EWT DW52-500 (EWT500)	IIA	37	500	1,704	38.9	1,990,000
EWT DW52-900 (EWT900)	IIA	40	900	2,184	27.7	2,000,000

The capacity factors listed above in table 5-3 are taken from Windographer and may change as a function of the site's optimized layout and should only be used for turbine comparison.

Due the lack of proven experience in remote arctic conditions, the Aeronautica wind turbine models were discarded from the analysis. Northern Power and EWT wind turbines have



been installed and are operating in similar site conditions in Nome, Alaska for EWT or in Kasigluk, Alaska for Northern Power and were thus further compared as part of the analysis.

The average community load at Cartwright during the project lifetime is around 500 kW. The following table shows the results of the WindFarmer optimization models using the required number of turbines to meet that load. The turbines were ranked based on their capacity factor, energy output and simple payback.

**Table 5-4: Preliminary Turbine Selection Results**

Turbine type	Number of wind turbine required	Total Capacity (kW)	Gross Energy Output (MWh/yr)	Gross Capacity Factor (%)	Total purchase cost (Million \$)	Ranking
<b>Northern Power NPS100 Arctic</b>	<b>5</b>	<b>500</b>	<b>1,813</b>	<b>41.4</b>	<b>1.625</b>	<b>2</b>
EWT250	2	500	2,945	67.2	3.960	4
EWT500	1	500	2,447	55.8	1.990	3
<b>EWT900</b>	<b>1</b>	<b>900</b>	<b>3,379</b>	<b>42.8</b>	<b>2.000</b>	<b>1</b>

\* Based on the gross energy output at 30 cents/kWh and the turbine purchase cost only.

Based on information provided by EWT, the 250 kW wind turbine has the same foundation design as the 500 kW and 900 kW machines and nearly the same price (\$10,000 difference). Because of the similar turbine costs of the three EWT models, from a financial point of view, the EWT900 becomes the most suitable having the lowest simple payback, and would also benefit from potential lower constructability and BOP cost.

The Northern power NPS100 Arctic can also be considered as potential candidates for the Cartwright project since it is a proven turbine in arctic conditions, and would provide for more redundancy due to number of turbines. The NPS100 has the advantage of being a smaller turbine and would be less difficult from a logistic and crane accessibility stand point.

The NPS100 and EWT900 turbines are two models that meet the wind class of the site and have proven technology for cold and icy environments.

Even though a more detailed turbine selection exercise will be required in later phase of the project, the NPS100 and EWT900 are considered suitable candidate turbines in order to complete the preliminary energy estimates for the potential Cartwright project.

### 5.3.2 *Layout Optimization*

The following section shows the WindFarmer modeling results which further refines the energy estimates for the turbines selected at the potential turbine positions and to confirm the capacity factor values. The table below outlines the parameters and constraints assumed to influence optimisation.



**Table 5-5: Layout Optimisation Parameters and Constraints**

Parameter / Constraint	Value	
<b>Annual Air Density</b>	1.30 kg.m <sup>-3</sup> at 91 m.a.s.l.	
<b>Turbulence Intensity</b>	14.4% at mast 2605 <i>Note: average value for information, the turbulence intensity is actually entered by wind-speed bins and by direction for energy prediction calculation</i>	
<b>Exclusion areas</b>	Due to the lack of information in regard to setbacks for wind energy projects in Newfoundland and Labrador, general restriction rules were used: - 500 m from habitations - 100 m from public roads - 50 m from lakes and rivers - 2 km by 1 km buffer zone from the airport track	
<b>WTG Minimum Separation Distance</b>	Elliptical separation: Minimum of 6 rotor diameters on long axis Minimum of 3 rotor diameters on short axis Bearing of long axis: 255 degrees	
<b>WTG Model</b>	EWT900	NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>WTG Power Curve</b>	See Appendix B	
<b>WTG Thrust Curve</b>	See Appendix B	
<b>Number of WTG's</b>	1	5
<b>Wind Farm Capacity (kW)</b>	900	500
<b>Wake Model</b>	Modified Park Model used for optimisation and Eddy Viscosity Model for final energy calculation as recommended by Garrad Hassan	
<b>Maximum Slope</b>	10 degrees	
<b>Optimization Strategy</b>	Layout designed in order to maximise energy production.	

The project layouts are presented at the end of this section.

The layouts are still considered preliminary. Land restrictions, communication corridors, noise and visual impacts, and other site-specific matters need to be evaluated through a detailed environmental assessment. Available land, road and collection system costs are also issues that will need to be addressed before the site layout can be finalized.



### 5.3.3 Energy production

Once the optimised layout has been produced, the energy production for each wind turbine is calculated. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow. These corrections result in an effective hub height for each wind turbine.

The calculation was executed with the power curves and thrust curves used for the optimisation and presented in Appendix B. The additional losses are described in the next section.

Note that air density is corrected by the software for each turbine location according to its elevation.

The following table is a summary of the estimated energy production. Detailed energy figures are presented per wind turbine on the next page.

**Table 5-6: Wind Farm Energy Production Summary**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
<b>WTG Rated Power (kW)</b>	900	100
<b>WTG Rotor Diameter (m)</b>	51.5	20.7
<b>WTG Hub Height (m)</b>	40.0	37.0
<b>Number of Wind Turbines</b>	1	5
<b>Wind Farm Capacity (kW)</b>	900	500
<b>Mean Free Wind Speed across Wind Farm (m/s)</b>	8.2	7.9
<b>Average Wake Losses (%)</b>	0.0	4.0
<b>Energy Production Before Additional Losses* (MWh/yr)</b>	3,379	1,813
<b>Capacity Factor Before Additional Losses* (%)</b>	42.8	41.4
<b>Additional Losses (%)</b>	14.2	14.0
<b>Net Energy Production (P50) (MWh/yr)</b>	<b>2,898</b>	<b>1,559</b>
<b>Net Capacity Factor (%)</b>	<b>36.7</b>	<b>35.6</b>

\* Includes topographic effect and wake losses



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**Table 5-7: Forecasted Energy Production at Wind Turbines**

Turbine ID	Easting (m)	Northing (m)	Altitude (m)	Mean Free Wind Speed (m/s)	Gross Energy Production* (MWh / Year)	Wake Losses (%)	Gross Energy - Wake* (MWh / Year)	Turbulence Intensity** (%)
<b>Layout 1 - EWT900</b>								
1	500851	5951650	47	8.2	3,379	0.0	3,379	15.1
<b>Layout 2 - NPS100 Arctic</b>								
1	500934	5951612	49	7.9	382	6.9	355	18.0
2	500888	5951482	48	7.7	367	2.9	356	17.1
3	500818	5951540	47	7.9	378	3.1	366	17.3
4	500783	5951622	41	7.8	376	1.8	369	17.0
5	500877	5951651	47	8.0	387	5.2	367	17.9

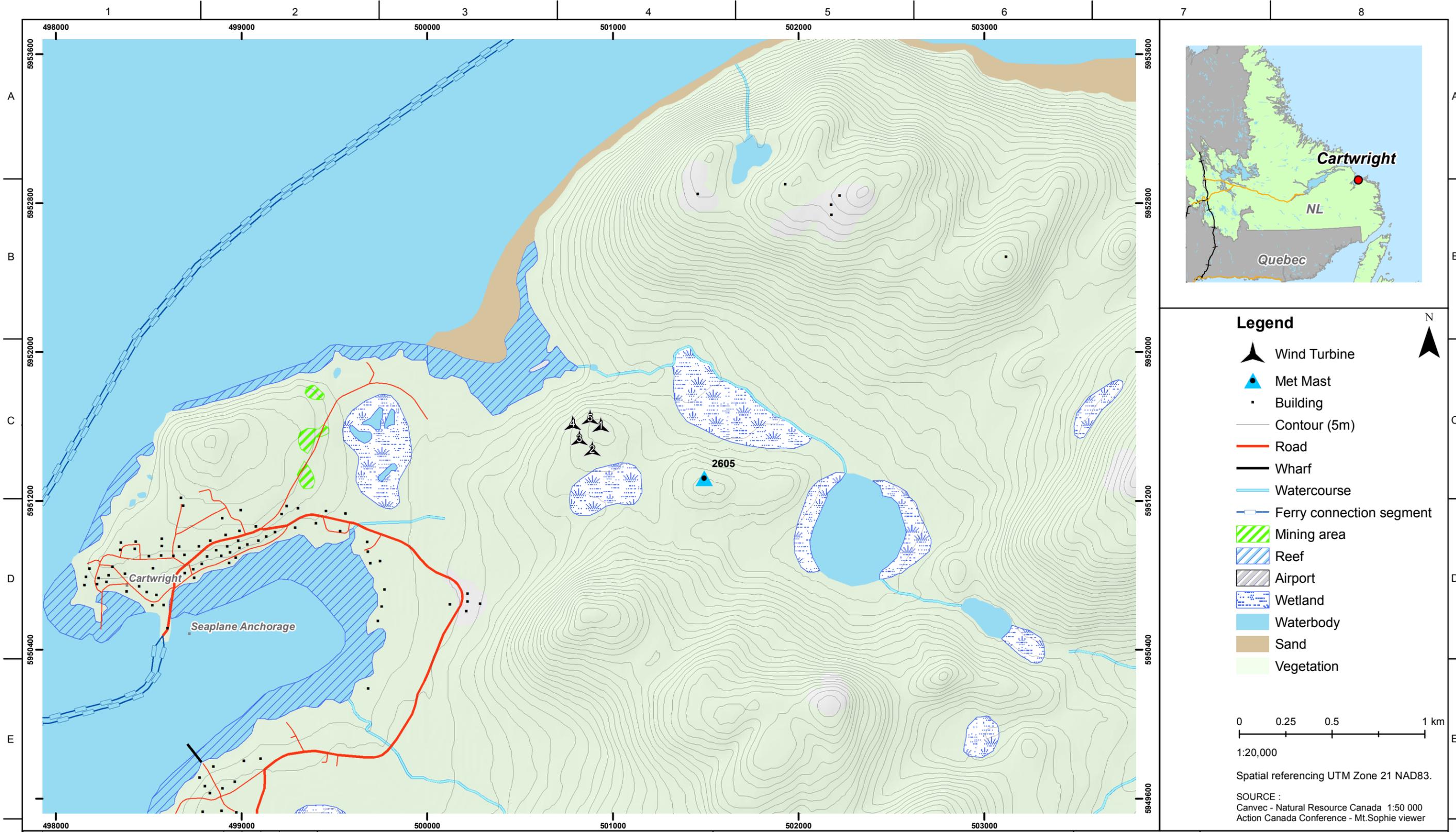
\* Gross energy production includes topographic effect; "Gross energy – Wake" includes topographic effect and wake losses.

\*\* Turbulence Intensity includes ambient turbulence and incident turbulence. The values represent true meteorological turbulence; they should not be compared directly with IEC models and consequently should not be used to establish the wind turbine class.



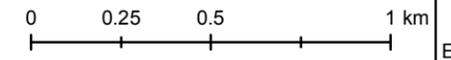
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**Legend**

- Wind Turbine
- Met Mast
- Building
- Contour (5m)
- Road
- Wharf
- Watercourse
- Ferry connection segment
- Mining area
- Reef
- Airport
- Wetland
- Waterbody
- Sand
- Vegetation



1:20,000  
 Spatial referencing UTM Zone 21 NAD83.  
 SOURCE :  
 Canvec - Natural Resource Canada 1:50 000  
 Action Canada Conference - Mt.Sophie viewer

Turbine model: Northern Power 100  
 Number of turbines: 5  
 Site capacity: 500 KW  
 Turbine rated power: 100 KW  
 Hub height: 37 m  
 File reference: Cartwright\_WF2\_Lay5.txt



DESIGNED BY DANY AWAD DATE: August 31, 2015	DRAWN BY SLADJANA PAVLOVIC DATE: August 31, 2015
CHECKED BY DANY AWAD DATE: August 31, 2015	

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**Cartwright - Layout 2**

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### 5.3.4 Losses

This section provides a description of the estimated losses included in the P50 estimate. These losses include environmental, electrical, availability, turbine performance losses and wake effects. The P50 is defined as the exceedance probability that denotes the level of annual wind-driven electricity generation that is forecasted to be exceeded 50% of the year. Half of the year's output is expected to surpass this level, and the other half is predicted to fall below it. Loss estimates should be reviewed as more detailed information becomes available.

The losses considered are presented in the following table and described hereafter.

**Table 5-8: Wind Farm Losses**

Loss Category	Loss Type	Losses (%)			
		Layout 1 - EWT900		Layout 2 - NPS100 Arctic	
<b>Environmental</b>	Blade Soiling and Degradation	1.0		1.0	
	High Wind Hysteresis	0.2		0.2	
	Icing	3.0	<b>4.5</b>	3.0	<b>4.2</b>
	Lightning	0.0		0.0	
	Low Temperature Shutdown	0.4		0.0	
<b>Electrical</b>	Collection Network	1.3	<b>3.7</b>	1.3	<b>2.2</b>
	Auxiliary power	2.4		0.9	
<b>Availability</b>	Wind Turbine Availability	5.0		6.5	
	Collection Network Outage	0.6	<b>5.8</b>	0.7	<b>7.3</b>
	Grid Availability	0.2		0.2	
<b>Turbine Performance</b>	Out-of-range Operation	1.0	<b>1.0</b>	1.0	<b>1.0</b>
<b>Wake effects</b>	Internal Wake Effects	0.0	<b>0.0</b>	3.9	<b>3.9</b>
	External Wake Effects	0.0		0.0	
<b>Total*</b>		<b>14.2</b>		<b>17.4</b>	

\* The total is the cumulated effect of the different losses and not their direct summation

**Blade soiling and Degradation** refers to the reduction of the blade's aerodynamic performance due to dust and/or insects. It also takes into account the future blade degradation attributed to wear of the blade's surface. The Cartwright project is not situated in



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a particularly dusty environment. This value is consistent with what is generally observed within the industry.

**High wind hysteresis** losses are caused by the control loop of the turbine around cut-out wind speed. They depend on the wind turbine design.

These estimations are based on the turbines' control loop specifications and high wind hysteresis simulations. Based on the available wind distribution at the mast, the loss induced by the hysteresis loop is 0.2%.

**Icing** losses happen in different ways: ice accumulation on blades alter their aerodynamic performance, nacelle-mounted instruments affected by ice give inaccurate readings and induce turbine control system errors, asymmetric icing causes mass or aerodynamic imbalance leading to vibrations that may force control systems to shut down the turbine. Icing can have different impact on the production of the turbine and the effect is site-specific. Some areas will be more affected by freezing rain or glaze ice and other regions are more prone to have rime ice or in-cloud icing.

Icing losses are estimated from the detection of icing events during met masts data quality control and translating the icing events into production losses. The level of ice is considered moderate as compared to other northern sites (up to 10% of icing losses).

Values should be taken with caution since no proven methodology is available and because the effect and characteristics of ice are highly site-specific. The uncertainty associated to these aspects is taken into account in the global uncertainty assessment.

**Lightning** has the potential to damage the turbine control system but also the blade integrity. Modern wind turbines have protection devices that most of the time allow continuous operation even after a lightning strike. There is however, a small chance that lightning will impact turbine operation. The lightning losses were estimated according to Environment Canada maps<sup>5</sup>.

**Low temperature shutdown** losses depend on the local climate, the turbine design and the control algorithm. In cold climates, turbine shutdowns can be driven by low temperature detection, even if the wind is blowing. According to the manufacturer's specifications, the wind turbines with cold weather package have an operation threshold of - 40°C. The loss is estimated based on the long-term temperature data measured at Cartwright Environment Canada station.

**Collection network** loss is considered at the interconnection point. It takes into account various elements, including the length of the cables connecting the wind turbines to the substation and the losses in the substation itself. Losses depend on the design of these elements.

These losses have been estimated by Hatch according to previous experiences with similar project size and conditions. They should be confirmed when the design of the collection network is finalized.

<sup>5</sup> <http://ec.gc.ca/foudre-lightning/default.asp?lang=En&n=42ADA306-1>



**Auxiliary power** losses account for various subsystems of a wind turbine that require electrical power, such as control systems or heaters. All of these losses are not always accounted for in the power curve. For example, cold packages designed for cold climate wind turbines can require energy even when the turbine is stopped.

Based on Hatch's experience, an estimated value is used to account for the consumption of standard auxiliary systems. Specific losses have been added for the Cold Package system delivered with the wind turbines. They have been estimated by simulation according to the Cold Package specifications of the EWT900 and NPS100 Arctic wind turbines.

**Wind turbine availability** losses represent the percentage of time over a year that the turbine is unavailable for power production. Losses include regular maintenance time and unexpected turbine shutdowns. A given availability rate is normally guaranteed by utility-scale wind turbine manufacturers such as EWT (95%), but in the case of smaller wind turbines (NPS100), no availability warranty will be offered by the manufacturer.

Based on Hatch's experience on wind farms in similar conditions and technology for isolated sites, Hatch considers the estimate of 6.5% to be adequate for the Project with NPS100 units. This estimation considers a standard maintenance schedule of 1 day per year per turbine, plus unscheduled repairs and delays due to site accessibility and weather conditions. This is based on information provided by the client that wind turbines will be considered as non-essential grid components and thus deficiencies will be considered as low priority, so that individual units may remain out of service for periods longer than normally considered.

**Collection Network Availability:** The collection network may be out of service, stopping energy delivery from the turbines to the grid. Collection network outage losses include shutdown time for scheduled maintenance and unexpected outages.

Based on the information provided by the client, the Cartwright based operators will manage the site and are expected to have the skills and manpower required to fix any collection system problem in a timely manner. The presence of a support team onsite has a positive impact on the availability of the collection network.

**Grid availability** losses depend on the utility distribution system quality and capacity. It represents the percentage of time over a year when the grid is not able to accept the energy produced by the wind turbines.

The value used assumes the wind turbines will be connected to the grid operated by NLH, which is assumed to be well maintained and operated.

**Out-of-range Operation** losses take into account the aspects usually not covered by the power curve warranty such as turbulence, wind shear and yaw errors. Parameters specific to the Project have been used to perform this loss estimate.

**Wake Effect** corresponds to the deficit in wind speed downstream of a wind turbine. Several models exist to quantify this effect in terms of induced energy losses. Hatch uses the Eddy Viscosity model which corresponds to a CFD calculation representing the development of the velocity deficit field using a solution of the Navier Stokes equations. Because of higher



precision as compared to the Park model and recommendations from WindFarmer, the Eddy Viscosity model is used to assess to the wake of the Project. Wake losses are highly dependent on the layout, especially regarding the distance between the turbine and the layout's compactness.

One of the input in the wake losses calculation is the thrust curve which is provided by the turbine manufacturer for the Project turbine model under consideration.

No other wind farm currently exist in the vicinity of the project. In addition, no future wind farm that may impact the Project in terms of wake is planned. Thus there are no additional wake losses.



## 6. Conclusions and Recommendations

### 6.1 Objectives of Analysis

The purpose of this report is to present a full wind resource assessment for the Cartwright site, including the estimation of the forecasted annual energy production.

### 6.2 Data Quality and Adjustments

The wind data recovery rates at the monitoring site, for the analysis period, exceed industry standards, with a recovery rate from 95.3% to 99.3% for the primary anemometers and 95.4% for the primary wind vane.

The measured data were adjusted to long-term through correlation with Environment Canada's Cartwright station, located 4 Km away from the project area. The Long-term adjustment method was applied since it was considered to be the best method for producing a representative dataset for the expected life of the project.

### 6.3 Wind Resource

The annual average wind speed at the met mast is a result of the measurements and the long-term adjustment. These wind speeds are summarised in the table below for top anemometer and hub heights.

**Table 6-1: Estimated Long-term Wind Speeds**

Mast (Measurement Height)	Estimated Long-term Wind Speed at Measurement Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s)	
		37 m	40 m
2605 (35 m)	7.0	7.3	7.3

The long-term dataset at the met mast was used to build the wind flow across the project area.

The complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 6.4 Forecasted Energy Production

The preliminary turbine selection analysis specified two suitable turbine models: EWT900 and NPS100 Arctic. These models were proven to be best in class for cold and icy environments and suitable for wind-diesel generation in remote community.

The main results of the energy production modeling are summarised in the table below.



**Table 6-2: Forecasted Annual Energy Production**

Item	Layout 1 - EWT900	Layout 2 - NPS100 Arctic
WTG Rated Power (kW)	900	100
Number of Wind Turbines	1	5
Wind Farm Capacity (kW)	900	500
Annual Net Energy Production (MWh/yr)	<b>2,898</b>	<b>1,559</b>
Net Capacity Factor (P50) (%)	<b>36.7</b>	<b>35.6</b>

There remains some uncertainty regarding loss estimates, which should be reassessed as more information becomes available, particularly in relation to warranty contracts and maintenance schedules. Note that the Annual Net Energy Production represents the total forecasted energy production by the wind turbines. The effective energy production used to displace fuel will be a bit lower and vary depending on the chosen layout scenario (type and number of wind turbines), timewise power load and wind resource.

## 6.5 Recommendations

It should be noted that a number of additional studies and more detailed analysis will be required to refine and validate the turbine selected, the turbine position, the energy and losses.

The integration optimization report will show which turbine model is considered optimal for the Cartwright site based on energy cost, control capabilities and logistics and provide recommendations for further analysis and studies prior to implementation.



## References

- [1] International Energy Agency Programme, *Recommended practices for wind turbine testing and evaluation – Task 11: Wind Speed Measurement and Use of Cup Anemometer*, 1999
- [2] National Renewable Energy Laboratory, *Wind Resource Assessment Handbook*, 1999
- [3] International Electrotechnical Commission, *Wind Turbines - Part 1: Design Requirements*, IEC 61400-1, Ed. 3, 2005-08.
- [4] International Electrotechnical Commission, *Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines*, IEC 61400-12-1, Ed. 1, 2005.
- [5] A Practical Guide to Developing a Wind Project, *Wind Resource Assessment*, 2011



# Appendix A

## Views at Mast Sites



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**View Facing North**



**View Facing East**



**View Facing South**



**View Facing West**

**Figure – A1: Views from Base of Mast 2605**

# Appendix B

## Wind Turbine Data



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**EWT DW52-900**

The power curve and the thrust curve were provided to Hatch by Emergya Wind Technologies.

**Table – B1: EWT Wind Turbine Performance Curves**

Rotor Diameter: 51.5 m		Hub Height: 40.0 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0		0		0		0.000	
1		0		1		0.000	
2		0		2		0.000	
3		7		3		0.866	
4		30		4		0.828	
5		69		5		0.776	
6		124		6		0.776	
7		201		7		0.776	
8		308		8		0.753	
9		439		9		0.722	
10		559		10		0.692	
11		698		11		0.613	
12		797		12		0.516	
13		859		13		0.441	
14		900		14		0.368	
15		900		15		0.296	
16		900		16		0.241	
17		900		17		0.199	
18		900		18		0.168	
19		900		19		0.143	
20		900		20		0.124	
21		900		21		0.109	
22		900		22		0.096	
23		900		23		0.085	
24		900		24		0.075	
25		900		25		0.067	



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**NPS100**

The power curve and the thrust curve were provided to Hatch by Northern Power.

**Table – B2: NPS100 Wind Turbine Performance Curves\***

Rotor Diameter: 20.7 m		Hub Height: 37.0 m		Air Density: 1.225 kg.m <sup>-3</sup>		Turbulence Intensity: N/A	
Wind Speed at Hub Height (m/s)		Electrical Power (kW)		Wind Speed at Hub Height (m/s)		Thrust Coefficients	
0		0		0		0	
1		0		1		0	
2		0		2		0	
3		0		3		0	
4		3.7		4		1.072	
5		10.5		5		0.963	
6		19.0		6		0.866	
7		29.4		7		0.820	
8		41.0		8		0.754	
9		54.3		9		0.687	
10		66.8		10		0.616	
11		77.7		11		0.548	
12		86.4		12		0.491	
13		92.8		13		0.436	
14		97.3		14		0.391	
15		100.0		15		0.347	
16		100.8		16		0.316	
17		100.6		17		0.286	
18		99.8		18		0.261	
19		99.4		19		0.239	
20		98.6		20		0.222	
21		97.8		21		0.206	
22		97.3		22		0.194	
23		97.3		23		0.184	
24		98.0		24		0.175	
25		99.7		25		0.167	

\* Power curve of the Northern Power 100 – standard model

Dany Awad  
DA:da



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Emergya Wind Technologies BV

Engineering

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Created by:	JT	Creation Date:	24-07-09
Checked by:	MB	Checked Date:	24-07-09
Approved by:	TY	Approved Date:	05-04-11

Title:

Specification

# **DIRECTWIND 52/54\*900 Technical Specification**

Revision	Date	Author	Approved	Description of changes
02	02-03-12	MB	TY	Format, minor text, blades, options
01	28-11-11	LE	TY	Corrections and drawings
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

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## 1 Introduction

This document provides a technical overview of the *DIRECTWIND 52/54\*900* Wind Turbine designed for the IEC class II/III application. It is to be read in conjunction with document S-1000921 "Directwind 52/54\*900 Electrical Specification".



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## 2 Technical Description

The *DIRECTWIND* 52/54\*900 is a direct-drive, variable speed, pitch regulated, horizontal axis, three-bladed upwind rotor wind turbine.

The gearless direct-driven synchronous generator operates at variable speed. This is made possible by an actively controlled AC-DC-AC IGBT power converter connected to the grid. Benefits of this design are low maintenance, constant power output at wind speed above rated, and relatively low structural loads compared to constant-speed stall-controlled or constant-speed pitch-controlled wind turbines.

The generator is fully integrated into the structural design of the turbine, which allows for a very compact nacelle design. The drive-train makes use of only one main bearing, whereas classic designs have separately supported main shaft, gearbox and generator. All dynamically loaded interfaces from the blades to the foundation are sturdy flange connections with machined surfaces, and high tensile steel pre-stressed bolt connections are used.

### 2.1 Operation and safety system

The turbine operates automatically under all wind conditions and is controlled by an industrial PLC (Programmable Logic Controller). The cut-in wind speed is approximately 3m/s. When the rotational speed reaches the cut-in threshold, the power converter begins to deliver power to the grid.

The power converter controls the generator power output and is programmed with a power set-point versus rotor speed curve. Below rated wind speed the power output is controlled to optimise rotor speed versus aerodynamic performance (optimum  $\lambda$ -control). Above rated wind speed the power output is kept constant at rated value by PD-controlled active blade pitching.

The dynamic responses of the drive train and power controller are optimised for high yield and negligible electrical power fluctuations. The variable speed rotor acts as a flywheel, absorbing fluctuating aerodynamic power input. The turbine controllers are located in the rotor hub and the tower base (with remote IO in the nacelle) and carry out all control functions and safety condition monitoring. In the case of a fault, or extreme weather conditions, the turbine is stopped by feathering of the blades to vane position (blades swivelled to 90° with respect to rotor's rotational plane). In case of power loss, an independent battery backup system in each blade ensures the blades are feathered.

In the case of less serious faults which have been resolved, or when extreme weather conditions have passed, the turbine restarts automatically to minimise downtime.

### 2.2 Generator

The multiple-pole, direct-drive generator is directly mounted to the hub. The stator is located in the non-moving outer ring and the wound pole, separately excited rotor rotates on the inner ring.

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The generator is designed such that all aerodynamic forces are directly transferred to the nacelle construction without interfering with the generator-induced loads.

## 2.3 Power Converter

The power converter is an AC-DC-AC IGBT active switching converter. It controls the generator to operate in its optimum range, and maintains power quality to the grid. The inverter can produce unity power factor ( $\cos\Phi=1$ ) to the grid under all load conditions. Power factor is also controllable within limits.

## 2.4 Rotor

The rotor is a three bladed construction, mounted up-wind of the tower. Rotational speed is regulated by active blade adjustment towards vane position. Blade pitch is adjusted using an electric servomotor on each of the blades.

Each blade has a complete, fully independent pitch system that is designed to be fail-safe. This construction negates the need for a mechanical rotor brake. The pitch system is the primary method of controlling the aerodynamic power input to the turbine.

At below rated wind speed the blade pitch setting is constant at optimum aerodynamic efficiency. At above rated wind speed the fast-acting control system keeps the average aerodynamic power at the rated level by keeping the rotor speed close to nominal, even in gusty winds.

The rigid rotor hub is a nodular cast iron structure mounted on the main bearing. Each rotor blade is connected to the hub using a pre-stressed ball bearing. It is sufficiently large to provide a comfortable working environment for two service technicians during maintenance of the pitch system, the three pitch bearings and the blade root from inside the structure.

## 2.5 Rotor blade set

The rotor blades are made of fibreglass-reinforced epoxy. The aerodynamic design represents state-of-the-art technology and is based on a pitch-regulated concept. No extenders are used and the aerodynamic design is optimal for this rotor diameter.

## 2.6 Main bearing

The large-diameter main bearing is a specially designed three row cylindrical roller bearing. The inner non-rotating ring is mounted to the generator stator. The outer rotating ring is mounted between the hub and generator rotor. The bearing takes axial and radial loads as well as bending moments. Entrance to the hub is through the inner-bearing ring. The bearing is greased by a fully automatic lubrication system controlled by the turbine PLC.

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## 2.7 Nacelle

The nacelle is a compact welded construction which houses the yaw mechanism, a service hoist and a control cabinet. Both the generator and the tower are flanged to the nacelle. The geometry of the construction assures an ideal transfer of loads to the tower and, with the absence of a shaft and gearbox, results in a simple design ensuring easy personnel access.

## 2.8 Yaw system

The yaw bearing is an internally geared ring with a pre-stressed four point contact ball bearing. Electric planetary gear motors yaw the nacelle. The yaw brake is passive and is based on the friction of brake pads sitting directly on the bearing ring, keeping the yaw system rigid under most loading conditions.

## 2.9 Tower

The nacelle assembly is supported on a tubular steel tower, fully protected against corrosion. The tower allows access to the nacelle via a secure hinged access door at its base. The tower is fitted with an internal ladder with safety wire and optional climb assistance, rest platforms and lighting. Standard hub heights are 35, 40, 50 and 75 metres.

## 2.10 Anchor

The turbine is supported by a concrete foundation. The connection to this foundation is provided by means of a cast-in tube or rod anchor.

## 2.11 Control System

### 2.11.1 Bachmann PLC

The M1 controller perfectly combines the openness of a PC-based controller with the reliability of industrial hardware platforms. Designed to withstand the toughest ambient conditions it guarantees error-free use over long periods of time.

A modern system architecture designed for consistent network-capability permits the easy integration of the M1 into the environment of the controller and system peripherals. Real-time ethernet permits the real-time networking of the controllers, and the support of all standard Fieldbus systems permits the connection of standard external components.

### 2.11.2 DMS

*DIRECTWIND* Monitoring System – EWT’s proprietary HMI featuring local monitoring and control at the turbine, integrated into a remote-access SCADA. DMS offers individual turbine control and total park monitoring and data logging from your Wind Turbine, Wind Park or internet access point.

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## 2.12 Earthing and lightning protection

The complete earthing system of the wind turbine incorporates:

1. Protective earthing:

A PE connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

2. Functional earthing:

Earthing system to minimize and/or remove the source of electrical interference that can adversely affect operation of sensitive electrical and control equipment.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, the functional earth connection may carry electric current during the normal operation of the turbine.

3. Lightning protection:

To provide predictable conductive path for the over-currents in case of a lightning strike and electromagnetic induction caused by lightning strike and to minimize and/or remove dangerous situations for humans and sensitive electrical equipment.

Since the mechanical construction is made of metal (steel), all earthing systems are combined.

## 2.13 Options

The following options are available:

- Cold climate operation (rated for operation down to -40°C)
- Ice detection and/or prevention system
- Aviation lights
- Shadow flicker prevention
- Low Voltage Ride-through (LVRT)
- Service lift (75m tower only)
- G59 protection relay

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### 3 Technical Data

Where data are separated by "/" this refers to the respective rotor diameter (52 / 54 m).

#### 3.1 Wind and Site Data

Wind class	II / III according to IEC 61400 – 1
Max 50-year extreme	59.5 / 52.5 m/s
Turbulence class	A ( $I_{15} = 0.16$ )
Maximum flow inclination (terrain slope)	8°
Max ann. mean wind speed at hub height	8.5 / 7.5 m/s
Nominal air density	1.225 kg/m <sup>3</sup>

#### 3.2 Operating Temperature

	Standard	Cold Climate
Min ambient operating	-20°C	-40°C
Max ambient operating	+40°C	+40°C

#### 3.3 Cooling

Generator cooling	Air cooled
Converter cooling	Water or air cooled (configuration-dependent)

#### 3.4 Operational Data

Cut in wind speed	3 m/s
Cut out wind speed	25 m/s
Rated wind speed	14 / 13.5 m/s
Rated rotor speed	26 rpm
Rotor speed range	12 to 33 rpm
Power output	900kW
Power factor	1.0 (adjustable 0.95 lagging to 0.95 leading) Measured at LV terminals

#### 3.5 Rotor

Diameter	52 / 54 m
Type	3-Bladed, horizontal axis
Position	Up-wind
Swept area	2,083 / 2,290 m <sup>2</sup>
Power regulation	Pitch control; Rotor field excitation
Rotor tilt angle	5°

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### 3.6 Blade Set

Type	PMC 24.5 / 25.8
Blade length	24.5 / 25.8 m
Chord at 22.0 m	0.879 m (90% of 24.5m blade radius)
Chord at 23.5 m	0.723 m (90% of 25.8m blade radius)
Chord Max at 5.5 m	2.402 m
Aerodynamic profile	DU 91, DU 98 and NACA 64618
Material	Glass reinforced epoxy
Leading edge protection	PU coating
Surface colour	Light grey RAL 7035
Twist Distribution	11.5° from root to 5.5m then decreases linearly to 0.29°, then non-linearly to 0°

### 3.7 Transmission System

Type	Direct drive
Couplings	Flange connections only

### 3.8 Controller

Type	Bachmann PLC
Remote monitoring	DIRECTWIND Monitoring System, proprietary SCADA

### 3.9 Pitch Control and Safety System

Type	Independent blade pitch control
Activation	Variable speed DC motor drive
Safety	Redundant electrical backup

### 3.10 Yaw System

Type	Active
Yaw bearing	4 point ball bearing
Yaw drive	3 x constant speed electric geared motors
Yaw brake	Passive friction brake

### 3.11 Tower

Type	Tapered tubular steel tower
Hub height options	HH = 35, 40, 50, 75 m
Surface colour	Interior: White RAL 9001, Exterior: Light grey RAL 7035

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### 3.12 Mass Data

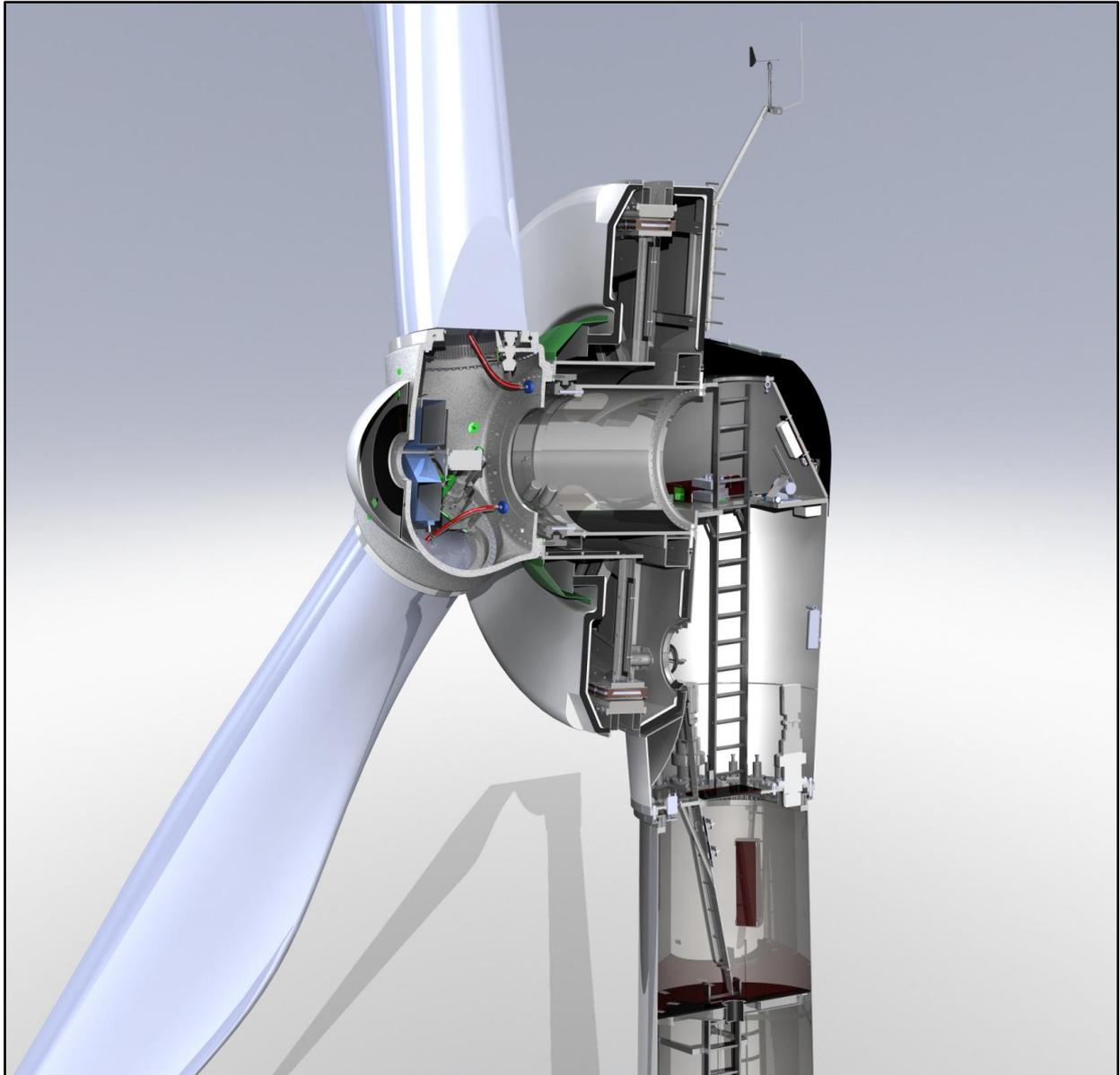
Hub	9,303 kg
Blade – each	1,919 / 1,931 kg
Rotor assembly	15,060 / 15,096 kg
Generator	30,000 kg
Nacelle assembly	10,000 kg
Tower HH35	28,300 kg
Tower HH40	34,000 kg
Tower HH50	46,000 kg
Tower HH75	86,500 kg

### 3.13 Service Brake

Type	Maintenance brake
Position	At hub flange
Calipers	Hydraulic 1-piece

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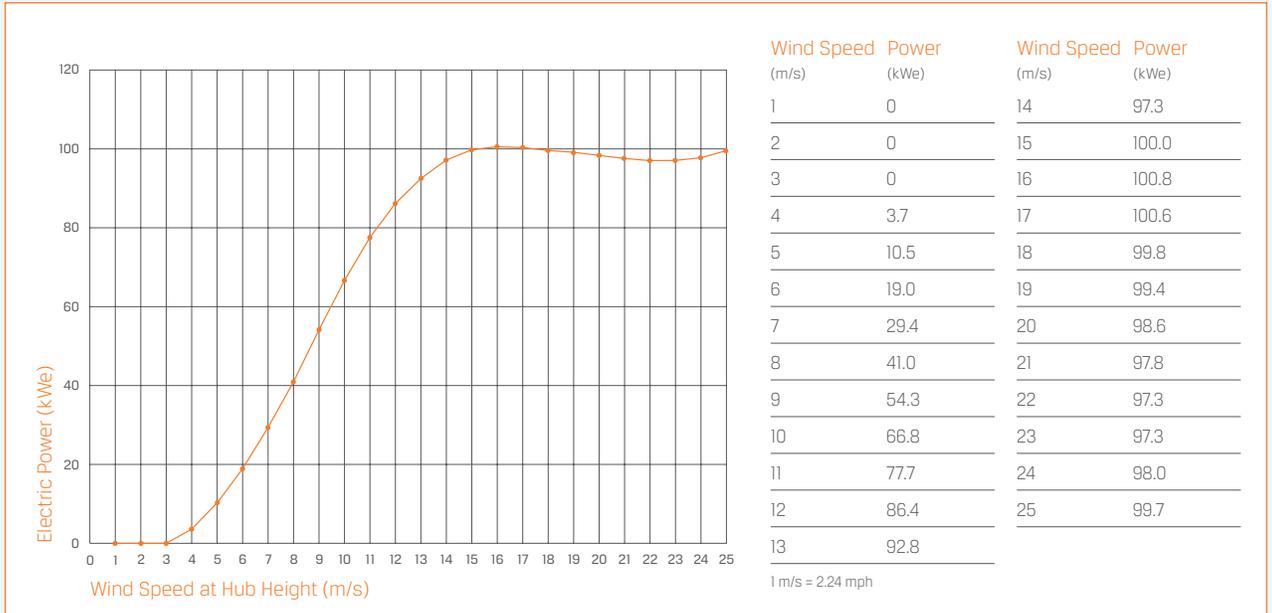
## APPENDIX 1: 3D image of main turbine components



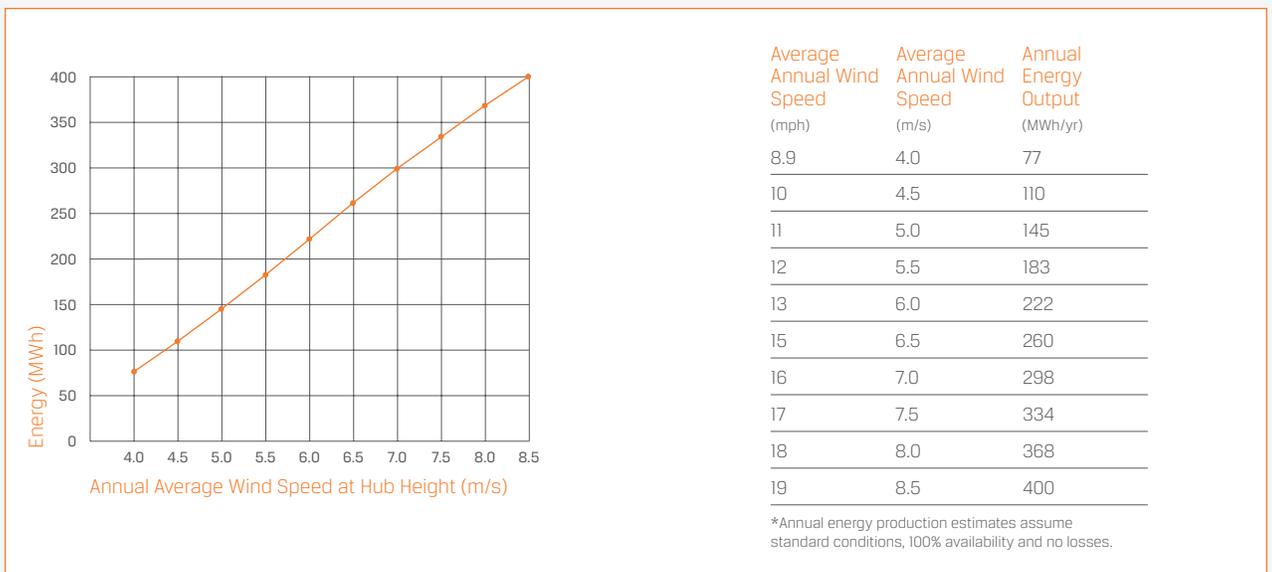


# Northern Power<sup>®</sup> 100

Power Curve: 21-Meter Rotor Standard Air Density (1.225 kg/m<sup>3</sup>)



Annual Energy Production\*: 21-Meter Rotor Standard Air Density, Rayleigh Wind Speed Distribution



## Specifications



GENERAL CONFIGURATION	DESCRIPTION
Model	Northern Power® 100
Design Class	IEC IIA (air density 1.225 kg/m <sup>3</sup> , average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 years
Hub Height	37 m (121 ft) / 30 m (98 ft)
Tower Type	Tubular steel monopole
Orientation	Upwind
Rotor Diameter	21 m (69 ft)
Power Regulation	Variable speed, stall control
Certifications	UL1741, UL1004-4, CSA C22.2 No.107.1-01, CSA C22.2 No. 100.04, and CE compliant
PERFORMANCE	DESCRIPTION
Rated Electrical Power	(standard conditions: air density of 1.225 kg/m <sup>3</sup> , equivalent to 15°C (59°F) at sea level) 100 kW, 3 Phase, 480 VAC, 60/50 Hz
Rated Wind Speed	14.5 m/s (32.4 mph)
Maximum Rotation Speed	59 rpm
Cut-In Wind Speed	3.5 m/s (7.8 mph)
Cut-Out Wind Speed	25 m/s (56 mph)
Extreme Wind Speed	59.5 m/s (133 mph)
WEIGHT	DESCRIPTION
Rotor (21-meter) & Nacelle (standard)	7,200 kg (16,100 lbs)
Tower (37-meter)	13,800 kg (30,000 lbs)
DRIVE TRAIN	DESCRIPTION
Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet, passively cooled
BRAKING SYSTEM	DESCRIPTION
Service Brake Type	Two motor-controlled calipers
Normal Shutdown Brake	Generator dynamic brake and two motor-controlled calipers
Emergency Shutdown Brake	Generator dynamic brake and two spring-applied calipers
YAW SYSTEM	DESCRIPTION
Controls	Active, electromechanically driven with wind direction/speed sensors and automatic cable unwind
CONTROL/ELECTRICAL SYSTEM	DESCRIPTION
Controller Type	DSP-based multiprocessor embedded platform
Converter Type	Pulse-width modulated IGBT frequency converter
Monitoring System	SmartView remote monitoring system, ModBus TCP over ethernet
Power Factor	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive Power	+/- 45 kVAR
NOISE	DESCRIPTION
Apparent Noise Level	55 dBA at 30 meters (98 ft)
ENVIRONMENTAL SPECIFICATIONS	DESCRIPTION
Temperature Range: Operational	-20°C to 50°C (-4°F to 122°F)
Temperature Range: Storage	-40°C to 55°C (-40°F to 131°F)
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection
Icing Protection	Turbine designed in accordance with Germanischer Lloyd Wind Guidelines Edition 2003

All Specifications subject to change without notice.

NPS100SS-2222011-US

# Appendix E: Wind Resource Assessment Report – L'Anse-Au-Loup



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H340923-0000-05-124-0012, Rev. B

Project Report

November 15, 2015

## Newfoundland and Labrador Hydro L'Anse au Loup Wind Project

### Distribution

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## Final Wind Resource Assessment Report



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H340923-0000-05-124-0004, Rev. 2  
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## DOCUMENT HISTORY

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2	November 15, 2015	Few edits based on comments from NLH on October 30, 2015 – Final Version



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## EXECUTIVE SUMMARY

In order to assess the potential of L'Anse au Loup site for wind power development, a wind resource assessment (WRA) was completed. The site is located near the community of L'Anse au Loup, Newfoundland and Labrador, Canada. The site was equipped with one met mast that is described in the table below.

Met Mast	Installation Date	Top Anemometer Height (m)	Elevation (m)	Data Collection* Starts...	Data Collection* Ends...
2604	October 5, 2013	35.0	179	November 01, 2013	October 31, 2014

\* A 12 month period is selected to estimate the annual energy production

In the analysis, the quality control process demonstrated that the data recovery rates exceeded 95.2 % on all instruments which meets industry standards for wind measurement campaign. Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements.

The **wind speed** measured at the mast is **7.7 m/s** on average. The **winds are dominant from southwest to west and from northeast to east-northeast** across the site.

The wind **turbulence intensity** observed at the site is generally **moderate**.

Given the land cover and topography at the mast the **wind shear exponent**, equal to **0.19**, is consistent with the expected value.

Met Mast	Period	Annual Average of Measured Wind Speed* (m/s)	Annual Average of Measured Turbulence Intensity* (%)	Annual Wind Shear
2604	November 1, 2013 to October 31, 2014	7.7	13.1	0.19

\* at Top Anemometer Height

During the data quality control process, icing events were detected on anemometers and wind vanes. **Icing occurred 6.8% of the time** at the site. Given the site elevation and the temperatures associated with these events, it is likely that about 44% of these events were caused by freezing rain and about 56% were caused by rime ice. Icing events mainly occurred during the months of December to February.

Temperature data were collected at the mast. The monthly averages range from **-13.7°C** in December to **13.4°C** in July, with an **annual average** of **-0.3°C** for the analysis period. The coldest 10-minute temperature recording during the data collection period was **-32.2°C**.

The **air density** was calculated at the mast according to the elevation and the local temperature. The annual value is **1.27 kg/m<sup>3</sup>**.



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The annual average power density is **620 W/m<sup>2</sup>**. The most powerful winds come from north to ENE, SW and WSW across the site.

In order to estimate the **long-term wind regime** at the site, several potential **reference stations** with historical data were selected.

The **Lourdes De Blanc Sablon A station** monitored by Environment Canada, located 30 km away from the potential wind farm site, was selected as the reference station for the long-term extrapolation of the data. The reference station data were then correlated to met mast 2604 and used to translate the short-term data into long-term estimates.

The long-term estimates were then extrapolated from measurement height to hub height.

Met Mast	Period	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height (m/s) at 40 m
2604	November 1, 2013 to October 31, 2014	8.0	8.2

The wind resource estimated at the mast was used to compute the wind flow across the project area. The wind flow was calculated with WAsP 11.01.0016 software, which is an appropriate model for the L'Anse au Loup project area which exhibits a moderate terrain complexity.

This wind flow was used to optimise the layout of the potential wind farm and to estimate the energy production with WindFarmer software.

A preliminary turbine selection analysis was completed and the Emergya Wind Technologies 900 kW (EWT900) wind turbine was selected. This model has proven technology in cold and icy environments and is suitable for wind-diesel generation in remote community.

A wind farm layout optimisation was completed taking in consideration energy production, information from the preliminary environmental screening and turbine extreme operating condition.

The main results of the energy production modeling are presented below. Additional losses include blade soiling, icing, collection network losses, auxiliary power consumption, wind turbines availability, high wind hysteresis, low temperature shutdown, collection network outage and grid availability.

Layout	Wind Farm Capacity (kW)	Net Energy Production (MWh/year)	Net Capacity Factor (%)	Wake Losses (%)	Additional Losses (%)
Layout 1 - EWT900	3600	11,651	36.9	1.2	13.7

Other energy production scenarios will be covered under separate portion of the wind penetration report.



## 1. Introduction

Hatch has been mandated by Newfoundland and Labrador Hydro (NLH) to carry out a wind resource assessment (WRA) for a potential wind project, located near the community of L'Anse au Loup, Newfoundland and Labrador, Canada.

The site was instrumented with one meteorological ("met") mast. The installation was completed on October 5, 2013. The mast was equipped with sensors at several heights to measure wind speed, wind direction and temperature. The analysed data cover a total measurement period of one year.

The second section of this report presents an overview of the site and the measurement campaign.

The third section presents the main characteristics of the wind climate.

The fourth section details the process used to translate the measured short-term data into long-term data.

The fifth section presents the methodology used to obtain the wind flow map over the project area. The wind flow map optimises the wind farm layout and helps determine monthly and annual energy production estimates. The key resulting values of these estimations are provided, including a description of the losses considered in the net energy calculation.

## 2. General Information

This section summarises general information about the site, the meteorological (met) mast installed and the measurement campaign.

### 2.1 Site Description

#### 2.1.1 Site Overview

The community of L'Anse au Loup is located on the extreme south of Labrador in the middle of the strait of Belle-Isle, near the Quebec border. The surroundings of the community consists mainly of small hills covered by Nordic type vegetation with an average elevation of 150m above sea level.





**Figure 2-1: Typical Landscape at the L'Anse au Loup Area**

### 2.1.2 Mast Location

The location of met mast 2604 was chosen with agreement between Hatch and NLH. Hatch proceeded with the installation of the mast and followed industry standards [1].

Table 2-1 provides a description of the mast, including the exact coordinates and the elevation.

The location of the mast is shown on the map provided on next page.

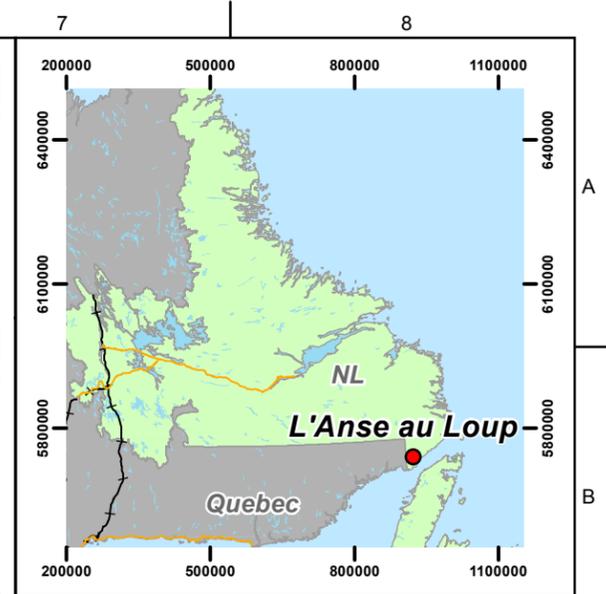
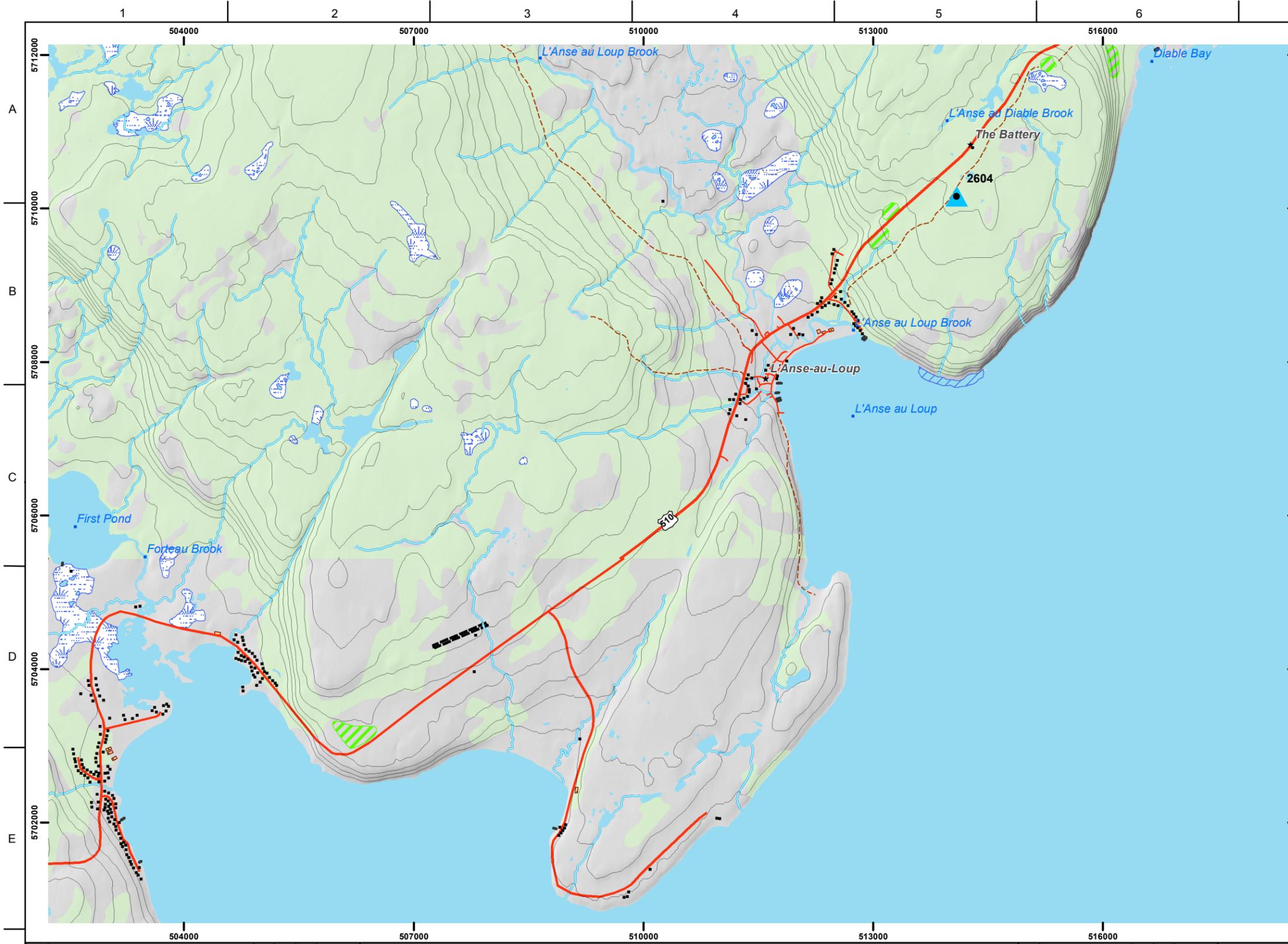
**Table 2-1: Met Mast Characteristics (Coordinate System: NAD83)**

ID	Type	Side Length (m)	Height (m)	Latitude	Longitude	Elevation (m)
2604	Square Lattice	0.404	36	N 51° 32' 32.4"	W 56° 47' 48.6"	179

The L'Anse au Loup met mast (#2604) is located on a hill which dominates the community on its northeast side. The hill maximum height is approximately 200m and the tower is located on the top of a bog. Near the tower, there are patches of pine trees that are no more than 4m high.

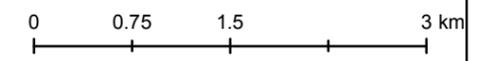
Pictures have been provided in Appendix A with views in the four main geographical directions at the met mast.





**Legend**

- Met Mast
- Building
- Contour Line (20m)
- Trail
- Road
- Wharf
- Watercourse
- Wetland
- Cemetery
- Mining area
- Reef
- Water Body
- Vegetation



1:55,000  
Spatial referencing UTM Zone 21 NAD83

SOURCE :  
Canadian Digital Elevation Data 1:50 000  
Canvec - Natural Resource Canada 1:50 000  
Environnement Canada: National Climate Data  
Google Earth Pro

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					
1					
2					

REV.	ISSUE FOR	AUTH. BY	DATE
ISSUE AUTHORIZATION			

**HATCH**

DESIGNED BY DANY AWAD	DRAWN BY SLADJANA PAVLOVIC
DATE: September 09, 2015	DATE: September 09, 2015
CHECKED BY DANY AWAD	
DATE: September 09, 2015	

NALCOR

**L'Anse au Loup Overview Map**

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## 2.2 Measurement Campaigns

The mast characteristics, instrumentation, installation dates and periods of data collection are provided in this section.

### 2.2.1 Installation and Collection Dates

The following table provides the date of mast installation and the period of data collection used in the analysis.

**Table 2-2: Installation Date and Period of Relevant Data Collection**

ID	Installation date	Date and time of first data used	Date and time of last data used
2604	October 5, 2013	November 01, 2013, 00:00 AM	October 31, 2014, 11:50 PM

### 2.2.2 Instrumentation

#### 2.2.2.1 Sensors Mounting

The met mast was equipped with anemometers and wind vanes mounted on booms at several heights. The dimensions of the booms, their heights and orientations on the mast, were designed to comply with the best practices in wind resource assessment as specified in [1] and [2].

For the met mast, the instrument and installation parameters are provided in the table below. All instruments and met mast underwent regular maintenance checks.

Heated anemometers and wind vanes were installed to increase the data recovery rate during icing periods. An Autonomous Power System (A.P.S.) developed by Hatch was installed to power supply the heating instruments. The A.P.S. consists of a set of batteries charged by a small wind turbine through a controller.

**Table 2-3: Installation Parameters of Instruments at the met Mast**

Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
<b>Mast 2604</b>							
<b>Data Acquisition System</b>							
N/A	N/A	N/A	NRG Symphonie PLUS3	Oct 05, 2013	July 17, 2015	N/A	N/A
<b>Anemometers</b>							
#1	A1	35.0	NRG #40C	Oct 05, 2013	July 17, 2015	Yes / No	P
#2	A2	35.0	NRG Icefree III	Oct 05, 2013	July 17, 2015	Yes / Yes	R
#3	A3	26.0	NRG #40C	Oct 05, 2013	July 17, 2015	Yes / No	P



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Channel	ID	Height (m)	Type	Date Installed	Date Uninstalled	Calibrated / Heated	Primary / Redundant
#4	A5	26.0	RMYoung 5103-AP	Oct 05, 2013	July 17, 2015	Yes / No	R
#13	A4	17.0	NRG #40C	Oct 05, 2013	July 17, 2015	Yes / No	P
<b>Wind Vanes</b>							
<b>#7</b>	<b>V1</b>	<b>33.0</b>	<b>NRG Icefree III</b>	Oct 05, 2013	<b>July 17, 2015</b>	<b>No / Yes</b>	<b>P</b>
#8	V2	26.0	RMYoung 5103-AP	Oct 05, 2013	July 17, 2015	No / No	R
#9	V3	15.0	NRG #200P	Oct 05, 2013	July 17, 2015	No / No	R
<b>Temperature Sensor</b>							
#10	T	34.0	NRG #110S	Oct 05, 2013	July 17, 2015	No / No	P

*Note: Lines in bold font correspond to the anemometer and wind vane considered as the principal instruments for wind characterisation at the mast location.*

#### 2.2.2.2 Data Acquisition System

For met mast 2604, the instruments were connected to a data acquisition system which stored the data on a memory card. The data were then sent to Hatch computer network by a satellite communication system every 3 days.



### 3. Meteorological Data Analysis

This section presents a comprehensive analysis of the data collected. In the first section, the quality of the data is reviewed. The characteristics of the wind measured at the mast are then presented in Section 3.2 through a number of relevant parameters:

- monthly and annual average wind speeds;
- wind speed distribution;
- wind direction distribution;
- wind shear;
- turbulence intensity;
- 50-year recurrence wind speed.

In the final section, other climatic information such as measured temperature, calculated air density, wind power density and icing events is presented and discussed.

#### 3.1 Quality Control

The quality and completeness of the data are key factors that determine the reliability of the wind resource assessment.

Data are collected periodically from the met masts and the quality of the data is analysed. This is done by applying a variety of logical and statistical tests, observing the concurrent readings from different instruments and relating these observations to the physical conditions at the site (e.g. wind shading, freezing potential, etc.). The process is semi-automated: the tests are implemented in a computer program developed by Hatch, but the expertise of quality analysts are required to accept, reject or replace data. There are many possible causes of erroneous data: faulty or damaged sensors, loose wire connections, broken wires, data logger malfunction, damaged mounting hardware, sensor calibration drift, icing events and different causes of shading (e.g. shading from the mast or from any obstacles at the site). A list of the possible error categories used during quality control is presented in Table 3-1. Data points that are deemed erroneous or unreliable are replaced by redundant data when available, or removed from the dataset.

The data recovery rate for the analysis period is then calculated for each of the instruments using the following equation:

$$\text{Data recovery rate (\%)} = \frac{\text{Number of valid observations}}{\text{Number of potential observations}} * 100$$

The “Number of valid observations” is evaluated once erroneous or unreliable data are replaced with available redundant data. The “Number of potential observations” is the theoretical maximum number of measurements that could be recorded during the analysis period. A high data recovery rate ensures that the set of data available is representative of the wind resource over the measurement period.



**Table 3-1: Quality Control Table**

Error Categories
Unknown event
Icing or wet snow event
Static voltage discharge
Wind shading from tower
Wind shading from building
Wind vane deadband
Operator error
Equipment malfunction
Equipment service
Missing data (no value possible)

### 3.1.1 **Data Replacement Policy**

Erroneous or unreliable data were replaced with available redundant data from instruments on the same met mast since these are considered to be equivalent wind measurements. Replacements were done directly or by using a linear regression equation. Direct replacement is applied to anemometers when the replaced and replacing instruments are of the same model, calibrated, at the same height, and well correlated. Direct replacement is also applied to wind vanes as long as they are well correlated.

An acceptable percentage of the dataset is replaced by equivalent instruments (e.g. A1-A2: 10% of replacement) and it is considered to have a small impact on the uncertainty of the measurements.

### 3.1.2 **Recovery Rates**

The following table presents the recovery rates calculated for each instrument after quality control and after replacements have been completed according to the replacement policy.

**Table 3-2: Instruments Data Recovery Rates**

Mast ID	A1	A3	A4	V1	T
2604	99.0%	97.9%	95.2%	98.2%	100.0%

Note that the recovery rates for the following instruments are identical, given the replacement policy:

- A1 and A2; A3 and A5
- V1, V2 and V3



### 3.1.3 Data History

The data recovery rates exceed industry standards [5]. A number of data were affected for short periods of time by usual effects, such as shading effect and short period of icing events, and were removed. An occasional high discrepancy on V3 was found as compared to other vanes due to high standard deviation in the dominant wind direction.

## 3.2 Wind Characteristics

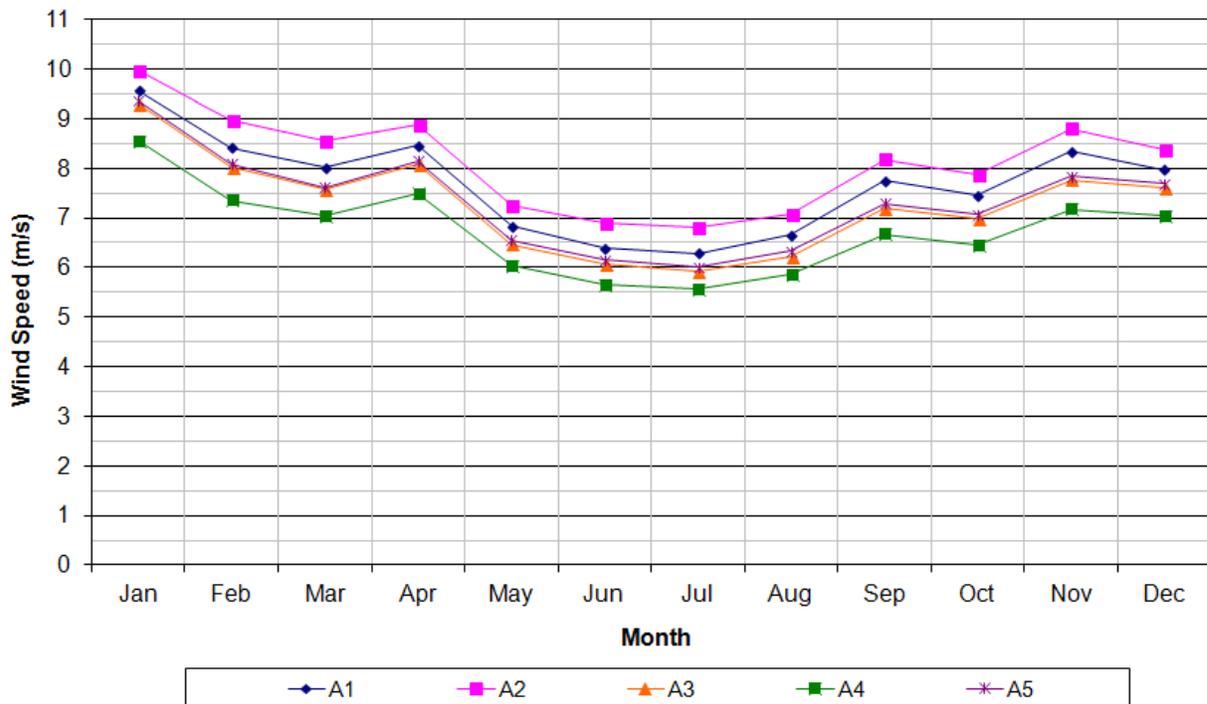
### 3.2.1 Annual and Monthly Wind Speed

The monthly wind speeds measured at each anemometer are shown in the following figures for mast 2604. The data are presented in two formats (see Figure 3-1 and Figure 3-2):

- a) for all instruments, the averaged monthly wind speed measured;
- b) for A1, all monthly wind speeds also reported.

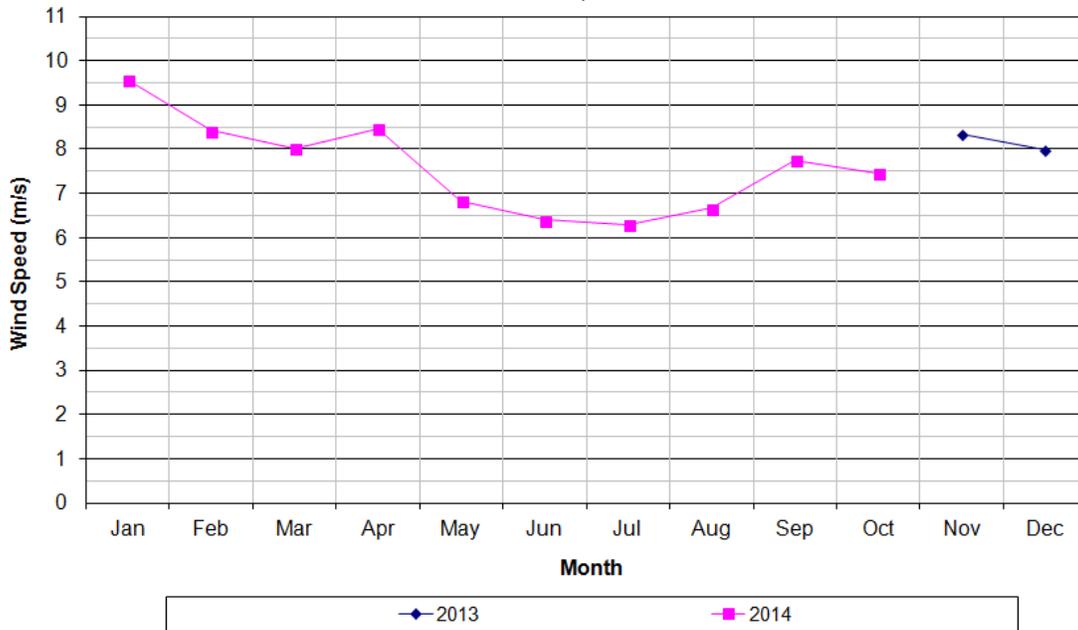
Although the results for anemometers A2 and A5 are presented, they will not be considered in further calculations as these sensors were used primarily for quality control and replacement purposes.

As expected, the data confirm that wind speeds increase with height above ground level (see section 3.2.4 for a description of wind shear). Furthermore, the graphs show the seasonal pattern of wind, which decreases towards summer months and increases towards winter months.



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**Figure 3-1: Averaged Monthly Wind Speeds for Each Anemometer at Mast 2604, November 1, 2013 to October 31, 2014**



**Figure 3-2: Monthly Wind Speeds Measured at the Top Anemometer at Mast 2604, November 1, 2013 to October 31, 2014**

The following table provides, the average wind speed and the maximum 1-second gust observed, and specifies the averaging method used and the period of data considered. The averaging method varies as it depends upon the available dataset:

- Annual: average of the wind speed recorded over one or more full years.
- Annualised: the annualised wind speed is a weighted wind speed that is calculated from all available monthly average wind speeds—e.g. if 2 values are available for January and only one is available for February, the February value will have twice the weight of each January value in the final average.
- Average: due to insufficient data collection, the annual average wind speed was not calculated. The value given is the average of all available data.

**Table 3-3: Wind Speed Characteristics at the Mast**

Mast	Top Anemometer Height (m)	Period	Average Wind Speed (m/s)	Maximum 1-second gust (m/s)	Method
2604	35.0	November 1, 2013 to October 31, 2014	7.7	41.1	Annual



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### 3.2.2 Wind Speed Frequency Distribution

The frequency distribution of wind speeds helps to evaluate how much power is contained in the wind (power is proportional to the cube of the wind speed). Wind turbines will produce more power as the wind speed increases (until reaching the “rated” value). Thus, as the frequency of higher wind speeds increases, more power can be produced.

Annual frequency distributions generally exhibit a Weibull shape that is controlled by its “scale factor” (closely linked to the average wind speed) and its shape factor.

The wind speed frequency distribution graph is presented below for the mast<sup>1</sup>.

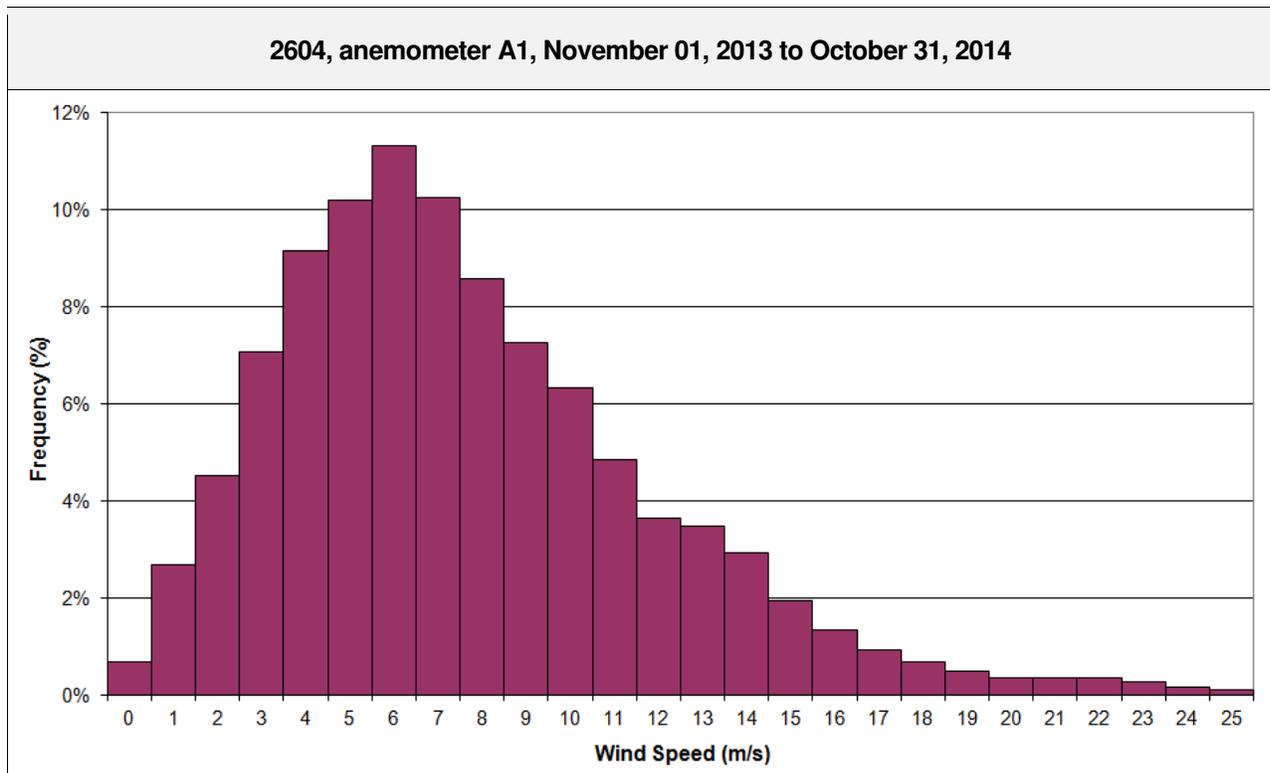


Figure 3-3: Wind Speed Frequency Distribution Graph

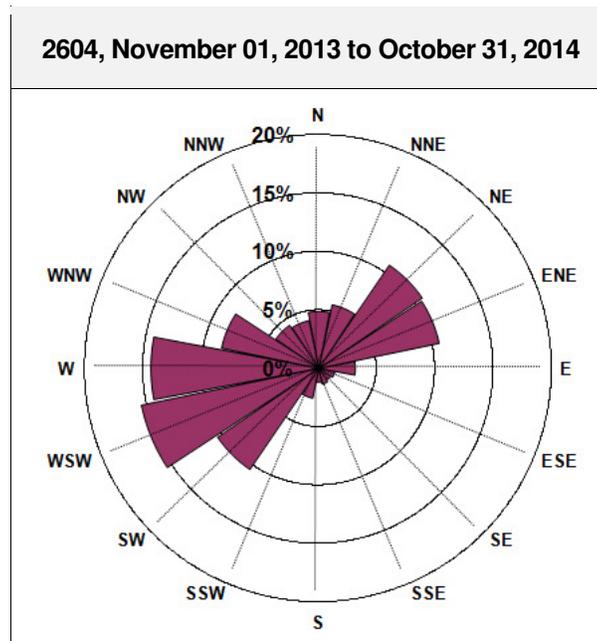
### 3.2.3 Wind Rose

The wind rose graph is presented below. The wind rose is divided into the conventional 16 compass sectors (22.5° wide sectors). Note that all compass orientations referenced in this report are based on the true geographic north, rather than the magnetic north.

<sup>1</sup> The 0 m/s wind speed bin indicates the fraction of the total number of measurements with a wind speed between 0 to 0.5 m/s. The other bins are 1 m/s wide and centered on the integer value (e.g.: the 1 m/s wind speed bin indicates the fraction with a wind speed between 0.5 to 1.5 m/s).



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**Figure 3-4: Wind Rose Graph**

The wind rose indicates that a significant proportion of the wind blows from southwest to west and from northeast to east-northeast, across the project area.

Note that wind roses are not adjusted to the long-term. Moreover, differences in wind directions between the levels of measurement are small enough to be neglected. As a consequence, the present wind rose will be considered as representative of the long-term wind rose at hub height.

### 3.2.4 Wind Shear

Wind speeds typically increase with height above the ground, because the frictional drag decreases with altitude. The increase in wind speed with height is referred to as wind shear and is commonly modeled either by a logarithmic law or by a power law.

When the power law is used, the wind shear can be quantified by a wind shear exponent. “Rough” surfaces, such as forested lands and urban areas, have a more pronounced frictional drag than “smooth” surfaces, such as a snow covered field or grasslands—the former will be associated with higher wind shear exponents. Over a smooth, level, grass-covered terrain, the wind shear exponent is typically around 0.14; over snow or calm sea it may be as low as 0.10; and over urban areas or tall buildings it may be as high as 0.40.

The roughness is not the only surface property that has a direct effect on the wind shear. When there is dense vegetation, the vertical wind speed profile is displaced vertically above the canopy, thereby displacing the level of zero wind speed to a certain fraction of the vegetation height above the ground. The “displacement height” is defined as the height at which the zero wind speed level is displaced above the ground. The displacement height is taken into account in all wind shear estimations.



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Finally, large topographic variations over short distances may also impact the wind vertical profile and thus affect the wind shear.

Hatch recommends using the log law to estimate the wind shear at mast locations. Internal studies have shown that the accuracy of the wind shear estimate is slightly improved with the log law when compared to the power law. When available, three wind speed measurements, each at a different height, are used and a log law curve is fitted through the average wind speeds at these heights. With the log law, the parameter that reflects roughness is called the roughness length, instead of the wind shear exponent. However, an equivalent wind shear exponent is calculated between the top anemometer height on a mast and the hub height for easier interpretation.

The equivalent wind shear exponent presented in this report was calculated between the top anemometer height of the mast and hub height of 40 m. The calculation was based on the measured wind speed at the anemometer height and the wind speed extrapolated to hub height by the log law method. The log law parameters were determined by fitting a logarithmic curve through the average measured wind speeds at the three measurement heights.

The average equivalent wind shear exponent is reported in the following table.

Based on our knowledge about the vegetation in the area of the mast, this value conforms to expected results.

**Table 3-4: Average Wind Shear at the Mast**

Mast	Period	Wind Shear
2604	November 01, 2013 to October 31, 2014	0.19

### 3.2.5 *Turbulence Intensity*

Turbulence characterises the gustiness of wind or high frequency changes in wind speed and direction (high turbulence is typical of very irregular wind flows, contaminated by whirls or vortices). Turbulence increases in areas with very uneven terrain and behind obstacles, such as buildings. In wind farms, it interferes with the effective operation of the wind turbines and increases their wear and tear.

The measurement of turbulence is expressed in terms of turbulence intensity, which is the standard deviation of the wind speed divided by the mean wind speed, over a given period. Turbulence intensity is expressed as a percentage. In the present study, the standard deviation and mean speed values are calculated from 1 second wind speed data averaged over a 10 minute period.

Turbulence intensity is more erratic and more difficult to quantify at low wind speeds. As a consequence, only wind speeds in excess of 4 m/s are used to calculate of the turbulence intensity. This threshold is consistent with IEC standards for wind turbine power performance measurements [4].

The turbulence intensity value was calculated with the top anemometer data.



The average turbulence intensity is reported in the next table. This value is considered moderate according to the reference values defined in reference [2]<sup>2</sup>. It is expected that turbulence will decrease with height, as the effect of obstacles and surface roughness will diminish.

**Table 3-5: Average Turbulence Intensity at the Mast**

Mast	Anemometer used	Period	Turbulence Intensity (%)
2604	A1	November 01, 2013 to October 31, 2014	13.1

### 3.2.6 *50-year recurrence wind speed*

The selected wind turbine Emergya Wind Technologies 900 kW (EWT900) is designed to survive a certain level of loading caused by an extreme wind event. Based on the specification provided by the manufacturer, the extreme survival wind speed at hub height is 59.5 m/s (see Appendix B).

At least 7 years of data at the met mast location or a nearby reference station are required. The Gumbel distribution was used to predict the once-in-fifty-year extreme wind speed. The data were extrapolated to hub height of 40 m with a power law exponent of 0.11 suggested for gusts as per Wind Energy Handbook [2] and IEC 61400-1 standard.

In the case of L'Anse au Loup project, the met mast has only 18 months of data. Thus, data from Lourdes De Blanc Sablon A Environment Canada station were used and based on hourly data at 10 metres height. The data cover the period from 2000 to 2014. The 50-year recurrence maximum wind speeds were estimated to be 50.8 m/s at 40 m which respect the turbines' specifications.

## 3.3 Other Climatic Data

### 3.3.1 *Temperature*

Temperature was measured at a height of 34 m. The following table presents the average monthly and annual temperature measured. The coldest 10-minute temperature recording measured during the data collection period was -32.2°C in the morning of January 3, 2014.

**Table 3-6: Average Monthly and Annual Temperatures**

Mast ID	Monthly Air Temperature (°C)												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2604	-12.2	-13.1	-11.0	-2.6	1.9	8.4	13.4	12.3	8.8	4.9	-1.9	-13.7	-0.3

<sup>2</sup> Low levels of turbulence intensity are defined as values less than or equal to 0.10, moderate levels are between 0.10 and 0.25, and high levels are greater than 0.25. This classification is for meteorological turbulence only; it should not be used in comparison with IEC models. Meteorological turbulence should not be used to establish the wind turbine class.



### 3.3.2 Air Density

Wind energy is directly proportional to the air density. Consequently, the amount of energy produced by a wind turbine will also be directly proportional to the air density at the turbine location. Air density decreases with increasing temperature, decreasing pressure and increasing altitude.

Based on the measured temperatures and the standard barometric pressure of 101.3 kPa at sea level, the monthly average air densities were calculated. Note that to correct for changes in atmospheric pressure with height, the calculations account for the site elevation. The values were calculated over the entire analysis period reported in Table 2-2.

**Table 3-7: Monthly and Annual Average Air Density**

Mast ID	Monthly Air Density (kg/m <sup>3</sup> )												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2604	1.32	1.32	1.31	1.27	1.25	1.22	1.20	1.21	1.22	1.24	1.27	1.32	1.27

### 3.3.3 Power density

Wind speed, wind direction and air density data can be combined to provide information about the average power density at mast location. Wind power density indicates how much energy is available at a given instant for conversion by a wind turbine<sup>3</sup>. For example, strong winds in the winter, when the air is colder and denser, will have a higher power density (i.e. carry more energy) than the same strong winds in the summer. Though power is an instantaneous value, it is calculated as an average over a given period of time.

Tables of the power density distribution per direction and per month were produced at the top anemometer height and are presented below.

At mast 2604, the most powerful winds come from north to ENE, SW and WSW, and appear in winter months. The annual average power density is 620 W/m<sup>2</sup> at 35 m.

**Table 3-8: Table of Wind Power Density per Direction, November 1, 2013 to October 31, 2014**

Wind Power Density per Direction (W/m <sup>2</sup> )															
N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1423	928	746	668	171	144	118	137	125	253	818	775	403	287	383	617

**Table 3-9: Table of Wind Power Density per Month, November 1, 2013 to October 31, 2014**

Wind Power Density per Month (W/m <sup>2</sup> )												Annual Average
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1120	935	771	638	372	280	236	354	505	568	922	669	620

<sup>3</sup> Note that the units "W/m<sup>2</sup>" refer to m<sup>2</sup> of rotor swept area.



### 3.3.4 Icing Events

Icing affects the operation of wind turbines. Icing on any exposed part of the turbine can occur in the form of wet snow (generally associated with temperatures between 0°C to 1°C), super-cooled rain or drizzle (that can occur at temperatures between 0°C to -8°C, but mostly in the upper part of this range), or in-cloud icing (that can occur below - 2°C). Losses during production due to ice occur in several ways:

- Ice accumulation on the blades alters their aerodynamic profile, reducing the power output.
- Nacelle-mounted instruments accumulate ice and give inaccurate readings. The turbine control system may detect a fault condition due to the turbine output being much greater than expected. This expectation is based on the wind speed. As a result, the turbine will be shut down until the ice is removed from the instruments and the turbine is reset.
- Asymmetric icing causes mass or aerodynamic imbalance leading to vibrations. Control systems that sense vibrations will normally shut down when these vibrations occur.

Icing is a complex phenomenon and predicting icing from meteorological conditions is notoriously difficult, requires a good set of observations from a number of meteorology variables, and can be misleading. As no reliable instrument is presently available to detect and quantify icing events for the purpose of estimating their impact on wind energy production, Hatch uses several tests during data quality control to detect icing events: detection of unusual standard deviations or changes with time of wind speeds and directions, comparison of measurements from a heated anemometer and a standard anemometer at the same level, in parallel with the measurement of temperature.

These tests cannot distinguish between the different types of icing, but a rough approximation can be done by utilising the temperature ranges measured during icing events. Therefore, in the following estimate, we will consider two categories: “glaze”, which is assumed to include wet snow, super-cooled rain and drizzle, and “rime ice”, which is assumed to include in-cloud icing and the very low temperature part of super-cooled rain or drizzle. The threshold of -5°C is used to differentiate between rime ice (below -5°C) and glaze (above -5°C).

The following table presents the estimated number of icing events in a month and the type of event assumed to occur in the project area. This estimate is based on the average of icing events detected on the mast during the measurement campaign.

**Table 3-10: Estimated Hours of Icing Events, October 5, 2013 to April 30, 2015**

	January	February	March	April	May	June	
<b>Hours</b>	164	135	46	39	2	0	
<b>Rime</b>	50%	80%	100%	0%	0%	-	
<b>Glaze</b>	50%	20%	0%	100%	100%	-	
	July	August	September	October	November	December	Annual Average
<b>Hours</b>	0	0	0	8	53	149	594
<b>Rime</b>	-	-	-	0%	10%	60%	56%
<b>Glaze</b>	-	-	-	100%	90%	40%	44%



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## 4. Long-term Wind Speed at Hub Height

The previous section presented the analysis of the wind regime as it was measured by the met mast installed on the project site. However, to forecast the energy production of a wind power plant, wind data that represent the historical wind conditions at the site are required. Unfortunately, wind resource assessments are generally conducted for a limited number of years, often no more than one or two years, which is not sufficient to capture the year-to-year variability of wind. For example, in North America, the annual average wind speed exhibits a standard deviation of about 6% (or  $1\sigma$  from a normal distribution) of the long-term average wind speed. Hence, the maximum deviation from the average wind speeds could reach as much as 20% (or  $3.3\sigma$ ). Consequently, it is necessary to translate the measured short-term data into long-term data. This is done through a correlation/adjustment process that makes reference to a meteorological station where historical data are available.

Moreover, when the top anemometers of the met masts are mounted at a lower height than the expected hub height of the wind turbines, the long-term data must also be extrapolated from these anemometer heights to the wind turbine's hub height.

The long-term projection process is presented in the next section and is followed by the extrapolation to hub height.

### 4.1 Long-term Projection

When required, selecting a reference dataset to perform a long-term correlation and adjustment is determined by the following process:

- A quality assessment of the potential long-term reference stations for the site (history, similarity of the local climate with regards to the meteorology mast climate, etc.);
- A quality assessment of the correlation equations obtained with acceptable long-term reference stations and the measured data for the concurrent period;
- A comparison of the long-term correlation results obtained with all acceptable reference stations;
- A crosscheck of the resulting long-term adjustments with the measured data and the long-term trends at nearby reference stations or at a regional level;

Once the reference dataset is selected, it is used to adjust the met mast data to long-term conditions. This can be achieved either by synthesizing non existing years of data at the met mast site or by applying an adjustment factor to the measured data in order to better reflect the reference period. The process is as follows:

- The measured data from the met mast is correlated with the reference dataset;
- If the correlation parameters meet the synthesis criteria, then data are synthesized at the measurement mast for the complete reference data period; this method is referred to as the Measure-Correlate-Predict (MCP);
- If the criteria are not met but a good correlation can still be obtained with hourly or daily intervals, then the measured dataset is scaled up (or down) to long-term using the reference long-term average wind speed and the correlation equation obtained; this method is referred to as the Long-term Adjustment;



- If no correlation can be clearly established between a reference site and the met mast site, the measured data stay unchanged.

#### 4.1.1 Selection of reference dataset

The present section summarises the results of the analysis.

Among the possible set of reference stations, one station was selected and considered suitable for the long-term projection of the data at the met mast. This station is Lourdes De Blanc Sablon A monitored by Environment Canada (EC). The location of this station is given in the table below. The station was moved in December 2014 to a new location nearby the airport, thus data up to end of 2014 were used in the current analysis.

**Table 4-1: Identification of the Long-term Reference**

Name	ID (Available Data Period)	Instruments Height (m)	Latitude	Longitude	Elevation (m)
Lourdes De Blanc Sablon A	7040813 (1970-2014)	10.0	N 51° 27' 00.0"	W 57° 11' 00.0"	37.2
	7040815 (2014-2015)		N 51° 26' 31.0"	W 57° 11' 10.0"	

#### 4.1.2 Long-term Adjustment

The long-term adjustment consists of:

- Correlating short term data at the met mast with short term data at the reference station;
- Using the obtained linear regression equation,  $Y = m X + b$ , where  $X$  represents the long-term average wind speed at the reference station and  $Y$  is the estimated long-term average at the met mast;
- Applying an adjustment factor (to speed up or scale down) to the met mast short term data in order to obtain an average wind speed equal to the estimated long-term average at met mast (i.e.  $Y$ ).

For mast 2604, which displayed 18 months of data recorded, the long-term adjustment method was used for the long-term projection.

The wind speed data of the met mast were correlated to the concurrent wind speed data at the long-term reference station Lourdes De Blanc Sablon A. Good correlation results were obtained with daily average values ( $R^2$  greater than or equal to 0.7 is good correlation, above 0.85 is excellent). The results of the correlations are given in the following table. Linear regression equations were used to compare the data, where  $m$  is the slope of the equation,  $b$  is the intercept, and  $R^2$  is the coefficient of determination.



**Table 4-2: Correlations between Reference Station and met mast Wind Speeds**

Reference Station	Met Mast	Correlation Period		Daily Wind Speed Correlations		
		Beginning	End	m	b	R <sup>2</sup>
Lourdes De Blanc Sablon A	2604	November 1, 2013	October 31, 2014	0.942	2.8	0.74

The regression equations were then used to estimate the long-term average wind speed at the mast as a function of the long-term wind speed at the reference station. The estimated long-term average at the Lourdes De Blanc Sablon A station is 5.5 m/s. It was estimated by averaging all annual averages over the period 2000 to 2014. The results are presented in the following table.

**Table 4-3: Long-term Adjustment factor at the met mast**

Met Mast	Wind Speed over Correlation Period (m/s)	Long-term Annual Wind Speed (m/s)	Adjustment Factor (%)
2604	7.7	8.0	4.5%

Finally, the 10-minute measured data recorded at the met mast were scaled by the adjustment factor to reflect the long-term value. In terms of the wind direction data, the one-year dataset for the met mast remained untouched. As a result, the mast has a set of wind speeds and wind directions that are the best estimate of the long-term wind regime.

## 4.2 Extrapolation to Hub Height

The wind shear exponent, calculated with the measured data, was used to adjust the dataset to hub height. The results are presented in the following table.

**Table 4-4: Estimated Long-term Wind Speed at Hub Height\***

Met Mast	Estimated Long-term Wind Speed at Top Anemometer Height (m/s)	Estimated Long-term Wind Speed at Hub Height of 40 m (m/s)
2604	8.0	8.2

\* Estimated using the calculated wind shear



## 5. Wind Resource Mapping and Projected Energy Production

Met masts provide a local estimate of the wind resource. Met mast locations are chosen based on how representative they are of the project site and in particular for potential wind turbine locations. However, since the number of met masts is usually limited compared to the expected number of wind turbines, it is necessary to build a wind flow map based on these measurements to extend the wind resource assessment to the whole project area.

Wind modeling software, such as MS-Micro and WAsP, are known to produce erroneous wind flows over complex terrain. In this case, Hatch applies a method based on the Ruggedness Index (RIX) to calculate the wind flow for each mast dataset while correcting errors on wind speed<sup>4</sup>. All produced wind flows are then merged by a distance-weighting process. When the RIX correction is not applicable, wind flows are calculated with each mast dataset and simply merged together by a distance-weighting process, without a RIX correction.

Once the wind flow map is built, it is possible to optimise the size and layout of the foreseen wind farm for the project, and then to calculate the projected energy production. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow (see section 3.2.4). These corrections result in an effective hub height for each wind turbine.

The wind flow and energy production are calculated with specialised software that require, apart from the met masts long-term data, background maps that contain the information on topography, elevation, roughness lengths (related to the land cover) and potential obstacles. This is also used in conjunction with the wind turbine characteristics. Finally, wind farm losses must be estimated in order to complete the energy estimate.

The first part of this section introduces the information and the methodology used to calculate the wind flow.

The next part will present the optimisation process and the results in terms of energy production.

The software used to map the wind resource and to calculate the energy production include:

- WAsP Issue 11.01.0016 from Risø for wind resource mapping;
- Wind Farmer Issue 4.2.2 from Garrad Hassan for layout optimisation and energy production calculations.

### 5.1 Background Data

#### 5.1.1 Topography and elevation

The topographic and elevation data come from files provided by the National Topographic Data Base (NTDB) and the NASA's Shuttle Radar Topography Mission (SRTM).

The contour line interval is 5 m within the project area and 20 m outside.

<sup>4</sup> Bowen, A.J. and N.G. Mortensen (2004). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.



### 5.1.2 *Roughness*

The base map for roughness lengths was determined from land cover information included in the NTDB and CANVEC files. This map was then checked and corrected using satellite imagery from Google Earth. Around mast location and wind turbines, pictures and information noted during site visits were also used to check and modify the land cover information. The spatial resolution considered for the roughness lengths is 30m.

The following table details the roughness lengths used by land cover category.

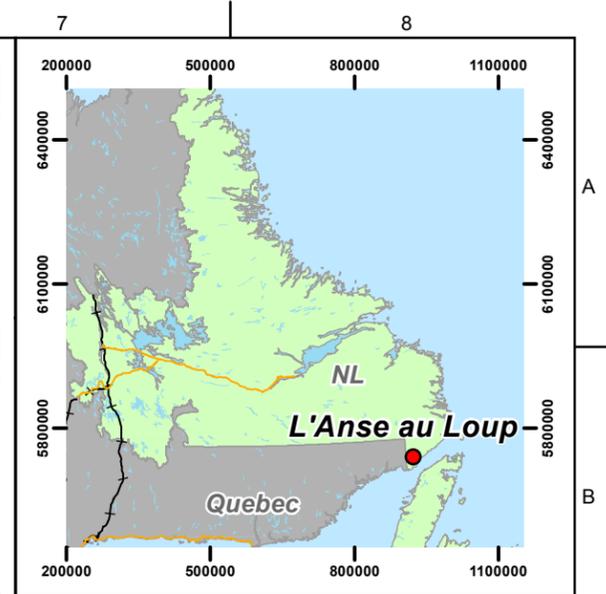
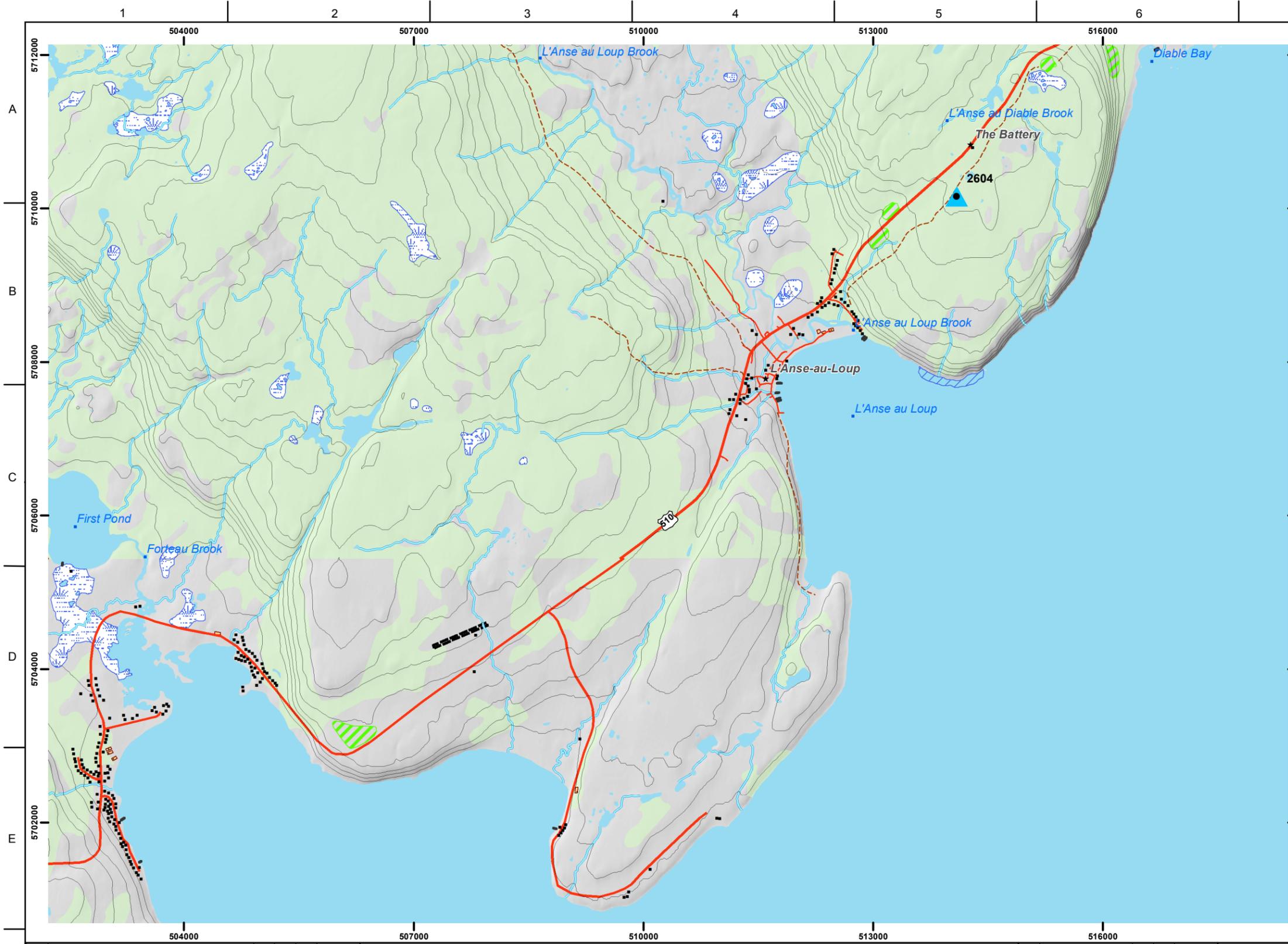
**Table 5-1: Roughness Lengths Categories**

Land Cover Type	Roughness Length (m)
Open farmland, high grass	0.04
Water	0
Forest	0.6

### 5.1.3 *Background Map*

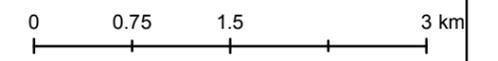
The background map, showing topography and contour lines is provided on the next page.





**Legend**

- Met Mast
- Building
- Contour Line (20m)
- Trail
- Road
- Wharf
- Watercourse
- Wetland
- Cemetery
- Mining area
- Reef
- Water Body
- Vegetation



1:55,000  
Spatial referencing UTM Zone 21 NAD83

SOURCE :  
Canadian Digital Elevation Data 1:50 000  
Canvec - Natural Resource Canada 1:50 000  
Environnement Canada: National Climate Data  
Google Earth Pro

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

REV.	ISSUE FOR	AUTH. BY	DATE

**HATCH**

DESIGNED BY DANY AWAD	DRAWN BY SLADJANA PAVLOVIC
DATE: September 09, 2015	DATE: September 09, 2015
CHECKED BY DANY AWAD	
DATE: September 09, 2015	

NALCOR

**L'Anse au Loup Overview Map**

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## 5.2 Wind Flow Calculation

### 5.2.1 *Terrain Complexity*

The wind flow is produced over semi-complex terrain. Wind modeling software, such as MS-Micro (used in Windfarm) and WAsP, are known to produce erroneous wind flows over complex terrain. Depending on the topography, predicted wind speeds can be over or underestimated at a given location. Errors can reach more than 20% in very complex areas.

In the present case, the complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 5.2.2 *Parameters*

The following parameters were used to calculate the wind flow map.

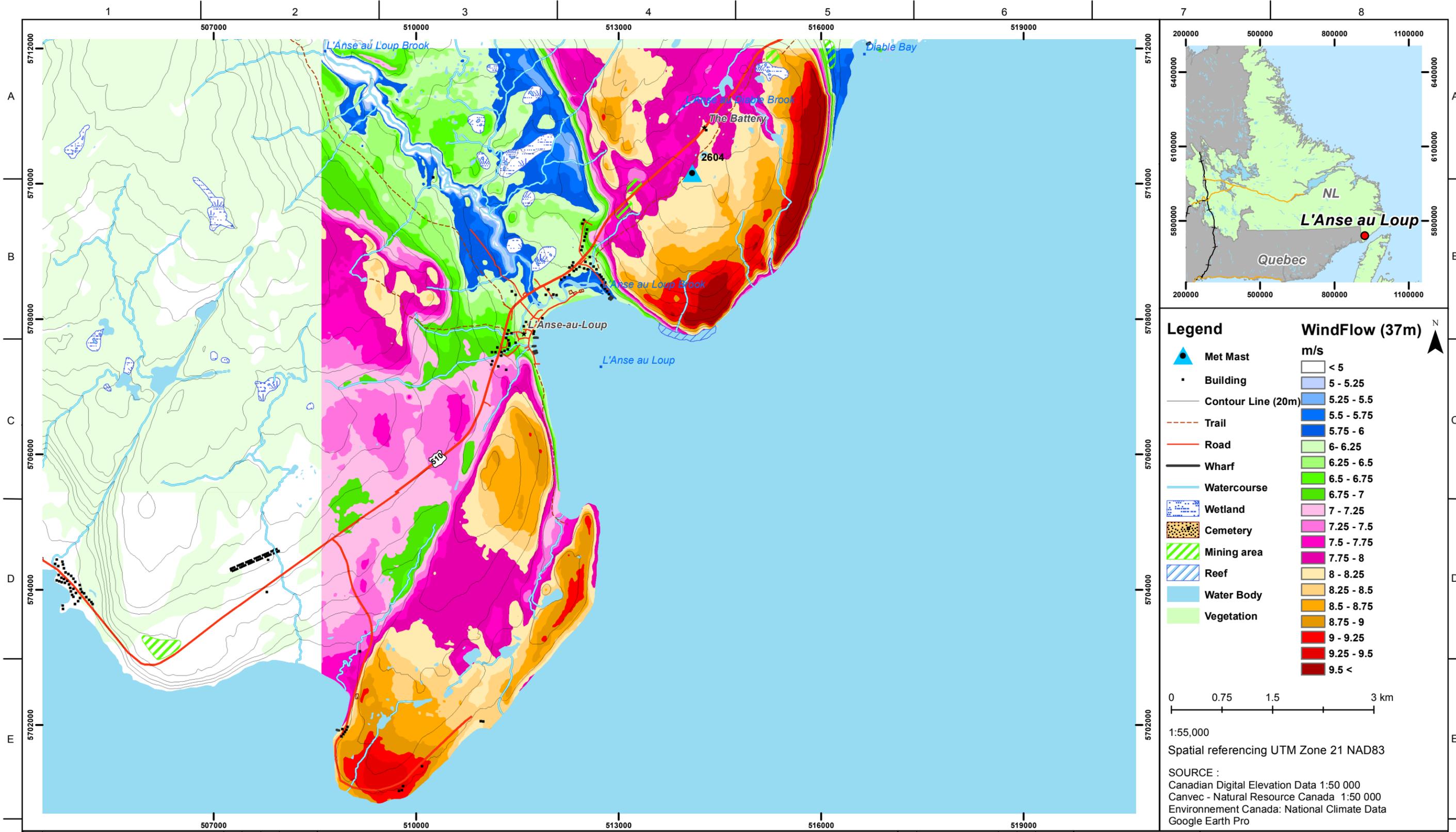
**Table 5-2: Wind Flow Calculation Parameters**

Parameter	Value
<b>Wind Resource Grid Spatial Resolution</b>	50 m
<b>Calculation Area</b>	8.8 km by 12.0 km
<b>Reference Mast</b>	2604
<b>Reference Height</b>	Top Anemometer Height
<b>Calculation height</b>	37 m
<b>Vertical Extrapolation Method</b>	Based on measured wind shear
<b>Roughness Change Model</b>	WAsP Standard Model

### 5.2.3 *Results*

The wind flow map used for layout optimisation and energy production estimates is presented on the next page.





**Legend**

- Met Mast
- Building
- Contour Line (20m)
- Trail
- Road
- Wharf
- Watercourse
- Wetland
- Cemetery
- Mining area
- Reef
- Water Body
- Vegetation

**WindFlow (37m)**

Wind Speed (m/s)	Color
< 5	Lightest Blue
5 - 5.25	Light Blue
5.25 - 5.5	Medium Light Blue
5.5 - 5.75	Medium Blue
5.75 - 6	Dark Blue
6 - 6.25	Light Green
6.25 - 6.5	Medium Green
6.5 - 6.75	Dark Green
6.75 - 7	Light Yellow-Green
7 - 7.25	Light Yellow
7.25 - 7.5	Yellow
7.5 - 7.75	Light Orange
7.75 - 8	Orange
8 - 8.25	Light Red
8.25 - 8.5	Red
8.5 - 8.75	Dark Red
8.75 - 9	Very Dark Red
9 - 9.25	Black
9.25 - 9.5	Dark Grey
9.5 <	Black

Scale: 0, 0.75, 1.5, 3 km

1:55,000  
Spatial referencing UTM Zone 21 NAD83

SOURCE :  
Canadian Digital Elevation Data 1:50 000  
Canvec - Natural Resource Canada 1:50 000  
Environnement Canada: National Climate Data  
Google Earth Pro

NO.	DESCRIPTION	BY	CHKD	APPD	DATE
REVISIONS					

Wind resource map created by Hatch with WAsP 11.01.0016  
 Height of calculation: 37 m  
 Spatial resolution of wind resource grid: 50 m  
 Source file: LAAL\_2604\_GridWRG\_37m\_WF2.asc  
 Source of data used to create the wind flow:  
 Topographic data are provided by the Center for Topographic Information (NRCan) and the NASA's Shuttle Radar Topography Mission (SRTM).  
 Meteorological data were collected from mast 2604, located 4 km on average from the center of the map, between 01/11/2013 and 31/10/2014.  
 Data were controlled by Hatch. Met data were adjusted for long term with reference to station Environment Canada Lourdes De Blanc Sablon A # 7040813 (reference period 2000-2014). It is believed that the present map gives a reliable overall picture of the wind resource. However, it is advised to confirm any information obtained from this map at any location by on-site measurements.

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ISSUE AUTHORIZATION			

**HATCH**

DESIGNED BY: DANY AWAD  
 DATE: September 09, 2015  
 CHECKED BY: DANY AWAD  
 DATE: September 09, 2015

DRAWN BY: SLADJANA PAVLOVIC  
 DATE: September 09, 2015

**NALCOR**

**L'Anse au Loup  
Windflow 2**

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### 5.3 Forecasting Energy Production

The layout was initially designed in order to maximise energy production. Turbines were spread out inside the project boundaries to minimise wake effects. The preliminary environmental screening and turbine extreme operating conditions also contributed to set the turbine locations.

#### 5.3.1 Preliminary Turbine Selection

A preliminary turbine selection was performed using Windographer software by comparing the performance of different turbines at the location of the met mast, where the dataset was recorded. The main parameters used for the comparison were the capacity factor of the wind turbine for the site specific conditions as well as the turbine purchase cost. Only turbines that meet the following criteria were considered:

- Site's turbine and turbulence class (IEC class II)
- Extreme wind and weather conditions (operation down to -40°C). The minimum 10-minute temperature recording of -32.2°C during the monitoring campaign confirms the site conditions are within the operating range of the turbine.
- Turbine capacity ranges from 500 kW to 1,000 kW to meet the community load
- Wind turbine's dimensions and weight versus crane capacity and accessibility

Hub heights of about 40 m to 50 m were used for this preliminary analysis.

Standard losses considered include: 12.5% technical losses and 2% wake losses.

The following table provides a summary of the turbine comparison.

**Table 5-3: Windographer Results at the Mast Location**

Turbine type	Turbine Class	Hub height (m)	Turbine Capacity (kW)	Mean Energy Output (MWh/yr)	Capacity Factor (%)	Turbine purchase cost (\$)
Aeronautica AW/Siva47-500	IB/IIA	47	500	1,745	39.9	1,632,000
EWT DW52-500 (EWT500)	IIA	37	500	1,951	44.5	1,990,000
EWT DW52-900 (EWT900)	IIA	40	900	2,666	33.8	2,000,000

The capacity factors listed above in table 5-3 are taken from Windographer and may change as a function of the site's optimized layout and should only be used for turbine comparison.

Due the lack of proven experience in remote arctic conditions, the Aeronautica wind turbine model was discarded from the analysis. EWT wind turbines have been installed and are operating in similar site conditions in Nome, Alaska for EWT or in Kasigluk, Alaska for Northern Power and were thus further compared as part of the analysis.

The average community load at L'Anse au Loup during the project lifetime is around 3000 kW. The following table shows the results of the WindFarmer optimization models using the



required number of turbines to meet that load. The turbines were ranked based on their capacity factor, energy output and simple payback.

**Table 5-4: Preliminary Turbine Selection Results**

Turbine type	Number of wind turbine required	Total Capacity (kW)	Gross Energy Output (MWh/yr)	Gross Capacity Factor (%)	Total purchase cost (Million \$)	Ranking
EWT500	6	3000	14,530	55.3	11.940	2
<b>EWT900</b>	<b>4</b>	<b>3600</b>	<b>13,500</b>	<b>42.8</b>	<b>8.000</b>	<b>1</b>

\* Based on the gross energy output at 30 cents/kWh and the turbine purchase cost only.

Based on information provided by EWT, the 500 kW wind turbine has the same foundation design as the 900 kW machine and nearly the same price (\$10,000 difference). Because of the similar turbine costs of the EWT models, from a financial point of view, the EWT900 becomes the most suitable having the lowest simple payback, and would also benefit from potential lower constructability and BOP cost.

The EWT900 turbine is the model that meets the wind class of the site and has proven technology for cold and icy environments.

Even though a more detailed turbine selection exercise will be required in later phase of the project, the EWT900 is considered suitable candidate turbine in order to complete the preliminary energy estimates for the potential L'Anse au Loup project.

### 5.3.2 **Layout Optimization**

The following section shows the WindFarmer modeling results which further refines the energy estimates for the turbines selected at the potential turbine positions and to confirm the capacity factor values. The table below outlines the parameters and constraints assumed to influence optimisation.

**Table 5-5: Layout Optimisation Parameters and Constraints**

Parameter / Constraint	Value
<b>Annual Air Density</b>	1.27 kg.m <sup>-3</sup> at 213 m.a.s.l.
<b>Turbulence Intensity</b>	13.1% at mast 2604 <i>Note: average value for information, the turbulence intensity is actually entered by wind-speed bins and by direction for energy prediction calculation</i>
<b>Exclusion areas</b>	Due to the lack of information in regard to setbacks for wind energy projects in Newfoundland and Labrador, general restriction rules were used: - 500 m from habitations



Parameter / Constraint	Value
	- 100 m from public roads - 50 m from lakes and rivers - 2 km by 1 km buffer zone from the airport track
<b>WTG Minimum Separation Distance</b>	Elliptical separation: Minimum of 5 rotor diameters on long axis Minimum of 3 rotor diameters on short axis Bearing of long axis: 240 degrees
<b>WTG Model</b>	EWT900
<b>WTG Rated Power (kW)</b>	900
<b>WTG Rotor Diameter (m)</b>	51.5
<b>WTG Hub Height (m)</b>	40.0
<b>WTG Power Curve</b>	See Appendix B
<b>WTG Thrust Curve</b>	See Appendix B
<b>Number of WTG's</b>	4
<b>Wind Farm Capacity (kW)</b>	3600
<b>Wake Model</b>	Modified Park Model used for optimisation and Eddy Viscosity Model for final energy calculation as recommended by Garrad Hassan
<b>Maximum Slope</b>	10 degrees
<b>Optimization Strategy</b>	Layout designed in order to maximise energy production.

The project layout is presented at the end of this section.

The layout is still considered preliminary. Land restrictions, communication corridors, noise and visual impacts, and other site-specific matters need to be evaluated through a detailed environmental assessment. Available land, road and collection system costs are also issues that will need to be addressed before the site layout can be finalized.

### 5.3.3 **Energy production**

Once the optimised layout has been produced, the energy production for each wind turbine is calculated. When necessary, wind turbine hub heights as well as met mast heights are corrected with the estimated displacement height. This is computed to account for the influence of trees on the wind flow. These corrections result in an effective hub height for each wind turbine.

The calculation was executed with the power curves and thrust curves used for the optimisation and presented in Appendix B. The additional losses are described in the next section.



Note that air density is corrected by the software for each turbine location according to its elevation.

The following table is a summary of the estimated energy production. Detailed energy figures are presented per wind turbine on the next page.

**Table 5-6: Wind Farm Energy Production Summary**

Item	Layout 1 - EWT900
<b>WTG Rated Power (kW)</b>	900
<b>WTG Rotor Diameter (m)</b>	51.5
<b>WTG Hub Height (m)</b>	40.0
<b>Number of Wind Turbines</b>	4
<b>Wind Farm Capacity (kW)</b>	3600
<b>Mean Free Wind Speed across Wind Farm (m/s)</b>	8.4
<b>Average Wake Losses (%)</b>	1.2
<b>Energy Production Before Additional Losses* (MWh/yr)</b>	13,500
<b>Capacity Factor Before Additional Losses* (%)</b>	42.8
<b>Additional Losses (%)</b>	13.7
<b>Net Energy Production (P50) (MWh/yr)</b>	<b>11,651</b>
<b>Net Capacity Factor (%)</b>	<b>36.9</b>

\* Includes topographic effect and wake losses

**Table 5-7: Forecasted Energy Production at Wind Turbines**

Turbine ID	Easting (m)	Northing (m)	Altitude (m)	Mean Free Wind Speed (m/s)	Gross Energy Production* (MWh / Year)	Wake Losses (%)	Gross Energy - Wake* (MWh / Year)	Turbulence Intensity** (%)
<b>Layout 1 - EWT900</b>								
1	513678	5709592	165	8.5	3418	0.8	3391	14.3
2	513992	5709950	180	8.5	3389	1.3	3344	14.5
3	514500	5710152	182	8.5	3395	1.7	3335	14.6
4	515007	5710539	179	8.7	3458	0.8	3430	14.1

\* Gross energy production includes topographic effect; "Gross energy – Wake" includes topographic effect and wake losses.

\*\* Turbulence Intensity includes ambient turbulence and incident turbulence. The values represent true meteorological turbulence; they should not be compared directly with IEC models and consequently should not be used to establish the wind turbine class.



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### 5.3.4 Losses

This section provides a description of the estimated losses included in the P50 estimate. These losses include environmental, electrical, availability, turbine performance losses and wake effects. The P50 is defined as the exceedance probability that denotes the level of annual wind-driven electricity generation that is forecasted to be exceeded 50% of the year. Half of the year's output is expected to surpass this level, and the other half is predicted to fall below it. Loss estimates should be reviewed as more detailed information becomes available.

The losses considered are presented in the following table and described hereafter.

**Table 5-8: Wind Farm Losses**

Loss Category	Loss Type	Losses (%)	
		Layout 1 - EWT900	
<b>Environmental</b>	Blade Soiling and Degradation	1.0	
	High Wind Hysteresis	0.2	
	Icing	3.0	<b>4.5</b>
	Lightning	0.0	
	Low Temperature Shutdown	0.4	
<b>Electrical</b>	Collection Network	1.3	<b>3.1</b>
	Auxiliary power	1.8	
<b>Availability</b>	Wind Turbine Availability	5.0	
	Collection Network Outage	0.6	<b>5.8</b>
	Grid Availability	0.2	
<b>Turbine Performance</b>	Out-of-range Operation	1.0	<b>1.0</b>
<b>Wake effects</b>	Internal Wake Effects	1.2	<b>1.2</b>
	External Wake Effects	0.0	
<b>Total*</b>		<b>13.7</b>	

\* The total is the cumulated effect of the different losses and not their direct summation

**Blade soiling and Degradation** refers to the reduction of the blade's aerodynamic performance due to dust and/or insects. It also takes into account the future blade degradation attributed to wear of the blade's surface. The L'Anse au Loup project is not



situated in a particularly dusty environment. This value is consistent with what is generally observed within the industry.

**High wind hysteresis** losses are caused by the control loop of the turbine around cut-out wind speed. They depend on the wind turbine design.

These estimations are based on the turbines' control loop specifications and high wind hysteresis simulations. Based on the available wind distribution at the mast, the loss induced by the hysteresis loop is 0.2%.

**Icing** losses happen in different ways: ice accumulation on blades alter their aerodynamic performance, nacelle-mounted instruments affected by ice give inaccurate readings and induce turbine control system errors, asymmetric icing causes mass or aerodynamic imbalance leading to vibrations that may force control systems to shut down the turbine. Icing can have different impact on the production of the turbine and the effect is site-specific. Some areas will be more affected by freezing rain or glaze ice and other regions are more prone to have rime ice or in-cloud icing.

Icing losses are estimated from the detection of icing events during met masts data quality control and translating the icing events into production losses. The level of ice is considered moderate as compared to other northern sites (up to 10% of icing losses).

Values should be taken with caution since no proven methodology is available and because the effect and characteristics of ice are highly site-specific. The uncertainty associated to these aspects is taken into account in the global uncertainty assessment.

**Lightning** has the potential to damage the turbine control system but also the blade integrity. Modern wind turbines have protection devices that most of the time allow continuous operation even after a lightning strike. There is however, a small chance that lightning will impact turbine operation. The lightning losses were estimated according to Environment Canada maps<sup>5</sup>.

**Low temperature shutdown** losses depend on the local climate, the turbine design and the control algorithm. In cold climates, turbine shutdowns can be driven by low temperature detection, even if the wind is blowing. According to the manufacturers' specifications, the wind turbines with cold weather package have an operation threshold of - 40°C. The loss is estimated based on the long-term temperature data measured at Lourdes De Blanc Sablon A Environment Canada station.

**Collection network** loss is considered at the interconnection point. It takes into account various elements, including the length of the cables connecting the wind turbines to the substation and the losses in the substation itself. Losses depend on the design of these elements.

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<sup>5</sup> <http://ec.gc.ca/foudre-lightning/default.asp?lang=En&n=42ADA306-1>

These losses have been estimated by Hatch according to previous experiences with similar project size and conditions. They should be confirmed when the design of the collection network is finalized.

**Auxiliary power** losses account for various subsystems of a wind turbine that require electrical power, such as control systems or heaters. All of these losses are not always accounted for in the power curve. For example, cold packages designed for cold climate wind turbines can require energy even when the turbine is stopped.

Based on Hatch's experience, an estimated value is used to account for the consumption of standard auxiliary systems. Specific losses have been added for the Cold Package system delivered with the wind turbines. They have been estimated by simulation according to the Cold Package specifications of the EWT900 wind turbine.

**Wind turbine availability** losses represent the percentage of time over a year that the turbine is unavailable for power production. Losses include regular maintenance time and unexpected turbine shutdowns. A given availability rate is normally guaranteed by utility-scale wind turbine manufacturers such as EWT (95%).

This estimation considers a standard maintenance schedule of 1 day per year per turbine, plus unscheduled repairs and delays due to site accessibility and weather conditions. This is based on information provided by the client that wind turbines will be considered as non-essential grid components and thus deficiencies will be considered as low priority, so that individual units may remain out of service for periods longer than normally considered.

**Collection Network Availability:** The collection network may be out of service, stopping energy delivery from the turbines to the grid. Collection network outage losses include shutdown time for scheduled maintenance and unexpected outages.

Based on the information provided by the client, the L'Anse au Loup based operators will manage the site and are expected to have the skills and manpower required to fix any collection system problem in a timely manner. The presence of a support team onsite has a positive impact on the availability of the collection network.

**Grid availability** losses depend on the utility distribution system quality and capacity. It represents the percentage of time in a year when the grid is not able to accept the energy produced by the wind turbines.

The value used assumes the wind turbines will be connected to the grid operated by NLH, which is assumed to be well maintained and operated.

**Out-of-range Operation** losses take into account the aspects usually not covered by the power curve warranty such as turbulence, wind shear and yaw errors. Parameters specific to the Project have been used to perform this loss estimate.

**Wake Effect** corresponds to the deficit in wind speed downstream of a wind turbine. Several models exist to quantify this effect in terms of induced energy losses. Hatch uses the Eddy Viscosity model which corresponds to a CFD calculation representing the development of the velocity deficit field using a solution of the Navier Stokes equations. Because of higher



precision as compared to the Park model and recommendations from WindFarmer, the Eddy Viscosity model is used to assess to the wake of the Project. Wake losses are highly dependent on the layout, especially regarding the distance between the turbine and the layout's compactness.

One of the input in the wake losses calculation is the thrust curve provided by the turbine manufacturer for the Project turbine model under consideration.

No other wind farm currently exists in the vicinity of the project. In addition, no future wind farm that may impact the Project in terms of wake is planned. Thus, there are no additional wake losses.



## 6. Conclusions and Recommendations

### 6.1 Objectives of Analysis

The purpose of this report is to present a full wind resource assessment for the L'Anse au Loup site, including the estimation of the forecasted annual energy production.

### 6.2 Data Quality and Adjustments

The wind data recovery rates at the monitoring site, for the analysis period, exceed industry standards, with recovery rates ranging from 95.2% to 99.0% for the primary anemometers and 98.2% for the primary wind vane.

The measured data were adjusted to long-term through correlation with Environment Canada's Lourdes De Blanc Sablon A station, located 30 km away from the project area. The long-term adjustment method was applied since it was considered to be the best method for producing a representative dataset for the expected life of the project.

### 6.3 Wind Resource

The annual average wind speed at the met mast is a result of the measurements and the long-term adjustment. These wind speeds are summarised in the table below for top anemometer and hub height.

**Table 6-1: Estimated Long-term Wind Speeds**

Mast (Measurement Height)	Estimated Long-term Wind Speed at Measurement Height (m/s)	Estimated Long-term Wind Speed at Hub Height at 40 m (m/s)
2604 (35 m)	8.0	8.2

The long-term dataset at the met mast was used to build the wind flow across the project area.

The complexity of the terrain is considered moderate and its effect on the modelled wind is not considered problematic.

### 6.4 Forecasted Energy Production

The preliminary turbine selection analysis specified one suitable turbine model: EWT900. This models was proven to be best in class for cold and icy environments and suitable for wind-diesel generation in remote community.

The main results of the energy production modeling are summarised in the table below.



**Table 6-2: Forecasted Annual Energy Production**

Item	Layout 1 - EWT900
WTG Rated Power (kW)	900
Number of Wind Turbines	4
Wind Farm Capacity (kW)	3600
Annual Net Energy Production (MWh/yr)	<b>11,651</b>
Net Capacity Factor (P50) (%)	<b>36.9</b>

There remains some uncertainty regarding loss estimates, which should be reassessed as more information becomes available, particularly in relation to warranty contracts and maintenance schedules. Note that the Annual Net Energy Production represents the total forecasted energy production by the wind turbines. The effective energy production used to displace fuel will be a bit lower and vary depending on the chosen layout scenario (type and number of wind turbines), timewise power load and wind resource.

## 6.5 Recommendation

It should be noted that a number of additional studies and more detailed analysis will be required to refine and validate the turbine selected, the turbine position, the energy and losses.

The integration optimization report will show which turbine model is considered optimal for the L'Anse au Loup site based on energy cost, control capabilities and logistics and provide recommendations for further analysis and studies prior to implementation.



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- [3] International Electrotechnical Commission, *Wind Turbines - Part 1: Design Requirements*, IEC 61400-1, Ed. 3, 2005-08.
- [4] International Electrotechnical Commission, *Wind Turbines - Part 12-1: Power performance measurements of electricity producing wind turbines*, IEC 61400-12-1, Ed. 1, 2005.
- [5] A Practical Guide to Developing a Wind Project, *Wind Resource Assessment*, 2011



# Appendix A

## Views at Mast Site



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**View Facing North**



**View Facing East**



**View Facing South**



**View Facing West**

**Figure – A1: Views from Base of Mast 2604**

# Appendix B

## Wind Turbine Data



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**EWT DW52-900**

The power curve and the thrust curve were provided to Hatch by Emergya Wind Technologies.

**Table – B1: EWT Wind Turbine Performance Curves**

<b>Rotor Diameter:</b> 51.5 m	<b>Hub Height:</b> 40.0 m	<b>Air Density:</b> 1.225 kg.m <sup>-3</sup>	<b>Turbulence Intensity:</b> N/A
<b>Wind Speed at Hub Height (m/s)</b>	<b>Electrical Power (kW)</b>	<b>Wind Speed at Hub Height (m/s)</b>	<b>Thrust Coefficients</b>
0	0	0	0.000
1	0	1	0.000
2	0	2	0.000
3	7	3	0.866
4	30	4	0.828
5	69	5	0.776
6	124	6	0.776
7	201	7	0.776
8	308	8	0.753
9	439	9	0.722
10	559	10	0.692
11	698	11	0.613
12	797	12	0.516
13	859	13	0.441
14	900	14	0.368
15	900	15	0.296
16	900	16	0.241
17	900	17	0.199
18	900	18	0.168
19	900	19	0.143
20	900	20	0.124
21	900	21	0.109
22	900	22	0.096
23	900	23	0.085
24	900	24	0.075
25	900	25	0.067

Dany Awad  
DA:da



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Emergya Wind Technologies BV

Engineering

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Created by:	JT	Creation Date:	24-07-09
Checked by:	MB	Checked Date:	24-07-09
Approved by:	TY	Approved Date:	05-04-11

Title:

Specification

# DIRECTWIND 52/54\*900 Technical Specification

Revision	Date	Author	Approved	Description of changes
02	02-03-12	MB	TY	Format, minor text, blades, options
01	28-11-11	LE	TY	Corrections and drawings
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

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## 1 Introduction

This document provides a technical overview of the *DIRECTWIND* 52/54\*900 Wind Turbine designed for the IEC class II/III application. It is to be read in conjunction with document S-1000921 "Directwind 52/54\*900 Electrical Specification".



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## 2 Technical Description

The *DIRECTWIND* 52/54\*900 is a direct-drive, variable speed, pitch regulated, horizontal axis, three-bladed upwind rotor wind turbine.

The gearless direct-driven synchronous generator operates at variable speed. This is made possible by an actively controlled AC-DC-AC IGBT power converter connected to the grid. Benefits of this design are low maintenance, constant power output at wind speed above rated, and relatively low structural loads compared to constant-speed stall-controlled or constant-speed pitch-controlled wind turbines.

The generator is fully integrated into the structural design of the turbine, which allows for a very compact nacelle design. The drive-train makes use of only one main bearing, whereas classic designs have separately supported main shaft, gearbox and generator. All dynamically loaded interfaces from the blades to the foundation are sturdy flange connections with machined surfaces, and high tensile steel pre-stressed bolt connections are used.

### 2.1 Operation and safety system

The turbine operates automatically under all wind conditions and is controlled by an industrial PLC (Programmable Logic Controller). The cut-in wind speed is approximately 3m/s. When the rotational speed reaches the cut-in threshold, the power converter begins to deliver power to the grid.

The power converter controls the generator power output and is programmed with a power set-point versus rotor speed curve. Below rated wind speed the power output is controlled to optimise rotor speed versus aerodynamic performance (optimum  $\lambda$ -control). Above rated wind speed the power output is kept constant at rated value by PD-controlled active blade pitching.

The dynamic responses of the drive train and power controller are optimised for high yield and negligible electrical power fluctuations. The variable speed rotor acts as a flywheel, absorbing fluctuating aerodynamic power input. The turbine controllers are located in the rotor hub and the tower base (with remote IO in the nacelle) and carry out all control functions and safety condition monitoring. In the case of a fault, or extreme weather conditions, the turbine is stopped by feathering of the blades to vane position (blades swivelled to 90° with respect to rotor's rotational plane). In case of power loss, an independent battery backup system in each blade ensures the blades are feathered.

In the case of less serious faults which have been resolved, or when extreme weather conditions have passed, the turbine restarts automatically to minimise downtime.

### 2.2 Generator

The multiple-pole, direct-drive generator is directly mounted to the hub. The stator is located in the non-moving outer ring and the wound pole, separately excited rotor rotates on the inner ring.

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The generator is designed such that all aerodynamic forces are directly transferred to the nacelle construction without interfering with the generator-induced loads.

## 2.3 Power Converter

The power converter is an AC-DC-AC IGBT active switching converter. It controls the generator to operate in its optimum range, and maintains power quality to the grid. The inverter can produce unity power factor ( $\cos\Phi=1$ ) to the grid under all load conditions. Power factor is also controllable within limits.

## 2.4 Rotor

The rotor is a three bladed construction, mounted up-wind of the tower. Rotational speed is regulated by active blade adjustment towards vane position. Blade pitch is adjusted using an electric servomotor on each of the blades.

Each blade has a complete, fully independent pitch system that is designed to be fail-safe. This construction negates the need for a mechanical rotor brake. The pitch system is the primary method of controlling the aerodynamic power input to the turbine.

At below rated wind speed the blade pitch setting is constant at optimum aerodynamic efficiency. At above rated wind speed the fast-acting control system keeps the average aerodynamic power at the rated level by keeping the rotor speed close to nominal, even in gusty winds.

The rigid rotor hub is a nodular cast iron structure mounted on the main bearing. Each rotor blade is connected to the hub using a pre-stressed ball bearing. It is sufficiently large to provide a comfortable working environment for two service technicians during maintenance of the pitch system, the three pitch bearings and the blade root from inside the structure.

## 2.5 Rotor blade set

The rotor blades are made of fibreglass-reinforced epoxy. The aerodynamic design represents state-of-the-art technology and is based on a pitch-regulated concept. No extenders are used and the aerodynamic design is optimal for this rotor diameter.

## 2.6 Main bearing

The large-diameter main bearing is a specially designed three row cylindrical roller bearing. The inner non-rotating ring is mounted to the generator stator. The outer rotating ring is mounted between the hub and generator rotor. The bearing takes axial and radial loads as well as bending moments. Entrance to the hub is through the inner-bearing ring. The bearing is greased by a fully automatic lubrication system controlled by the turbine PLC.

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## 2.7 Nacelle

The nacelle is a compact welded construction which houses the yaw mechanism, a service hoist and a control cabinet. Both the generator and the tower are flanged to the nacelle. The geometry of the construction assures an ideal transfer of loads to the tower and, with the absence of a shaft and gearbox, results in a simple design ensuring easy personnel access.

## 2.8 Yaw system

The yaw bearing is an internally geared ring with a pre-stressed four point contact ball bearing. Electric planetary gear motors yaw the nacelle. The yaw brake is passive and is based on the friction of brake pads sitting directly on the bearing ring, keeping the yaw system rigid under most loading conditions.

## 2.9 Tower

The nacelle assembly is supported on a tubular steel tower, fully protected against corrosion. The tower allows access to the nacelle via a secure hinged access door at its base. The tower is fitted with an internal ladder with safety wire and optional climb assistance, rest platforms and lighting. Standard hub heights are 35, 40, 50 and 75 metres.

## 2.10 Anchor

The turbine is supported by a concrete foundation. The connection to this foundation is provided by means of a cast-in tube or rod anchor.

## 2.11 Control System

### 2.11.1 Bachmann PLC

The M1 controller perfectly combines the openness of a PC-based controller with the reliability of industrial hardware platforms. Designed to withstand the toughest ambient conditions it guarantees error-free use over long periods of time.

A modern system architecture designed for consistent network-capability permits the easy integration of the M1 into the environment of the controller and system peripherals. Real-time ethernet permits the real-time networking of the controllers, and the support of all standard Fieldbus systems permits the connection of standard external components.

### 2.11.2 DMS

*DIRECTWIND* Monitoring System – EWT’s proprietary HMI featuring local monitoring and control at the turbine, integrated into a remote-access SCADA. DMS offers individual turbine control and total park monitoring and data logging from your Wind Turbine, Wind Park or internet access point.

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## 2.12 Earthing and lightning protection

The complete earthing system of the wind turbine incorporates:

1. Protective earthing:

A PE connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault (a "short circuit"), a very high current flows, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

2. Functional earthing:

Earthing system to minimize and/or remove the source of electrical interference that can adversely affect operation of sensitive electrical and control equipment.

A functional earth connection serves a purpose other than providing protection against electrical shock. In contrast to a protective earth connection, the functional earth connection may carry electric current during the normal operation of the turbine.

3. Lightning protection:

To provide predictable conductive path for the over-currents in case of a lightning strike and electromagnetic induction caused by lightning strike and to minimize and/or remove dangerous situations for humans and sensitive electrical equipment.

Since the mechanical construction is made of metal (steel), all earthing systems are combined.

## 2.13 Options

The following options are available:

- Cold climate operation (rated for operation down to -40°C)
- Ice detection and/or prevention system
- Aviation lights
- Shadow flicker prevention
- Low Voltage Ride-through (LVRT)
- Service lift (75m tower only)
- G59 protection relay

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### 3 Technical Data

Where data are separated by "/" this refers to the respective rotor diameter (52 / 54 m).

#### 3.1 Wind and Site Data

Wind class	II / III according to IEC 61400 – 1
Max 50-year extreme	59.5 / 52.5 m/s
Turbulence class	A ( $I_{15} = 0.16$ )
Maximum flow inclination (terrain slope)	8°
Max ann. mean wind speed at hub height	8.5 / 7.5 m/s
Nominal air density	1.225 kg/m <sup>3</sup>

#### 3.2 Operating Temperature

	Standard	Cold Climate
Min ambient operating	-20°C	-40°C
Max ambient operating	+40°C	+40°C

#### 3.3 Cooling

Generator cooling	Air cooled
Converter cooling	Water or air cooled (configuration-dependent)

#### 3.4 Operational Data

Cut in wind speed	3 m/s
Cut out wind speed	25 m/s
Rated wind speed	14 / 13.5 m/s
Rated rotor speed	26 rpm
Rotor speed range	12 to 33 rpm
Power output	900kW
Power factor	1.0 (adjustable 0.95 lagging to 0.95 leading) Measured at LV terminals

#### 3.5 Rotor

Diameter	52 / 54 m
Type	3-Bladed, horizontal axis
Position	Up-wind
Swept area	2,083 / 2,290 m <sup>2</sup>
Power regulation	Pitch control; Rotor field excitation
Rotor tilt angle	5°

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### 3.6 Blade Set

Type	PMC 24.5 / 25.8
Blade length	24.5 / 25.8 m
Chord at 22.0 m	0.879 m (90% of 24.5m blade radius)
Chord at 23.5 m	0.723 m (90% of 25.8m blade radius)
Chord Max at 5.5 m	2.402 m
Aerodynamic profile	DU 91, DU 98 and NACA 64618
Material	Glass reinforced epoxy
Leading edge protection	PU coating
Surface colour	Light grey RAL 7035
Twist Distribution	11.5° from root to 5.5m then decreases linearly to 0.29°, then non-linearly to 0°

### 3.7 Transmission System

Type	Direct drive
Couplings	Flange connections only

### 3.8 Controller

Type	Bachmann PLC
Remote monitoring	DIRECTWIND Monitoring System, proprietary SCADA

### 3.9 Pitch Control and Safety System

Type	Independent blade pitch control
Activation	Variable speed DC motor drive
Safety	Redundant electrical backup

### 3.10 Yaw System

Type	Active
Yaw bearing	4 point ball bearing
Yaw drive	3 x constant speed electric geared motors
Yaw brake	Passive friction brake

### 3.11 Tower

Type	Tapered tubular steel tower
Hub height options	HH = 35, 40, 50, 75 m
Surface colour	Interior: White RAL 9001, Exterior: Light grey RAL 7035

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### 3.12 Mass Data

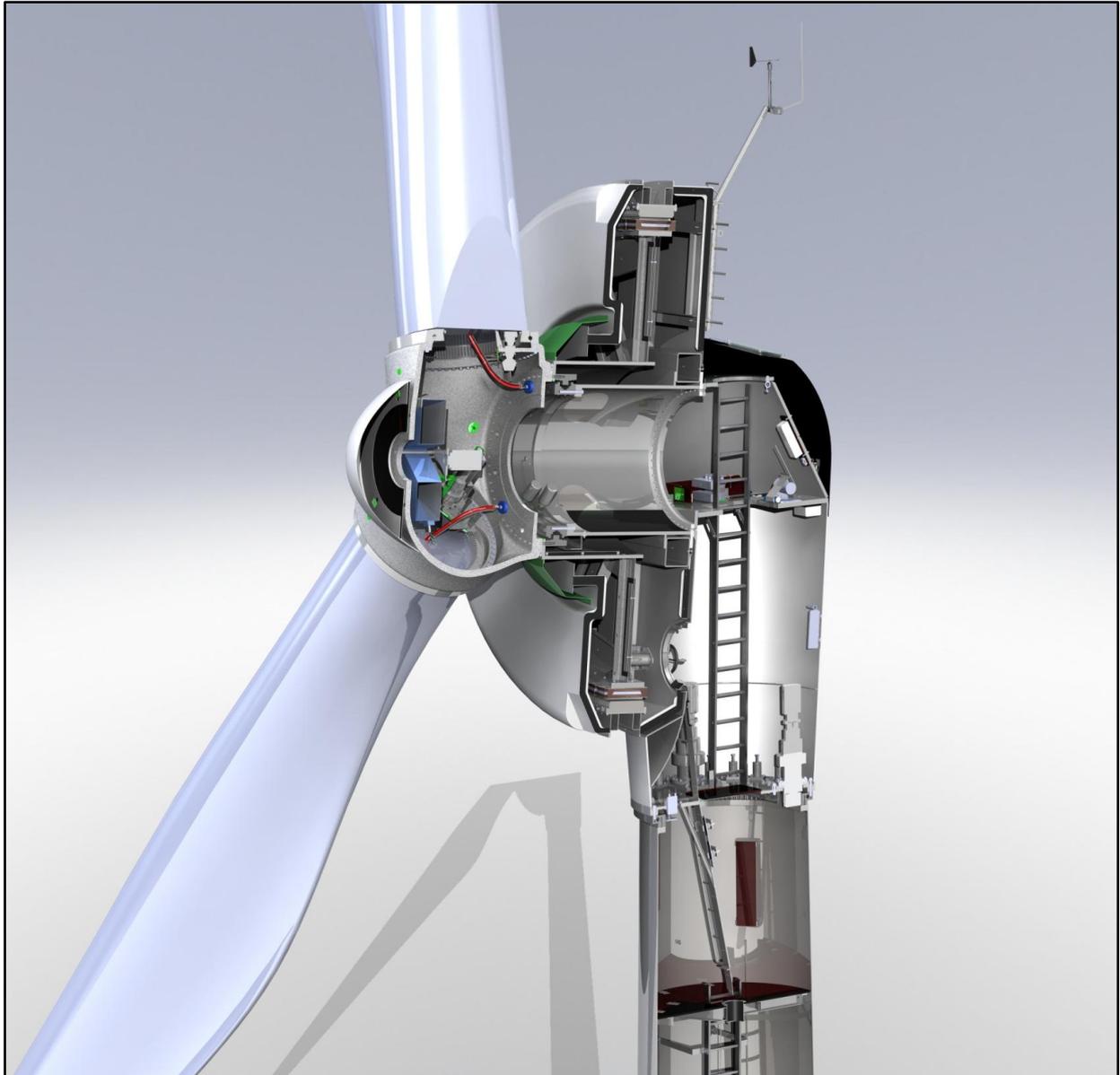
Hub	9,303 kg
Blade – each	1,919 / 1,931 kg
Rotor assembly	15,060 / 15,096 kg
Generator	30,000 kg
Nacelle assembly	10,000 kg
Tower HH35	28,300 kg
Tower HH40	34,000 kg
Tower HH50	46,000 kg
Tower HH75	86,500 kg

### 3.13 Service Brake

Type	Maintenance brake
Position	At hub flange
Calipers	Hydraulic 1-piece

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## APPENDIX 1: 3D image of main turbine components



# Appendix F: Hybrid system modelling and optimisation report - Nain



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Project Report

November 9, 2015

# Coastal Labrador Wind Monitoring Program

## Nain Hybrid System Modeling and Optimization

Distribution  
Trevor Andrew – NLH  
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Timothy Manning – NLH  
Terry Gardiner – NLH  
Louis Auger – Hatch  
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## 1. Introduction, Objectives and Scope of Work

As part of the project titled, Coastal Labrador Wind Monitoring Program, Newfoundland and Labrador Hydro (NLH) mandated Hatch to complete a wind monitoring campaign to determine the feasibility of adding Wind Turbine Generators (WTG) to Labrador isolated communities of Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. This report presents the methodology and results related to Nain.

The wind monitoring periods are listed in the table below and additional information on the wind monitoring campaigns can be found in the respective WRA reports completed for each community.

	Date of first data recorded	Date of last data recorded
<b>Nain (mast 2601)</b>	30 October 2013	19 July 2015
<b>Hopedale (mast 2602)</b>	27 October 2013	19 July 2015
<b>Makkovik (mast 2603)</b>	25 October 2013	19 July 2015
<b>Cartwright (mast 2605)</b>	5 November 2013	13 July 2015
<b>L'Anse au Loup (mast 2604)</b>	5 October 2013	27 April 2015

**Table 1 : Sites and Monitoring Periods**

The specific objectives of the mandate were to provide the potential wind turbine capacity that can be installed on these 5 communities, the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

## 2. Overview of Existing Diesel Grid on Site

Nain is one of the largest communities in Northern Labrador and consequently has a large electrical demand compared to neighbouring communities. The electrical equipment on site as well as electrical load and future forecast are defined below, based on the information provided by NLH.

### 2.1 Installed Power Generation Equipment

The power grid operated by NLH at Nain currently relies on three (3) diesel generators (Gensets). A fourth unit is scheduled to be installed onsite in 2015. This configuration is common for isolated communities where it would be too costly to interconnect to the main provincial grid. The gensets currently on site include the following units:

Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
<b>G1)574</b>	865	Detroit Diesel	Se2000R1637K36	1800	2001
<b>(G3)576</b>	865	Detroit Diesel	Se2000R1637K36	1800	2001
<b>(G2)2085</b>	1275	CAT	D-3512B	1800	2009
<b>(G4)TBD</b>	750	MTU	12V4000G73	1200	Planned 2015

**Table 2 : Diesel Gensets on Site**



## 2.2 Generator Control Scheme

The gensets on site are managed by an automated control scheme. NLH explained that the control logic aims to minimize the number and size of the gensets running at any given time while also insuring sufficient spinning reserve to meet increases in load. To do so, whenever the unit running is operating at less than 75% load ratio, the system switches to a smaller unit, if available. Whenever the unit running is loaded at more than 85%, the system switches to a larger unit, if available, or starts a second generator to share the load.

The minimum load ratio for all gensets operated by NLH is 30%.

These control parameters are important for the modeling part of the process and will be discussed later.

## 2.3 Electric Load

The electric load at Nain varies significantly between winter and summer months. NLH provided historical monthly average hourly electrical load. This data is shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nain	1,347	1,125	985	912	856	679	632	725	689	924	898	1,226

**Table 3 : Average Load (kW)**

Furthermore, a monitoring system was recently installed by NLH to record 15 minute electrical production from each genset. The data recorded by this system, which covers the period of December 2014 to April 2015, was made available for inclusion in the model. This dataset provided the basis of calculation for the production of a daily hourly load profile, an essential component of the modeling exercise.

It should be noted that the 15 minute dataset provided shows that more genset hours are required to produce the energy for the site compared to what is predicted by the modelling software.

## 2.4 Forecasted Load and Fuel Price

NLH provided information showing anticipated growth of peak hourly power demand and total yearly energy for the years 2015 to 2033 for Nain. The expected average fuel cost for each year was also supplied for the same period. The table below summarizes this information.

Nain	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Gross Peak (kW)	1,981	2,026	2,066	2,107	2,148	2,165	2,207	2,250	2,294	2,339	2,385	2,426	2,467	2,509	2,552	2,596	2,638	2,681	2,724
Net Peak (kW)	1,929	1,973	2,014	2,054	2,095	2,113	2,155	2,198	2,242	2,287	2,333	2,374	2,415	2,457	2,500	2,544	2,586	2,629	2,672
Gross Energy (MWh)	9,301	9,516	9,711	9,908	10,104	10,306	10,513	10,723	10,937	11,156	11,379	11,578	11,781	11,987	12,197	12,410	12,615	12,823	13,035
Net Energy (MWh)	9,019	9,228	9,418	9,608	9,799	9,995	10,195	10,398	10,606	10,819	11,035	11,228	11,424	11,624	11,828	12,035	12,233	12,435	12,640
Fuel Price forecast	\$0.96	\$1.02	\$1.02	\$1.06	\$1.09	\$1.09	\$1.13	\$1.19	\$1.24	\$1.31	\$1.39	\$1.43	\$1.47	\$1.50	\$1.54	\$1.58	\$1.62	\$1.67	\$1.71

**Table 4 : Forecasted load and fuel price growth (2015-2033)**



The forecasted load growth and fuel price increase were important components in the evaluation of the various available system configurations as the objective was to find the most desirable system over the life of the project.

### 3. Design methodology

#### 3.1 Software Used

The electrical system and integration of the wind turbines was modelled and simulated using HOMER (Hybrid Optimization of Multiple Electric Renewables). This software is specifically used to model and optimize the configuration of micro-grid systems composed of multiple components, which can include wind turbine generators, photovoltaic solar panels, hydroelectric generators, batteries as well as generators running on various types of fuel. Using inputs comprising electric load profile, electrical architecture of the system (DC vs AC, etc.), renewable resources as well as costs for the purchase, operation and replacement of each component, HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or fuel used by the system. In the context of the current assignment, the outputs of the software were integrated in MS Excel spreadsheets to include electrical load and fuel cost variations over time with the aim of selecting the most efficient solution over the life of the project.

#### 3.2 Model Building

NLH provided valuable information related to the historical operating performance of the existing system. The data provided included operations and maintenance (O&M) costs and overhaul costs, as well as data linking electrical production and fuel consumption. Each genset model was created in HOMER to accurately reflect these parameters, as well as the specific fuel curve provided by NLH.

The average monthly electrical load provided by NLH was used as the basis for the load profile included in the model. The 15 minute genset production dataset, covering a 5 month period, was used to establish a daily electric production profile. The assumption was made that the electric production at any given time was equal to the electric demand, so the daily load profile would be the same as the daily production profile. This daily load profile proved to be similar in shape for all 5 months of data provided, with differing magnitudes across months. As such, the assumption was made that the typical daily load profile shape would be the same for all 12 months but that it would be scaled to reflect the monthly averages provided by NLH. This daily load profile for each month was integrated as the electric load for the project. HOMER uses the base hourly profile and introduces hour to hour and day to day random variations based on parameters defined by the user. The result is a random time series for the load that has a pattern similar to the actual load.

At this point an iteration of the model was run in a configuration representing the equipment present on site to verify that HOMER would yield results similar to the numbers provided by NLH. The energy cost, generator run hours and quantity of fuel burned per year all came to within 5% of the numbers provided by NLH for project year 1. This provided validation that the model could be relied upon to accurately represent the system.



A preliminary turbine selection for the Nain project was completed as part of the Wind Resource assessment phase and two WTGs models from two different OEMs were selected; additional information on the turbine selection methodology is available in the WRA report. These turbines are the Northern Power Systems 100kW arctic version (NPS100) and the Emergya Wind Technologies 900kW (EWT900). Both WTGs were modeled in HOMER based on manufacturer provided specifications. The long term wind resource calculated in the wind resource assessment campaign was integrated in the model and the energy production predicted by the software WindFarmer for each turbine model was compared with the energy calculated by HOMER. WindFarmer is routinely used to optimize wind farm layouts with regard to energy, topography and restrictions and to estimate the energy production. WindFarmer outputs are considered more accurate than HOMER for this aspect. Following some minor model adjustments, the comparison showed that the HOMER results were similar to the WindFarmer results within a few percent, confirming that the simulation used realistic wind energy production numbers.

The following assumptions were made during the optimization process and in the simulation phase:

- The daily load profile was derived from time series and historical values provided by NLH
- Fuel costs and load growth were based on information provided by NLH, as presented in Section 2.4
- An inflation rate of 2.21% and average NLH long term marginal cost of debt (rounded) of 6.48% were used, according to historical values specified by NLH
- Construction costs have been defined based on information from manufacturers and historical values from past projects

### 3.3 System Sizing and Optimization

The sizing and optimisation of the proposed wind project for Nain was determined through an iterative process. HOMER simulations were run using varying numbers of each WTG model selected in the previous phase. The objective of the iterations was to determine the number of WTGs for each model that would result in the lowest calculated cost of energy (COE).

The outputs from Homer were integrated in Excel spreadsheets to evaluate the impact of increasing fuel costs, electrical demand, inflation and cost of borrowed capital. Some key metrics were identified to compare the various configurations and determine the most economically viable scenarios. The results are presented in the following section.



## 4. Results

### 4.1 Proposed Configuration

Based on the modeling performed in HOMER, the optimal number of turbines for integration in the Nain system is 12 when considering the NPS100 and 2 when considering the EWT900. Since the turbines are very different in scale, a qualitative comparison between the models is presented at the end of the current section. The table below shows a summary of the results for integration of various numbers of each WTG model.

	Fuel saved vs base case	Yearly Fuel Savings	Wind Penetration	WTG energy over 20 yrs (kWh)	Excess energy over 20 yrs (kWh)	Cost of Energy (\$/kWh)
<b>No WTG</b>	0%	\$0	0%	0	0	\$0.321
<b>10 NPS100</b>	29.2%	\$1,085,126	30.1%	67,582,180	3,260,801	\$0.312
<b>12 NPS100</b>	33.8%	\$1,256,596	34.8%	81,098,760	6,719,029	\$0.310
<b>14 NPS100</b>	37.6%	\$1,403,601	38.9%	94,615,200	11,620,161	\$0.311
<b>1 EWT900</b>	26.9%	\$785,467	27.7%	61,517,240	2,374,253	\$0.283
<b>2 EWT900</b>	43.2%	\$1,461,339	44.7%	123,034,480	27,592,535	\$0.263
<b>3 EWT900</b>	50.1%	\$1,757,036	52.0%	184,552,320	73,430,369	\$0.272

**Table 5 : Summary of Results**

The estimated energy production of each proposed configuration accounts for the possible losses in a wind farm, such as wake, aerodynamic, electrical, operational and power curve losses. The figures of availability should be defined with more accuracy at the detailed turbine selection stage, based on statistics for the turbine selected and after confirmation of the O & M strategy and review of the draft O&M contract if applicable. Based on preliminary manufacturer's discussions, other factors that will need to be considered for availability include the benefit of having a greater number of turbine units due to potential difficulties to execute repairs in the winter months. This will need to be analyzed as part of the turbine selection process.

As noted in Sections 4.2 and 4.3, the cost of energy does not include all applicable costs. As such, this preliminary cost of energy provides an indicator that, at this point, the project is viable and warrants further study. Additional costs not reflected include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

### 4.2 Construction Costs

The total estimated cost of building a wind farm at Nain include development, turbine, construction and project management. Project contingency was also included, at 5% for WTG components and 10% for construction costs. Additional integration and pre-development costs include logistics study, integration study, electrical and mechanical stability studies have not been included. System integration costs have also been left out of the equation, as well as any associated integration and communication equipment costs since this scope were



not included in the present project. All of the aforementioned studies would need to be completed to fully assess the viability of the project. The following table shows a summary of the included project costs for various iterations:

Number of units	NPS 100			EWT 900		
	10	12	14	1	2	3
<b>Development costs</b>	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000
<b>Turbine costs</b>	\$4,400,000	\$5,280,000	\$6,160,000	\$2,375,000	\$4,750,000	\$7,125,000
<b>Construction costs</b>	\$3,629,757	\$3,926,409	\$4,223,060	\$2,363,800	\$3,291,300	\$4,102,200
<b>Project management</b>	\$840,476	\$958,141	\$1,075,806	\$511,380	\$841,630	\$1,160,220
<b>Contingency</b>	\$704,523	\$789,955	\$875,387	\$443,768	\$688,293	\$919,992
<b>Total project CapEx:</b>	<b>\$9,949,756</b>	<b>\$11,329,505</b>	<b>\$12,709,253</b>	<b>\$6,068,948</b>	<b>\$9,946,223</b>	<b>\$13,682,412</b>
<b>CapEx per installed MW:</b>	\$9,949,756	\$9,441,254	\$9,078,038	\$6,743,276	\$5,525,679	\$5,067,560

**Table 6 : Summary of Construction Costs**

For the detailed construction costs see Annex 1.

#### 4.3 Further Study Required – System Integration

The installation of WTGs on the grid at Nain will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in the following section include no allocation for additional control and communication equipment.

#### 4.4 Penetration and Energy Cost

The cost of energy for each option is calculated based on the total cost of producing the required quantity of energy during the life of the project and the total amount of energy produced. Costs are based on the cost of borrowed capital for CapEx, increasing fuel costs and energy demand as well as anticipated discount rate (inflation) over the duration of the project. All costs presented in this report are based on the average long term marginal cost of debt of 6.48% provided by NLH. However this historical value may not be representative of future interest rates and a different value could have a significant impact on the cost of energy for configurations using WTGs because of the large investment required. For information purposes, the resulting cost of energy associated with an interest rate of 4.5% was included in the Figure 1 : Average Cost of Energy.

The level of penetration of wind energy in the energy pool at Nain is proportional to the number of WTG installed on site. This value represents the total amount of power produced by wind turbines over the project life divided by the total amount of power used.

The results for average cost of energy and wind penetration over the expected project life of 20 years are shown in the figure below. From this figure, it can clearly be seen that there are



configurations using either WTG model that produce a COE lower than the base case. However, the EWT900 results in a much lower overall cost of energy and a much higher wind penetration level than the NPS100. The design methodology leading to these results was provided in Section 3.

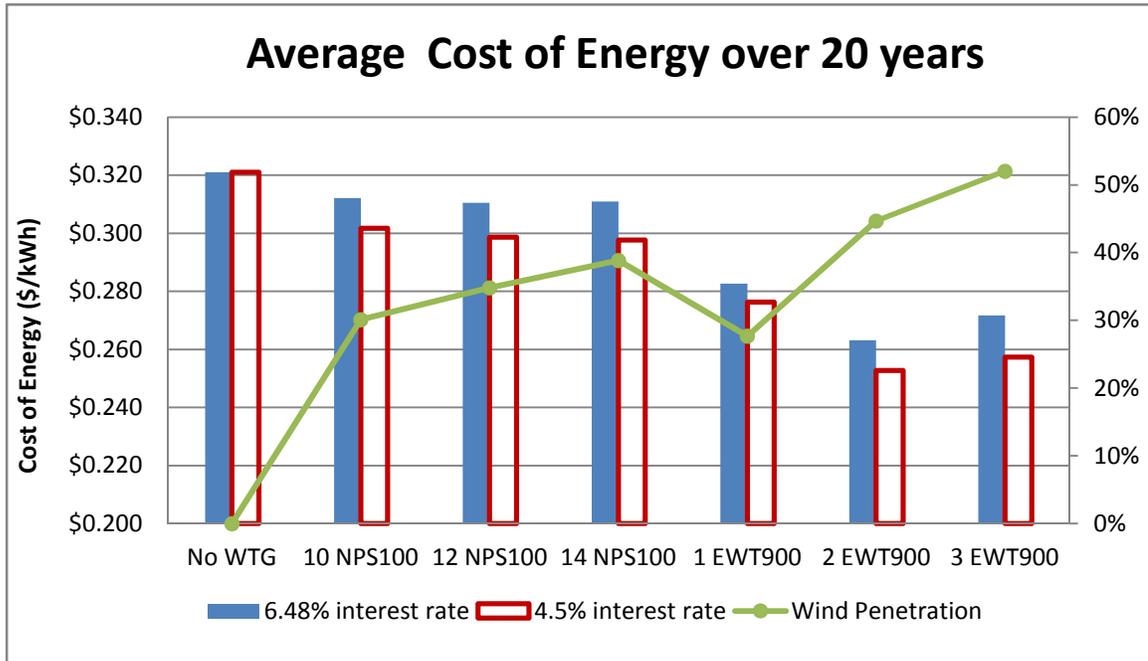


Figure 1 : Average Cost of Energy

#### 4.5 Evolution of Cost of Energy

Figure 2 : Evolution of Cost of Energy shows the evolution of the non-discounted cost of power over the 20 years of the project life. It illustrates that the inclusion of more WTGs or larger WTGs in the energy mix reduces the impact of rising fuel costs on the average cost of energy over the project life. The graph also indicates that scenarios with the EWT900 turbine result in much lower energy costs. Scenarios with the NPS100 also result in a lower energy cost than the base case, but the cost is significantly higher than the results with the EWT900.

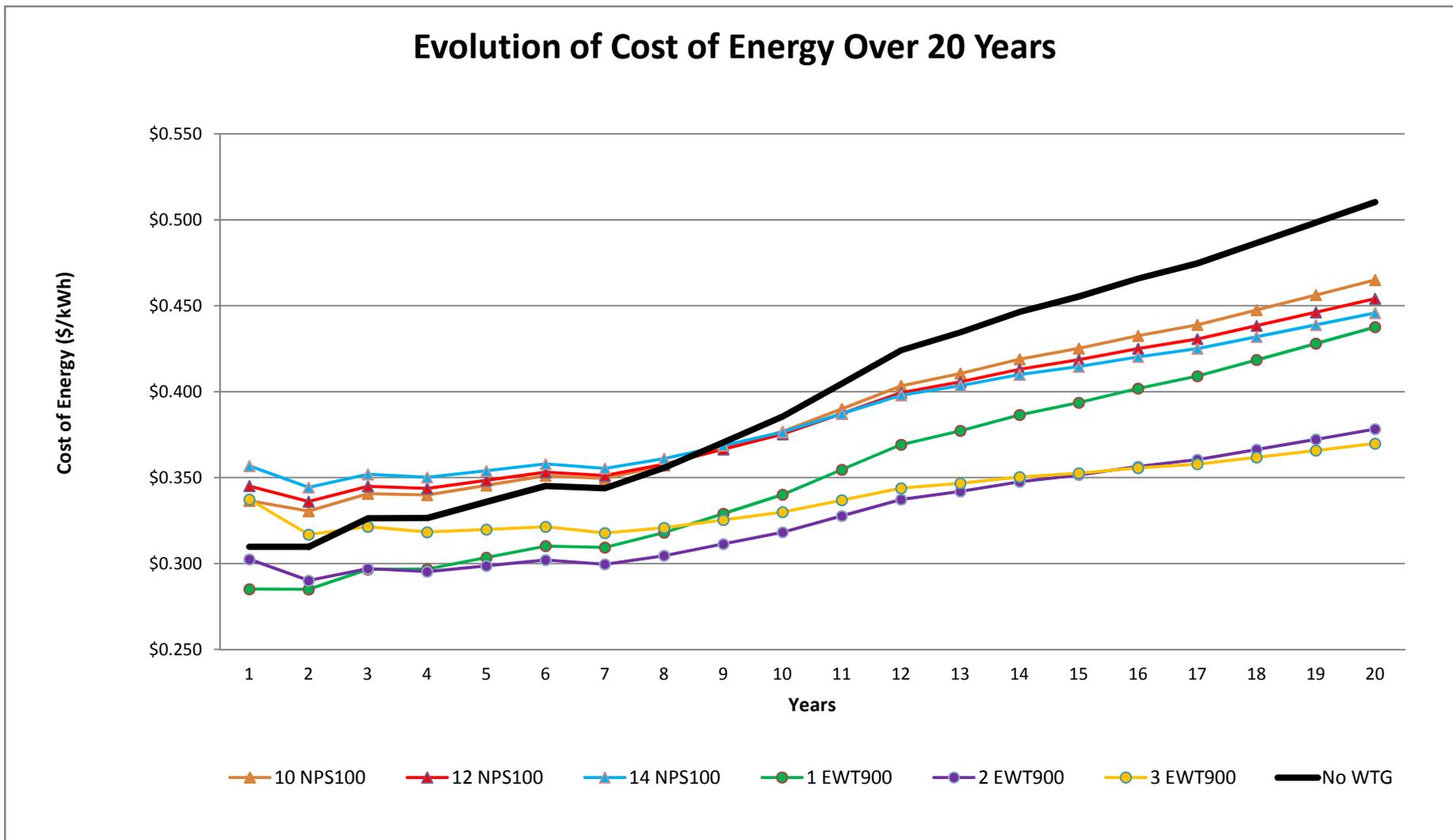


Figure 2 : Evolution of Cost of Energy



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#### 4.6 Fuel Costs and Excess Wind Energy

The average yearly fuel costs provide a good indication of the system reliance on fossil fuels for operation. The greater the installed wind capacity, the lower the annual fuel costs. However because of the magnitude and variability of electrical load on site, above a certain quantity of turbines, not all the energy produced by the turbines can be used by the system, causing the WTG to be less efficient.

The following figure shows the average yearly fuel costs for each configuration as well as the associated percentage fuel saved. The percentage of wasted WTG energy is also shown.

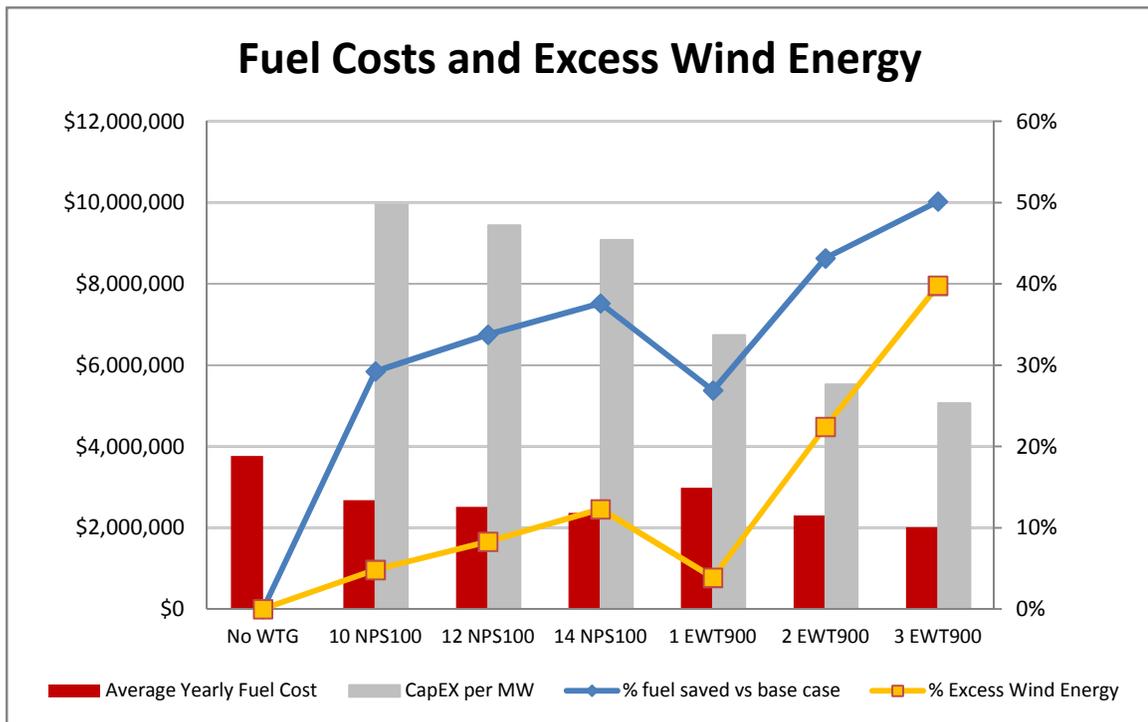


Figure 3 : Fuel Costs and Excess Wind Energy

#### 4.7 Avoided Greenhouse Gas Emissions

The addition of renewable energy to the Cartwright electrical grid would have an impact on the amount of Greenhouse Gas (GHG) emissions resulting from energy production. NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each liter of diesel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration is as follows:



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Case	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
No WTG	0	0
10 NPS100	2,318	46,359
12 NPS100	2,676	53,525
14 NPS100	2,981	59,623
1 EWT900	2,133	42,659
2 EWT900	3,421	68,421
3 EWT900	3,974	79,485

**Table 7 : Avoided Emissions of CO<sub>2</sub>**

Note: As of 2010, total Newfoundland and Labrador Green house gas emissions were 8.9 million tonnes per year, so avoided emissions by the installation of 2 EWT900 WTG at Nain would be equal to 0.038 % of total Provincial emissions.

#### 4.8 Qualitative Comparison of WTG Models

The results presented in Section 4.1 clearly highlight the difference in wind penetration and energy cost between the two turbines being considered. The NPS100 is a small wind turbine that is easier to deploy yet has limited control capabilities, while the EWT900 is a full-size turbine with a large rotor diameter and the full control package associated with a utility scale turbine. Both turbines have an excellent track record in arctic conditions, making both potential candidates for the application. On the economic aspect, though the cost estimates will need to be validated in the next phase of the project, the cost per installed kW is much lower for the larger turbine which is generally common within the wind industry. Consequently, the energy produced comes at a lower price for the EWT900 than the NPS100. On the electrical side, the EWT is oversized for the application and produces much more energy than the NPS. Accordingly, the amount of excess energy by the EWT WTG is far above the NPS model, however the overall cost of useful energy remains lower for the EWT. The excess energy is expected to be easier to manage on the EWT as well, since it has active curtailment and derating management capabilities. From an environmental perspective, the EWT allows for more avoided emissions than the NPS. The practical O&M aspect also favors the EWT, as the manufacturer offers O&M options through long term contracts and, under certain circumstances, will even offer an availability warranty.

The size of the EWT900 makes for a more complex deployment, construction and installation. The logistical capabilities, including the remoteness, of the Nain port and community are not well documented and may make the delivery, unloading, transport and installation of the EWT turbine much more expensive than budgeted at present. This could be a fatal flaw associated with the EWT900 WTG. A full logistic analysis is strongly recommended to confirm whether the installation of the EWT900 WTG is feasible. It needs to be noted that turbine models between 100 KW to 900 KW are not commonly available from many OEMs especially for use in arctic conditions. A more detailed turbine selection process should be initiated in following phases of the project.

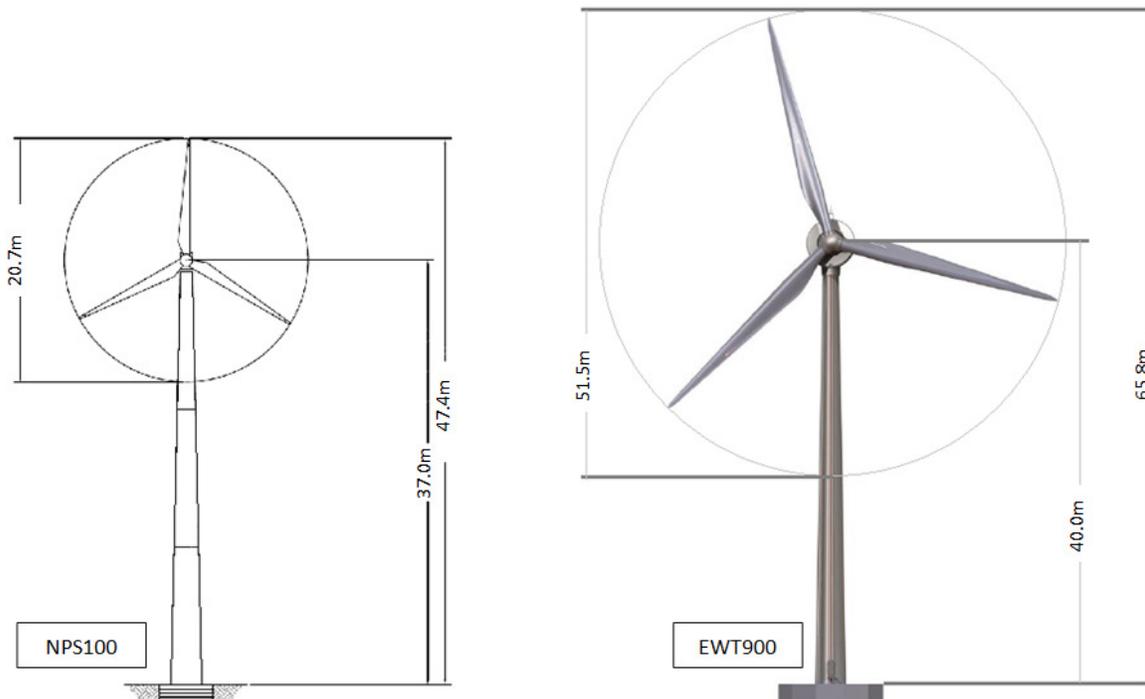


The table below shows a comparison between the two models with “X” indicating superiority in each category:

Category	NPS100	EWT900
Track Record	X	X
Turbine Cost		X
Energy Production		X
Control Capabilities		X
Avoided Emissions		X
O&M		X
Logistics	X	

**Table 8 : WTG qualitative comparison**

Figure 4 highlights the size differences between the NPS100 and the EWT900.



**Figure 4 : Turbines Size**

## 5. Conclusion and Recommendations

Based on the system modeling and preliminary economic analysis performed by Hatch, the optimal system design for Nain is the installation of two EWT900 WTGs. This result is based on the anticipated energy production of the existing gensets and the future wind turbines, according to the functional specifications of the local grid as provided by NLH. It should be noted that several components were excluded from this analysis, including the value of avoided GHG emissions, the level of community acceptance and government policy implications. It is recommended that NLH gather more information on these topics prior to moving forward with further assessments of project viability.

It is important to note that a detailed mechanical and electrical stability study was not performed at this stage. It is critical that such a study be performed in advance of the detailed design stage to determine the impacts of adding WTGs to the existing system, as well as the actual limitations of the current grid. Furthermore, a logistics analysis needs to be completed to determine whether the local capabilities allow for the installation of the EWT900 turbine.

ELB

Attachment(s)/Enclosure :

Annex 1 - Construction Costs.pdf

H340923-0000-05-124-0001\_rev4.pdf (Nain Final Wind Resource Assessment Report)



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# Appendix G: Hybrid system modelling and optimisation report - Hopedale



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H340923-0000-05-124-0012, Rev. B

Project Report

November 9, 2015

# Coastal Labrador Wind Monitoring Program Hopedale Hybrid System Modeling and Optimization

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## 1. Introduction, Objectives and Scope of Work

As part of the project titled, Coastal Labrador Wind Monitoring Program, Newfoundland and Labrador Hydro (NLH) mandated Hatch to complete a wind monitoring campaign to determine the feasibility of adding Wind Turbine Generators (WTG) to Labrador isolated communities of Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. This report presents the methodology and results related to Hopedale.

The wind monitoring periods are listed in the table below and additional information on the wind monitoring campaigns can be found in the respective WRA reports completed for each community.

	Date of first data recorded	Date of last data recorded
<b>Nain (mast 2601)</b>	30 October 2013	19 July 2015
<b>Hopedale (mast 2602)</b>	27 October 2013	19 July 2015
<b>Makkovik (mast 2603)</b>	25 October 2013	19 July 2015
<b>Cartwright (mast 2605)</b>	5 November 2013	13 July 2015
<b>L'Anse au Loup (mast 2604)</b>	5 October 2013	27 April 2015

**Table 1 : Sites and Monitoring Periods**

The specific objectives of the mandate were to provide the potential wind turbine capacity that can be installed on these 5 communities, the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

## 2. Overview of Existing Diesel Grid on Site

Hopedale is an average size community in Northern Labrador and consequently has a moderate electrical demand compared to neighbouring communities. The electrical equipment on site as well as electrical load and future forecast are defined below, based on the information provided by NLH.

### 2.1 Installed Power Generation Equipment

The power grid operated by NLH at Hopedale currently relies on four (4) diesel generators (Gensets). This configuration is common for isolated communities where it would be too costly to interconnect to the main provincial grid. The gensets currently on site include the following units:

Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
<b>(G1)2074</b>	569	CAT	3412C	1800	2005
<b>(G2)2054</b>	475	CAT	D-3508	1200	1999
<b>(G3)2053</b>	545	CAT	D-3412	1800	1998
<b>(G4)925</b>	925	MTU	12V4000G73	1200	2014

**Table 2 : Diesel Gensets on Site**



## 2.2 Generator Control Scheme

The gensets on site are managed by an automated control scheme. NLH explained that the control logic aims to minimize the number and size of the gensets running at any given time while also insuring sufficient spinning reserve to meet increases in load. To do so, whenever the unit running is operating at less than 75% load ratio, the system switches to a smaller unit, if available. Whenever the unit running is loaded at more than 85%, the system switches to a larger unit, if available, or starts a second generator to share the load.

The minimum load ratio for all gensets operated by NLH is 30%.

These control parameters are important for the modeling part of the process and will be discussed later.

## 2.3 Electric Load

The electric load at Hopedale varies significantly between winter and summer months. NLH provided the 2014 monthly average hourly electrical load. This data is shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>Hopedale</b>	754	652	581	517	558	407	338	369	376	524	544	720

**Table 3 : Average Load (kW)**

Furthermore, a monitoring system was recently installed by NLH, in some communities, to record 15 minute electrical production from each genset. The data recorded by this system was made available for inclusion in the model. Unfortunately this information was not provided for Hopedale, either because the system has not been installed there, or the dataset was not available. Since the hourly average productions for each month is an essential component of the modeling exercise, Section 3.2 describes how it has been defined for Hopedale.

## 2.4 Forecasted Load and Fuel Price

NLH provided information showing anticipated growth of peak hourly power demand and total yearly energy for the years 2015 to 2033 for Hopedale. The expected average fuel cost for each year was also supplied for the same period. The table below summarizes this information.

<b>Hopedale</b>	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Gross Peak (kW)	1,294	1,315	1,359	1,379	1,421	1,474	1,518	1,563	1,603	1,643	1,684	1,726	1,769	1,808	1,848	1,888	1,930	1,968	2,008
Net Peak (kW)	1,215	1,237	1,281	1,301	1,342	1,395	1,439	1,484	1,524	1,564	1,605	1,647	1,690	1,729	1,769	1,809	1,851	1,889	1,929
Gross Energy (MWh)	5,944	6,040	6,239	6,330	6,517	6,713	6,914	7,122	7,300	7,482	7,669	7,861	8,058	8,235	8,416	8,601	8,790	8,966	9,146
Net Energy (MWh)	5,334	5,420	5,599	5,681	5,849	6,024	6,205	6,391	6,551	6,714	6,882	7,054	7,231	7,390	7,552	7,718	7,888	8,046	8,207
Fuel Price (\$/L)	\$0.98	\$1.04	\$1.04	\$1.07	\$1.11	\$1.10	\$1.15	\$1.20	\$1.26	\$1.33	\$1.41	\$1.45	\$1.49	\$1.53	\$1.56	\$1.60	\$1.64	\$1.69	\$1.74

**Table 4 : Forecasted load and fuel price growth (2015-2033)**



The forecasted load growth and fuel price increase were important components in the evaluation of the various available system configurations as the objective was to find the most desirable system over the life of the project.

### 3. Design methodology

#### 3.1 Software Used

The electrical system and integration of the wind turbines was modelled and simulated using HOMER (Hybrid Optimization of Multiple Electric Renewables). This software is specifically used to model and optimize the configuration of micro-grid systems composed of multiple components, which can include wind turbine generators, photovoltaic solar panels, hydroelectric generators, batteries as well as generators running on various types of fuel. Using inputs comprising electric load profile, electrical architecture of the system (DC vs AC, etc.), renewable resources as well as costs for the purchase, operation and replacement of each component, HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or fuel used by the system. In the context of the current assignment, the outputs of the software were integrated in MS Excel spreadsheets to include electrical load and fuel cost variations over time with the aim of selecting the most efficient solution over the life of the project.

#### 3.2 Model Building

NLH provided valuable information related to the historical operating performance of the existing system. The data provided included operations and maintenance (O&M) costs and overhaul costs, as well as data linking electrical production and fuel consumption. Each genset model was created in HOMER to accurately reflect these parameters, as well as the specific fuel curve provided by NLH.

The average monthly electrical load provided by NLH was used as the basis for the load profile included in the model. For the other communities, a 5 month of 15 minute electrical production has been provided and use to calculate the hourly average productions for each month. This information has not been provided for Hopedale, but based on the 2014 monthly average hourly production, Hopedale has a similar shape than Nain, thus the daily hourly load profile of Nain has been used as the basis of calculation for the average hourly production for each month at Hopedale. The assumption was made that the typical daily load profile shape would be the same for all 12 months but that it would be scaled to reflect the monthly averages provided by NLH for Hopedale. This daily load profile for each month was integrated as the electric load for the project. HOMER uses the base hourly profile and introduces hour to hour and day to day random variations based on parameters defined by the user. The result is a random time series for the load that has a pattern similar to the actual load.

At this point an iteration of the model was run in a configuration representing the equipment present on site to verify that HOMER would yield results similar to the numbers provided by NLH. The energy cost, generator run hours and quantity of fuel burned per year all came to

within 5% of the numbers provided by NLH for project year 1. This provided validation that the model could be relied upon to accurately represent the system.

A preliminary turbine selection for the Hopedale project was completed as part of the Wind Resource assessment phase and two WTGs models from two different OEMs were selected; additional information on the turbine selection methodology is available in the WRA report. These turbines are the Northern Power Systems 100kW arctic version (NPS100) and the Emergya Wind Technologies 900kW (EWT900). Both WTGs were modeled in HOMER based on manufacturer provided specifications. The long term wind resource calculated in the wind resource assessment campaign was integrated in the model and the energy production predicted by the software WindFarmer for each turbine model was compared with the energy calculated by HOMER. WindFarmer is routinely used to optimize wind farm layouts with regard to energy, topography and restrictions and to estimate the energy production. WindFarmer outputs are considered more accurate than HOMER for this aspect. Following some minor model adjustments, the comparison showed that the HOMER results were similar to the WindFarmer results within a few percent, confirming that the simulation used realistic wind energy production numbers.

The following assumptions were made during the optimization process and in the simulation phase:

- The daily load profile was derived from time series and historical values provided by NLH
- Fuel costs and load growth were based on information provided by NLH, as presented in Section 2.4
- An inflation rate of 2.21% and average NLH long term marginal cost of debt (rounded) of 6.48% were used, according to historical values specified by NLH
- Construction costs have been defined based on information from manufacturers and historical values from past projects

### 3.3 System Sizing and Optimization

The sizing and optimisation of the proposed wind project for Hopedale was determined through an iterative process. HOMER simulations were run using varying numbers of each WTG model selected in the previous phase. The objective of the iterations was to determine the number of WTGs for each model that would result in the lowest calculated cost of energy (COE).

The outputs from Homer were integrated in Excel spreadsheets to evaluate the impact of increasing fuel costs, electrical demand, inflation and cost of borrowed capital. Some key metrics were identified to compare the various configurations and determine the most economically viable scenarios. The results are presented in the following section.



## 4. Results

### 4.1 Proposed Configuration

Based on the modeling performed in HOMER, the optimal number of turbines for integration in the Hopedale system is 8 when considering the NPS100 and 1 when considering the EWT900. Since the turbines are very different in scale, a qualitative comparison between the models is presented at the end of the current section. The table below shows a summary of the results for integration of various numbers of each WTG model.

	Fuel saved vs base case	Yearly Fuel Savings	Wind Penetration	WTG energy over 20 yrs (kWh)	Excess energy over 20 yrs (kWh)	Cost of Energy (\$/kWh)
No WTG	0%	\$0	0%	0	0	\$0.327
6 NPS100	29.8%	\$696,662	29.2%	41,446,900	2,838,768	\$0.308
7 NPS100	32.9%	\$773,230	32.9%	48,354,800	4,820,916	\$0.308
8 NPS100	36.1%	\$851,018	36.2%	55,262,720	7,325,970	\$0.307
9 NPS100	39.0%	\$798,480	39.2%	62,170,360	10,313,566	\$0.308
1 EWT900	41.0%	\$854,928	41.3%	67,983,500	13,264,799	\$0.262
2 EWT900	53.9%	\$1,203,635	54.8%	135,967,020	63,469,302	\$0.270

**Table 5 : Summary of Results**

The estimated energy production of each proposed configuration accounts for the possible losses in a wind farm, such as wake, aerodynamic, electrical, operational and power curve losses. The figures of availability should be defined with more accuracy at the detailed turbine selection stage, based on statistics for the turbine selected and after confirmation of the O & M strategy and review of the draft O&M contract if applicable. Based on preliminary manufacturer's discussions, other factors that will need to be considered for availability include the benefit of having a greater number of turbine units due to potential difficulties to execute repairs in the winter months. This will need to be analyzed as part of the turbine selection process.

As noted in Sections 4.2 and 4.3, the cost of energy does not include all applicable costs. As such, this preliminary cost of energy provides an indicator that, at this point, the project is viable and warrants further study. Additional costs not reflected include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

### 4.2 Construction Costs

The total estimated cost of building a wind farm at Hopedale includes development, turbine, construction and project management. Project contingency was also included, at 5% for WTG components and 10% for construction costs. Additional integration and pre-development costs include logistics study, integration study, electrical and mechanical stability studies have not been included. System integration costs have also been left out of the equation, as well as any associated integration and communication equipment costs since this scope were



not included in the present project. All of the aforementioned studies would need to be completed to fully assess the viability of the project. The following table shows a summary of the included project costs for various iterations:

Number of units	NPS 100				EWT 900	
	6	7	8	9	1	2
<b>Development costs</b>	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000
<b>Turbine costs</b>	\$2,640,000	\$3,080,000	\$3,520,000	\$3,960,000	\$2,375,000	\$4,750,000
<b>Construction costs</b>	\$1,491,504	\$1,625,255	\$1,759,006	\$1,892,757	\$1,605,900	\$2,416,800
<b>Project management</b>	\$450,650	\$508,026	\$565,401	\$622,776	\$435,590	\$754,180
<b>Contingency</b>	\$363,715	\$404,828	\$445,941	\$487,053	\$360,399	\$592,098
<b>Total project CapEx:</b>	<b>\$5,320,870</b>	<b>\$5,993,109</b>	<b>\$6,665,347</b>	<b>\$7,337,586</b>	<b>\$5,151,889</b>	<b>\$8,888,078</b>
<b>CapEx per installed MW:</b>	\$8,868,117	\$8,561,584	\$8,331,684	\$8,152,873	\$5,724,321	\$4,937,821

**Table 6 : Summary of Construction Costs**

For the detailed construction costs see Annex 1.

### 4.3 Further Study Required – System Integration

The installation of WTGs on the grid at Hopedale will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in the following section include no allocation for additional control and communication equipment.

### 4.4 Penetration and Energy Cost

The cost of energy for each option is calculated based on the total cost of producing the required quantity of energy during the life of the project and the total amount of energy produced. Costs are based on the cost of borrowed capital for CapEx, increasing fuel costs and energy demand as well as anticipated discount rate (inflation) over the duration of the project. All costs presented in this report are based on the average long term marginal cost of debt of 6.48% provided by NLH. However this historical value may not be representative of future interest rates and a different value could have a significant impact on the cost of energy for configurations using WTGs because of the large investment required. For information purposes, the resulting cost of energy associated with an interest rate of 4.5% was included in the Figure 1 : Average Cost of Energy.

The level of penetration of wind energy in the energy pool at Hopedale is proportional to the number of WTG installed on site. This value represents the total amount of power produced by wind turbines over the project life divided by the total amount of power used.

The results for average cost of energy and wind penetration over the expected project life of 20 years are shown in the figure below. From this figure, it can clearly be seen that there are



configurations using either WTG model that produce a COE lower than the base case. However, the EWT900 results in a much lower overall cost of energy and a much higher wind penetration level than the NPS100. The design methodology leading to these results was provided in Section 3.

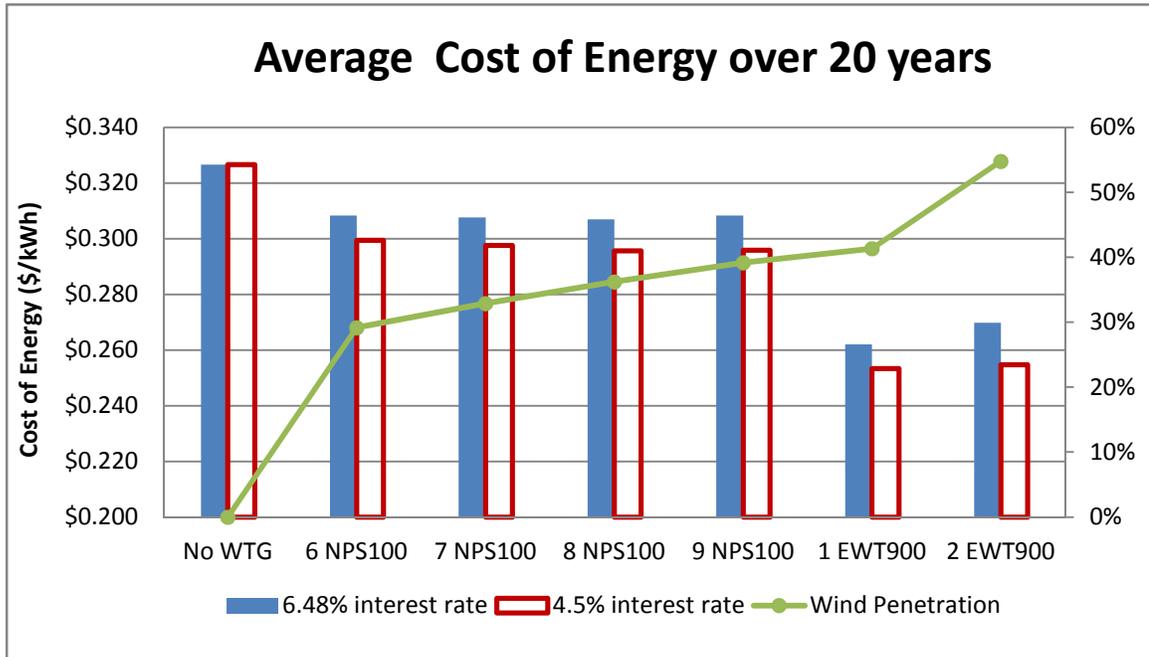


Figure 1 : Average Cost of Energy

#### 4.5 Evolution of Cost of Energy

Figure 2 : Evolution of Cost of Energy shows the evolution of the non-discounted cost of power over the 20 years of the project life. It illustrates that the inclusion of more WTGs or larger WTGs in the energy mix reduces the impact of rising fuel costs on the average cost of energy over the project life. The graph also indicates that scenarios with the EWT900 turbine result in much lower energy costs. Scenarios with the NPS100 also result in a lower energy cost than the base case, but the cost is significantly higher than the results with the EWT900.

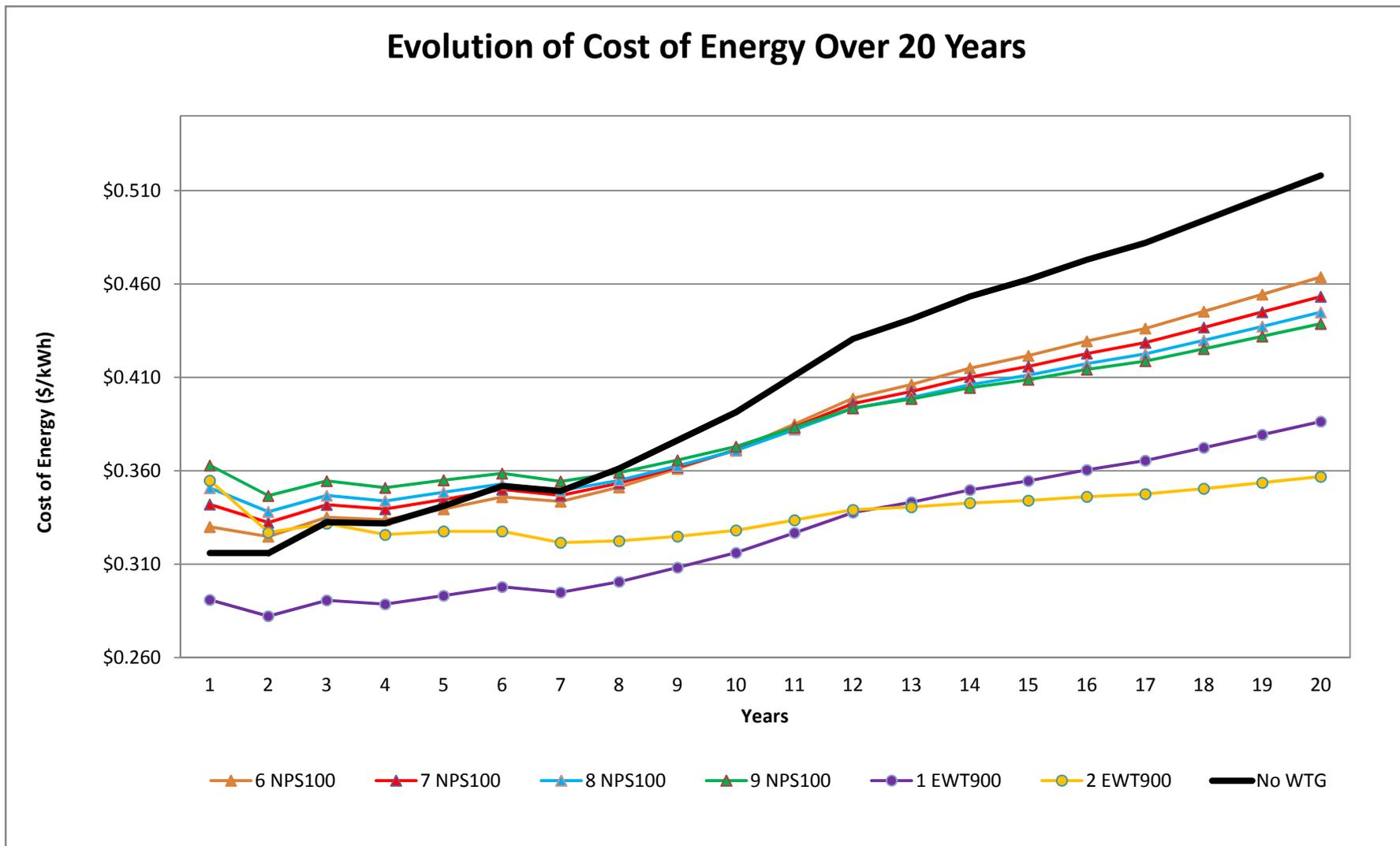


Figure 2 : Evolution of Cost of Energy



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#### 4.6 Fuel Costs and Excess Wind Energy

The average yearly fuel costs provide a good indication of the system reliance on fossil fuels for operation. The greater the installed wind capacity, the lower the annual fuel costs. However because of the magnitude and variability of electrical load on site, above a certain quantity of turbines, not all the energy produced by the turbines can be used by the system, causing the WTG to be less efficient.

The following figure shows the average yearly fuel costs for each configuration as well as the associated percentage fuel saved. The percentage of wasted WTG energy is also shown.

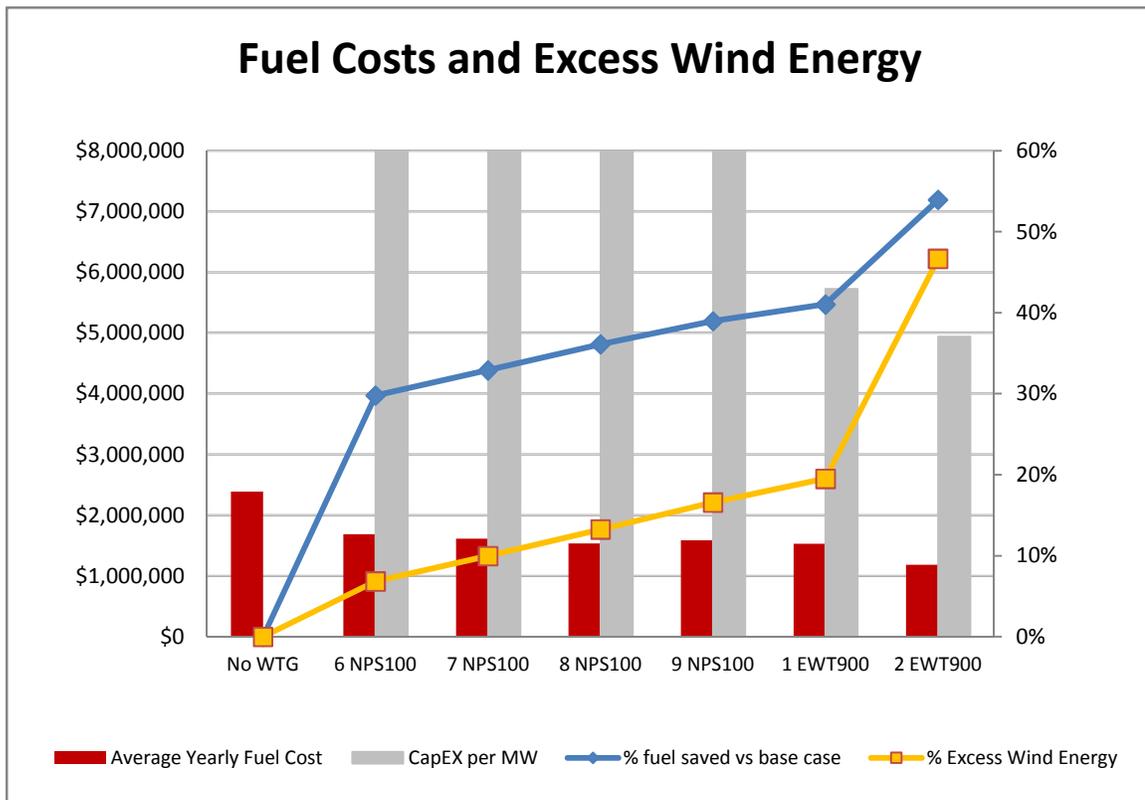


Figure 3 : Fuel Costs and Excess Wind Energy

#### 4.7 Avoided Greenhouse Gas Emissions

The addition of renewable energy to the Cartwright electrical grid would have an impact on the amount of Greenhouse Gas (GHG) emissions resulting from energy production. NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each liter of diesel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration is as follows:

Case	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
No WTG	0	0
6 NPS100	1,466	29,316
7 NPS100	1,619	32,376
8 NPS100	1,777	35,531
9 NPS100	1,917	38,340
1 EWT900	2,019	40,373
2 EWT900	2,654	53,076

**Table 7 : Avoided Emissions of CO<sub>2</sub>**

Note: As of 2010, total Newfoundland and Labrador Green house gas emissions were 8.9 million tonnes per year, so avoided emissions by the installation of 1 EWT900 WTG at Hopedale would be equal to 0.023 % of total Provincial emissions.

#### 4.8 Qualitative Comparison of WTG Models

The results presented in Section 4.1 clearly highlight the difference in wind penetration and energy cost between the two turbines being considered. The NPS100 is a small wind turbine that is easier to deploy yet has limited control capabilities, while the EWT900 is a full-size turbine with a large rotor diameter and the full control package associated with a utility scale turbine. Both turbines have an excellent track record in arctic conditions, making both potential candidates for the application. On the economic aspect, though the cost estimates will need to be validated in the next phase of the project, the cost per installed kW is much lower for the larger turbine which is generally common within the wind industry.

Consequently, the energy produced comes at a lower price for the EWT900 than the NPS100. On the electrical side, the EWT is oversized for the application and produces much more energy than the NPS. Accordingly, the amount of excess energy by the EWT WTG is far above the NPS model, however the overall cost of useful energy remains lower for the EWT. The excess energy is expected to be easier to manage on the EWT as well, since it has active curtailment and derating management capabilities. From an environmental perspective, the EWT allows for more avoided emissions than the NPS. The practical O&M aspect also favors the EWT, as the manufacturer offers O&M options through long term contracts and, under certain circumstances, will even offer an availability warranty.

The size of the EWT900 makes for a more complex deployment, construction and installation. The logistical capabilities, including the remoteness, of the Hopedale port and community are not well documented and may make the delivery, unloading, transport and installation of the



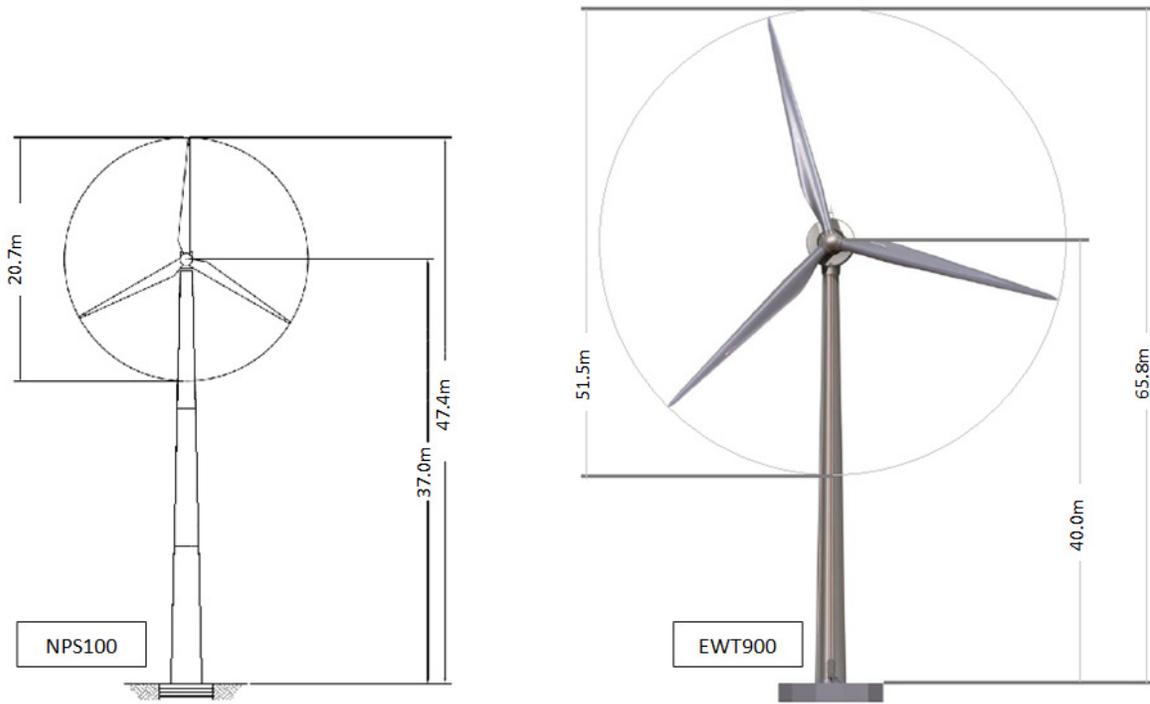
EWT turbine much more expensive than budgeted at present. This could be a fatal flaw associated with the EWT900 WTG. A full logistic analysis is strongly recommended to confirm whether the installation of the EWT900 WTG is feasible. It needs to be noted that turbine models between 100 KW to 900 KW are not commonly available from many OEMs especially for use in arctic conditions. A more detailed turbine selection process should be initiated in following phases of the project.

The table below shows a comparison between the two models with “X” indicating superiority in each category:

Category	NPS100	EWT900
Track Record	X	X
Turbine Cost		X
Energy Production		X
Control Capabilities		X
Avoided Emissions		X
O&M		X
Logistics	X	

**Table 8 : WTG qualitative comparison**

Figure 4 highlights the size differences between the NPS100 and the EWT900.



**Figure 4 : Turbines Size**

## 5. Conclusion and Recommendations

Based on the system modeling and preliminary economic analysis performed by Hatch, the optimal system design for Hopedale the installation of one EWT900 WTGs. This result is based on the anticipated energy production of the existing gensets and the future wind turbines, according to the functional specifications of the local grid as provided by NLH. It should be noted that several components were excluded from this analysis, including the value of avoided GHG emissions, the level of community acceptance and government policy implications. It is recommended that NLH gather more information on these topics prior to moving forward with further assessments of project viability.

It is important to note that a detailed mechanical and electrical stability study was not performed at this stage. It is critical that such a study be performed in advance of the detailed design stage to determine the impacts of adding WTGs to the existing system, as well as the actual limitations of the current grid. Furthermore, a logistics analysis needs to be completed to determine whether the local capabilities allow for the installation of the EWT900 turbine.

### ELB

Attachment(s)/Enclosure :

Annex 1 - Construction Costs.pdf

H340923-0000-05-124-0002\_rev2.pdf (Hopedale Final Wind Resource Assessment Report)



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## Annex 1 – Construction Costs Used in HOMER Model

<b>Costs to add turbines at various sites</b>	<b>NPS100</b>	<b>EWT900</b>
WTG O&M (\$/y)	\$ 20,000	\$ 60,000
Project development (lump sum)	\$ 200,000	\$ 200,000
Engineering and studies (lump sum)	\$ 175,000	\$ 175,000
Deployment cost (lump sum)	\$ 75,000	\$ 175,000
New electrical line (\$/km)	\$ 250,000	\$ 250,000
New road (\$/km)	\$ 300,000	\$ 300,000
Interconnection to local grid	\$ 50,000	\$ 50,000
Rock blasting (per turbine)	\$ 20,000	\$ 250,000
Concrete batch plant deployment	\$ 25,000	\$ 25,000
Foundation concrete content (cubic yards)	29.09	250.00
Concrete cost (\$/cubic yard)	\$ 900	\$ 900
Other foundation material and labor	\$ 25,000	\$ 125,000
Total foundation cost (per turbine)	\$ 71,180	\$ 600,000
Turbine purchase cost (per turbine)	\$ 325,000	\$ 2,000,000
Extra turbine cost for arctic version (per turbine)	\$ 20,000	\$ -
Turbine transportation to site (per turbine)	\$ 45,000	\$ 250,000
Turbine installation (per turbine)	\$ 50,000	\$ 125,000
Turbine peak power output (kW)	100	900
Project management (% of total project cost)	10%	10%
Construction management (% of construction costs)	6%	6%
Contingency for turbine components	5%	5%
Contingency for construction costs	10%	10%

# Appendix H: Hybrid system modelling and optimisation report - Makkovik



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H340923-0000-05-124-0012, Rev. B

Project Report

November 9, 2015

# Coastal Labrador Wind Monitoring Program

## Makkovik Hybrid System Modeling and Optimization

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## 1. Introduction, Objectives and Scope of Work

As part of the project titled, Coastal Labrador Wind Monitoring Program, Newfoundland and Labrador Hydro (NLH) mandated Hatch to complete a wind monitoring campaign to determine the feasibility of adding Wind Turbine Generators (WTG) to Labrador isolated communities of Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. This report presents the methodology and results related to Makkovik.

The wind monitoring periods are listed in the table below and additional information on the wind monitoring campaigns can be found in the respective WRA reports completed for each community.

	Date of first data recorded	Date of last data recorded
<b>Nain (mast 2601)</b>	30 October 2013	19 July 2015
<b>Hopedale (mast 2602)</b>	27 October 2013	19 July 2015
<b>Makkovik (mast 2603)</b>	25 October 2013	19 July 2015
<b>Cartwright (mast 2605)</b>	5 November 2013	13 July 2015
<b>L'Anse au Loup (mast 2604)</b>	5 October 2013	27 April 2015

**Table 1 : Sites and Monitoring Periods**

The specific objectives of the mandate were to provide the potential wind turbine capacity that can be installed on these 5 communities, the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

## 2. Overview of Existing Diesel Grid on Site

Makkovik is a small community in Northern Labrador and consequently has a small electrical demand compared to neighbouring communities. The electrical equipment on site as well as electrical load and future forecast are defined below, based on the information provided by NLH.

### 2.1 Installed Power Generation Equipment

The power grid operated by NLH in Makkovik currently relies on three (3) diesel generators (Gensets). This configuration is common for isolated communities where it would be too costly to interconnect to the main provincial grid. The gensets currently on site include the following units:

Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
<b>(G1)2059</b>	635	CAT	D-3412	1800	2000
<b>(G2)3033</b>	450	CAT	D-3412	1800	1992
<b>(G3)2029</b>	465	CAT	D-3412	1800	1990

**Table 2 : Diesel Gensets on Site**



## 2.2 Generator Control Scheme

The gensets on site are managed by an automated control scheme. NLH explained that the control logic aims to minimize the number and size of the gensets running at any given time while also insuring sufficient spinning reserve to meet increases in load. To do so, whenever the unit running is operating at less than 75% load ratio, the system switches to a smaller unit, if available. Whenever the unit running is loaded at more than 85%, the system switches to a larger unit, if available, or starts a second generator to share the load.

The minimum load ratio for all gensets operated by NLH is 30%.

These control parameters are important for the modeling part of the process and will be discussed later.

## 2.3 Electric Load

The electric load at Makkovik varies a little between winter and summer months. NLH provided the 2014 monthly average hourly electrical load. This data is shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Makkovik	574	502	449	389	404	308	358	507	348	391	400	521

**Table 3 : Average Load (kW)**

Furthermore, a monitoring system was recently installed by NLH to record 15 minute electrical production from each genset. The data recorded by this system, which covers the period of December 2014 to April 2015, was made available for inclusion in the model. This dataset provided the basis of calculation for the production of a daily hourly load profile, an essential component of the modeling exercise.

It should be noted that the 15 minute dataset provided shows that more genset hours are required to produce the energy for the site compared to what is predicted by the modelling software.

## 2.4 Forecasted Load and Fuel Price

NLH provided information showing anticipated growth of peak hourly power demand and total yearly energy for the years 2015 to 2033 for Makkovik. The expected average fuel cost for each year was also supplied for the same period. The table below summarizes this information.

Makkovik	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Gross Peak (kW)	965	975	985	995	1,004	1,017	1,027	1,037	1,047	1,057	1,067	1,077	1,087	1,097	1,107	1,117	1,127	1,137	1,148
Net Peak (kW)	921	931	941	951	960	973	983	993	1,003	1,013	1,023	1,033	1,043	1,053	1,063	1,073	1,083	1,093	1,104
Gross Energy (MWh)	4,468	4,510	4,550	4,592	4,633	4,675	4,717	4,759	4,802	4,846	4,887	4,928	4,970	5,012	5,055	5,098	5,141	5,185	5,229
Net Energy (MWh)	4,175	4,214	4,252	4,292	4,330	4,369	4,408	4,448	4,488	4,528	4,567	4,605	4,645	4,684	4,724	4,764	4,805	4,845	4,887
Fuel Price (\$/L)	\$0.93	\$0.99	\$0.99	\$1.02	\$1.06	\$1.05	\$1.09	\$1.15	\$1.20	\$1.27	\$1.34	\$1.38	\$1.42	\$1.46	\$1.49	\$1.53	\$1.57	\$1.61	\$1.66

**Table 4 : Forecasted load and fuel price growth (2015-2033)**

The forecasted load growth and fuel price increase were important components in the evaluation of the various available system configurations as the objective was to find the most desirable system over the life of the project.

## 3. Design methodology

### 3.1 Software Used

The electrical system and integration of the wind turbines was modelled and simulated using HOMER (Hybrid Optimization of Multiple Electric Renewables). This software is specifically used to model and optimize the configuration of micro-grid systems composed of multiple components, which can include wind turbine generators, photovoltaic solar panels, hydroelectric generators, batteries as well as generators running on various types of fuel. Using inputs comprising electric load profile, electrical architecture of the system (DC vs AC, etc.), renewable resources as well as costs for the purchase, operation and replacement of each component, HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or fuel used by the system. In the context of the current assignment, the outputs of the software were integrated in MS Excel spreadsheets to include electrical load and fuel cost variations over time with the aim of selecting the most efficient solution over the life of the project.

### 3.2 Model Building

NLH provided valuable information related to the historical operating performance of the existing system. The data provided included operations and maintenance (O&M) costs and overhaul costs, as well as data linking electrical production and fuel consumption. Each genset model was created in HOMER to accurately reflect these parameters, as well as the specific fuel curve provided by NLH.

The average monthly electrical load provided by NLH was used as the basis for the load profile included in the model. The 15 minute genset production dataset, covering a 5 month



period, was used to establish a daily electric production profile. The assumption was made that the electric production at any given time was equal to the electric demand, so the daily load profile would be the same as the daily production profile. This daily load profile proved to be similar in shape for all 5 months of data provided, with differing magnitudes across months. As such, the assumption was made that the typical daily load profile shape would be the same for all 12 months but that it would be scaled to reflect the monthly averages provided by NLH. This daily load profile for each month was integrated as the electric load for the project. HOMER uses the base hourly profile and introduces hour to hour and day to day random variations based on parameters defined by the user. The result is a random time series for the load that has a pattern similar to the actual load.

At this point an iteration of the model was run in a configuration representing the equipment present on site to verify that HOMER would yield results similar to the numbers provided by NLH. The energy cost, generator run hours and quantity of fuel burned per year all came to within 5% of the numbers provided by NLH for project year 1. This provided validation that the model could be relied upon to accurately represent the system.

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- The daily load profile was derived from time series and historical values provided by NLH
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### 3.3 System Sizing and Optimization

The sizing and optimisation of the proposed wind project for Makkovik was determined through an iterative process. HOMER simulations were run using varying numbers of each WTG model selected in the previous phase. The objective of the iterations was to determine the number of WTGs for each model that would result in the lowest calculated cost of energy (COE).

The outputs from Homer were integrated in Excel spreadsheets to evaluate the impact of increasing fuel costs, electrical demand, inflation and cost of borrowed capital. Some key metrics were identified to compare the various configurations and determine the most economically viable scenarios. The results are presented in the following section.

## 4. Results

### 4.1 Proposed Configuration

Based on the modeling performed in HOMER, the optimal number of turbines for integration in the Makkovik system is 5 when considering the NPS100 and 1 when considering the EWT900. Since the turbines are very different in scale, a qualitative comparison between the models is presented at the end of the current section. The table below shows a summary of the results for integration of various numbers of each WTG model.

	Fuel saved vs base case	Yearly Fuel Savings	Wind Penetration	WTG energy over 20 yrs (kWh)	Excess energy over 20 yrs (kWh)	Cost of Energy (\$/kWh)
<b>No WTG</b>	0%	\$0	0%	0	0	\$0.3249
<b>3 NPS100</b>	22.3%	\$342,136	22.8%	20,729,500	262,833	\$0.3113
<b>4 NPS100</b>	28.5%	\$439,416	29.4%	27,639,360	1,223,202	\$0.3050
<b>5 NPS100</b>	33.5%	\$517,163	34.8%	34,549,260	3,326,212	\$0.3046
<b>6 NPS100</b>	37.3%	\$576,633	38.9%	41,459,020	6,539,543	\$0.3070
<b>1 EWT900</b>	42.6%	\$660,449	44.7%	62,032,680	21,872,061	\$0.2788
<b>2 EWT900</b>	50.7%	\$787,027	53.5%	124,065,340	76,030,524	\$0.3265

**Table 5 : Summary of Results**

The estimated energy production of each proposed configuration accounts for the possible losses in a wind farm, such as wake, aerodynamic, electrical, operational and power curve losses. The figures of availability should be defined with more accuracy at the detailed turbine selection stage, based on statistics for the turbine selected and after confirmation of the O & M strategy and review of the draft O&M contract if applicable. Based on preliminary manufacturer's discussions, other factors that will need to be considered for availability include the benefit of having a greater number of turbine units due to potential difficulties to execute repairs in the winter months. This will need to be analyzed as part of the turbine selection process.



As noted in Sections 4.2 and 4.3, the cost of energy does not include all applicable costs. As such, this preliminary cost of energy provides an indicator that, at this point, the project is viable and warrants further study. Additional costs not reflected include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

## 4.2 Construction Costs

The total estimated cost of building a wind farm at Makkovik includes development, turbine, construction and project management. Project contingency was also included, at 5% for WTG components and 10% for construction costs. Additional integration and pre-development costs include logistics study, integration study, electrical and mechanical stability studies have not been included. System integration costs have also been left out of the equation, as well as any associated integration and communication equipment costs since this scope were not included in the present project. All of the aforementioned studies would need to be completed to fully assess the viability of the project. The following table shows a summary of the included project costs for various iterations:

Number of units	NPS 100				EWT 900	
	3	4	5	6	1	2
Development costs	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000
Turbine costs	\$1,320,000	\$1,760,000	\$2,200,000	\$2,640,000	\$2,375,000	\$4,750,000
Construction costs	\$798,752	\$932,503	\$1,066,254	\$1,200,004	\$1,372,700	\$2,241,900
Project management	\$249,375	\$306,750	\$364,125	\$421,500	\$412,270	\$736,690
Contingency	\$208,313	\$249,425	\$290,538	\$331,650	\$334,747	\$572,859
<b>Total project CapEx:</b>	<b>\$2,951,440</b>	<b>\$3,623,679</b>	<b>\$4,295,917</b>	<b>\$4,968,155</b>	<b>\$4,869,717</b>	<b>\$8,676,449</b>
<b>CapEx per installed MW:</b>	<b>\$9,838,134</b>	<b>\$9,059,196</b>	<b>\$8,591,834</b>	<b>\$8,280,259</b>	<b>\$5,410,797</b>	<b>\$4,820,249</b>

**Table 6 : Summary of Construction Costs**

For the detailed construction costs see Annex 1.

## 4.3 Further Study Required – System Integration

The installation of WTGs on the grid at Makkovik will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in the following section include no allocation for additional control and communication equipment.

## 4.4 Penetration and Energy Cost

The cost of energy for each option is calculated based on the total cost of producing the required quantity of energy during the life of the project and the total amount of energy produced. Costs are based on the cost of borrowed capital for CapEx, increasing fuel costs



and energy demand as well as anticipated discount rate (inflation) over the duration of the project. All costs presented in this report are based on the average long term marginal cost of debt of 6.48% provided by NLH. However this historical value may not be representative of future interest rates and a different value could have a significant impact on the cost of energy for configurations using WTGs because of the large investment required. For information purposes, the resulting cost of energy associated with an interest rate of 4.5% was included in the Figure 1 : Average Cost of Energy.

The level of penetration of wind energy in the energy pool at Makkovik is proportional to the number of WTG installed on site. This value represents the total amount of power produced by wind turbines over the project life divided by the total amount of power used.

The results for average cost of energy and wind penetration over the expected project life of 20 years are shown in the figure below. From this figure, it can clearly be seen that there are configurations using either WTG model that produce a COE lower than the base case. However, the EWT900 results in a much lower overall cost of energy and a much higher wind penetration level than the NPS100. The design methodology leading to these results was provided in Section 3.

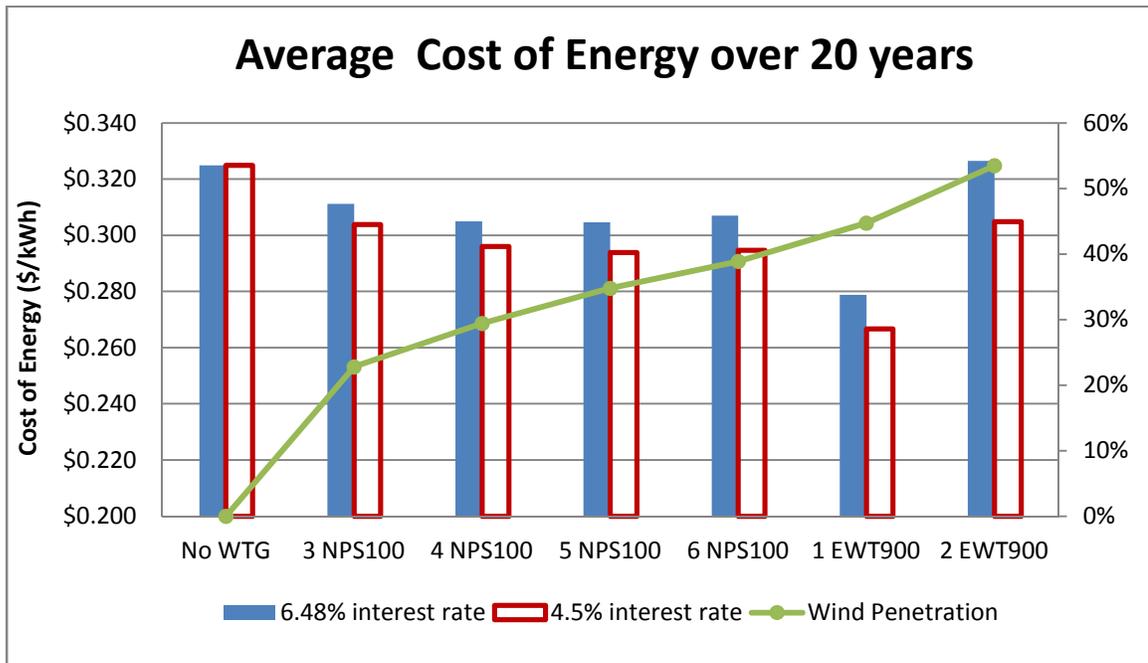


Figure 1 : Average Cost of Energy

#### 4.5 Evolution of Cost of Energy

Figure 2 : Evolution of Cost of Energy shows the evolution of the non-discounted cost of power over the 20 years of the project life. It illustrates that the inclusion of more WTGs or



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larger WTGs in the energy mix reduces the impact of rising fuel costs on the average cost of energy over the project life. The graph also indicates that scenarios with the EWT900 turbine result in much lower energy costs. Scenarios with the NPS100 also result in a lower energy cost than the base case, but the cost is significantly higher than the results with the EWT900.



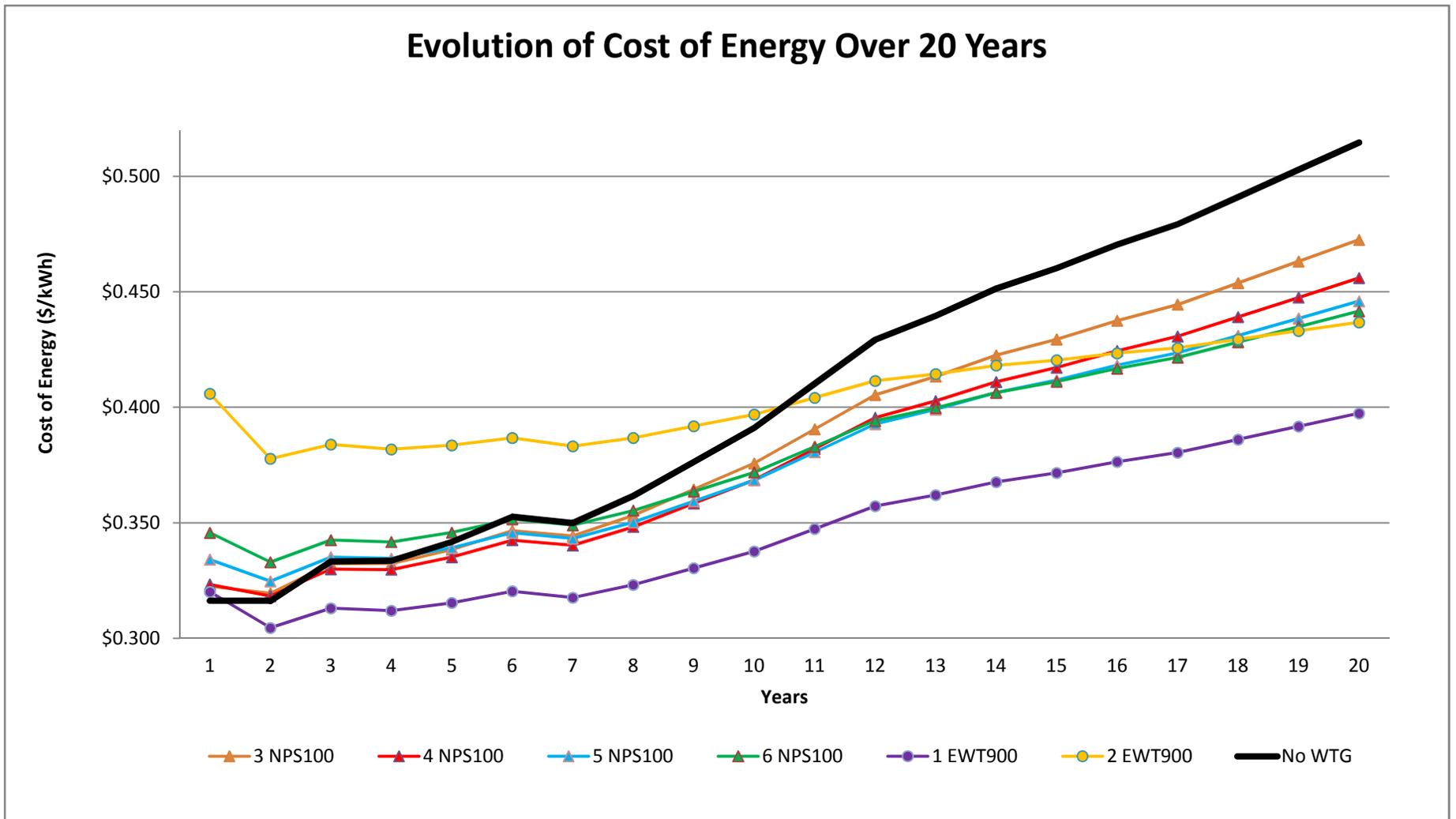


Figure 2 : Evolution of Cost of Energy

#### 4.6 Fuel Costs and Excess Wind Energy

The average yearly fuel costs provide a good indication of the system reliance on fossil fuels for operation. The greater the installed wind capacity, the lower the annual fuel costs. However because of the magnitude and variability of electrical load on site, above a certain quantity of turbines, not all the energy produced by the turbines can be used by the system, causing the WTG to be less efficient.

The following figure shows the average yearly fuel costs for each configuration as well as the associated percentage fuel saved. The percentage of wasted WTG energy is also shown.

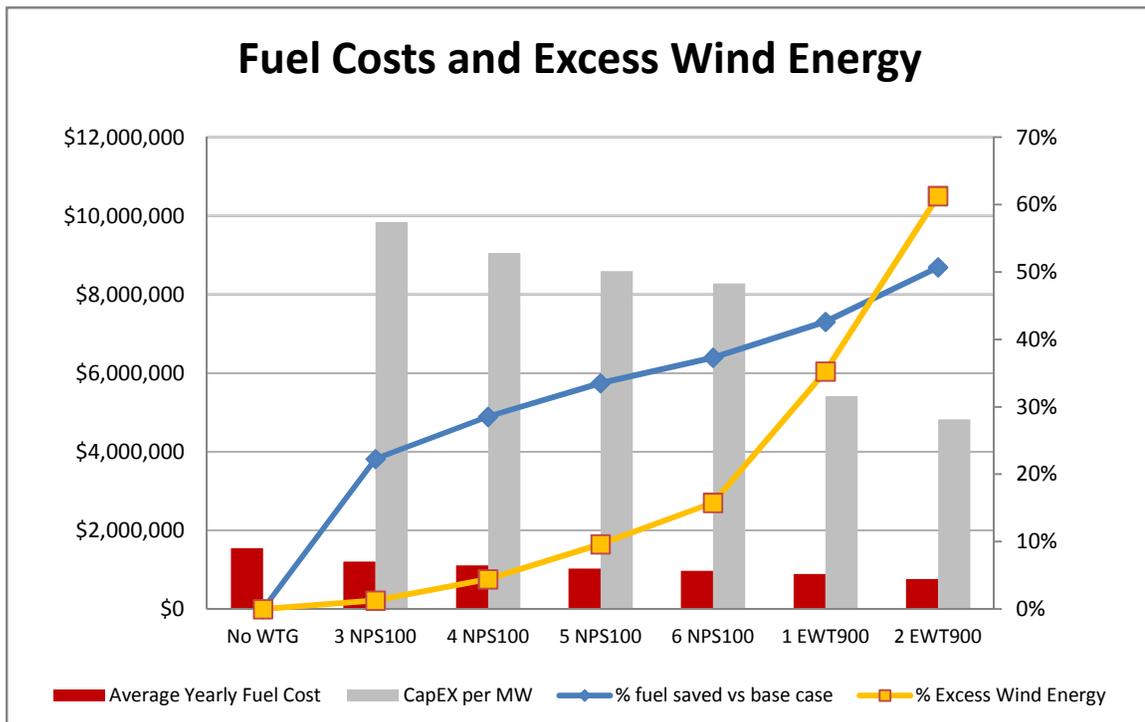


Figure 3 : Fuel Costs and Excess Wind Energy

#### 4.7 Avoided Greenhouse Gas Emissions

The addition of renewable energy to the Cartwright electrical grid would have an impact on the amount of Greenhouse Gas (GHG) emissions resulting from energy production. NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each liter of diesel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration is as follows:

Case	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
No WTG	0	0
3 NPS100	758	15,164
4 NPS100	971	19,427
5 NPS100	1,141	22,810
6 NPS100	1,269	25,388
1 EWT900	1,450	29,009
2 EWT900	1,726	34,517

**Table 7 : Avoided Emissions of CO<sub>2</sub>**

Note: As of 2010, total Newfoundland and Labrador Green house gas emissions were 8.9 million tonnes per year, so avoided emissions by the installation of 1 EWT900 WTG at Makkovik would be equal to 0.016 % of total Provincial emissions.

#### 4.8 Qualitative Comparison of WTG Models

The results presented in Section 4.1 clearly highlight the difference in wind penetration and energy cost between the two turbines being considered. The NPS100 is a small wind turbine that is easier to deploy yet has limited control capabilities, while the EWT900 is a full-size turbine with a large rotor diameter and the full control package associated with a utility scale turbine. Both turbines have an excellent track record in arctic conditions, making both potential candidates for the application. On the economic aspect, though the cost estimates will need to be validated in the next phase of the project, the cost per installed kW is much lower for the larger turbine which is generally common within the wind industry.

Consequently, the energy produced comes at a lower price for the EWT900 than the NPS100. On the electrical side, the EWT is oversized for the application and produces much more energy than the NPS. Accordingly, the amount of excess energy by the EWT WTG is far above the NPS model, however the overall cost of useful energy remains lower for the EWT. The excess energy is expected to be easier to manage on the EWT as well, since it has active curtailment and derating management capabilities. From an environmental perspective, the EWT allows for more avoided emissions than the NPS. The practical O&M aspect also favors the EWT, as the manufacturer offers O&M options through long term contracts and, under certain circumstances, will even offer an availability warranty.

The size of the EWT900 makes for a more complex deployment, construction and installation. The logistical capabilities, including the remoteness, of the Makkovik port and community are not well documented and may make the delivery, unloading, transport and installation of the



EWT turbine much more expensive than budgeted at present. This could be a fatal flaw associated with the EWT900 WTG. A full logistic analysis is strongly recommended to confirm whether the installation of the EWT900 WTG is feasible. It needs to be noted that turbine models between 100 KW to 900 KW are not commonly available from many OEMs especially for use in arctic conditions. A more detailed turbine selection process should be initiated in following phases of the project.

The table below shows a comparison between the two models with “X” indicating superiority in each category:

Category	NPS100	EWT900
Track Record	X	X
Turbine Cost		X
Energy Production		X
Control Capabilities		X
Avoided Emissions		X
O&M		X
Logistics	X	

**Table 8 : WTG qualitative comparison**

Figure 4 highlights the size differences between the NPS100 and the EWT900.

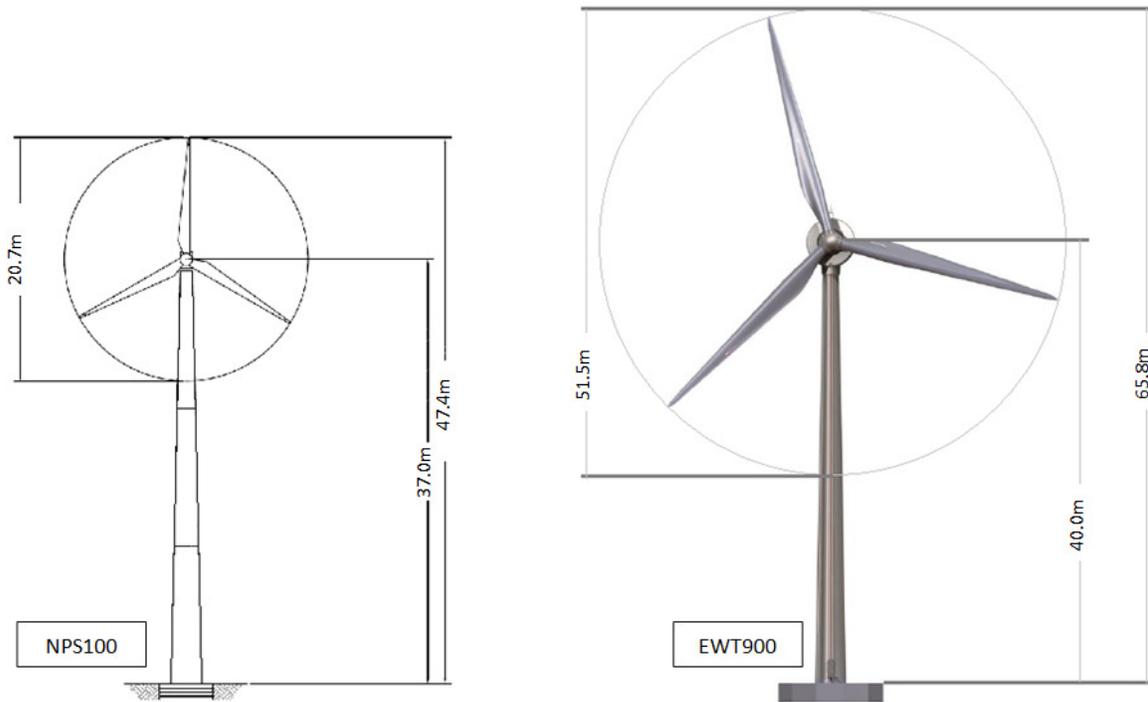


Figure 4 : Turbines Size

## 5. Conclusion and Recommendations

Based on the system modeling and preliminary economic analysis performed by Hatch, the optimal system design for Makkovik is the installation of one EWT900 WTGs. This result is based on the anticipated energy production of the existing gensets and the future wind turbines, according to the functional specifications of the local grid as provided by NLH. It should be noted that several components were excluded from this analysis, including the value of avoided GHG emissions, the level of community acceptance and government policy implications. It is recommended that NLH gather more information on these topics prior to moving forward with further assessments of project viability.

It is important to note that a detailed mechanical and electrical stability study was not performed at this stage. It is critical that such a study be performed in advance of the detailed design stage to determine the impacts of adding WTGs to the existing system, as well as the actual limitations of the current grid. Furthermore, a logistics analysis needs to be completed to determine whether the local capabilities allow for the installation of the EWT900 turbine.

### ELB

Attachment(s)/Enclosure :

Annex 1 - Construction Costs.pdf

H340923-0000-05-124-0003\_rev2.pdf (Makkovik Final Wind Resource Assessment Report)



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## Annex 1 – Construction Costs Used in HOMER Model

Costs to add turbines at various sites	NPS100	EWT900
WTG O&M (\$/y)	\$ 20,000	\$ 60,000
Project development (lump sum)	\$ 200,000	\$ 200,000
Engineering and studies (lump sum)	\$ 175,000	\$ 175,000
Deployment cost (lump sum)	\$ 75,000	\$ 175,000
New electrical line (\$/km)	\$ 250,000	\$ 250,000
New road (\$/km)	\$ 300,000	\$ 300,000
Interconnection to local grid	\$ 50,000	\$ 50,000
Rock blasting (per turbine)	\$ 20,000	\$ 250,000
Concrete batch plant deployment	\$ 25,000	\$ 25,000
Foundation concrete content (cubic yards)	29.09	250.00
Concrete cost (\$/cubic yard)	\$ 900	\$ 900
Other foundation material and labor	\$ 25,000	\$ 125,000
Total foundation cost (per turbine)	\$ 71,180	\$ 600,000
Turbine purchase cost (per turbine)	\$ 325,000	\$ 2,000,000
Extra turbine cost for arctic version (per turbine)	\$ 20,000	\$ -
Turbine transportation to site (per turbine)	\$ 45,000	\$ 250,000
Turbine installation (per turbine)	\$ 50,000	\$ 125,000
Turbine peak power output (kW)	100	900
Project management (% of total project cost)	10%	10%
Construction management (% of construction costs)	6%	6%
Contingency for turbine components	5%	5%
Contingency for construction costs	10%	10%

# Appendix I: Hybrid system modelling and optimisation report - Cartwright



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H340923-0000-05-124-0012, Rev. B

Project Report

November 9, 2015

# Coastal Labrador Wind Monitoring Program Cartwright Hybrid System Modeling and Optimization

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## 1. Introduction, Objectives and Scope of Work

As part of the project titled, Coastal Labrador Wind Monitoring Program, Newfoundland and Labrador Hydro (NLH) mandated Hatch to complete a wind monitoring campaign to determine the feasibility of adding Wind Turbine Generators (WTG) to Labrador isolated communities of Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. This report presents the methodology and results related to Cartwright.

The wind monitoring periods are listed in the table below and additional information on the wind monitoring campaigns can be found in the respective WRA reports completed for each community.

	Date of first data recorded	Date of last data recorded
<b>Nain (mast 2601)</b>	30 October 2013	19 July 2015
<b>Hopedale (mast 2602)</b>	27 October 2013	19 July 2015
<b>Makkovik (mast 2603)</b>	25 October 2013	19 July 2015
<b>Cartwright (mast 2605)</b>	5 November 2013	13 July 2015
<b>L'Anse au Loup (mast 2604)</b>	5 October 2013	27 April 2015

**Table 1 : Sites and Monitoring Periods**

The specific objectives of the mandate were to provide the potential wind turbine capacity that can be installed on these 5 communities, the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

## 2. Overview of Existing Diesel Grid on Site

Cartwright is an average size community in Labrador and consequently has a moderate electrical demand compared to neighbouring communities. The electrical equipment on site as well as electrical load and future forecast are defined below, based on the information provided by NLH.

### 2.1 Installed Power Generation Equipment

The power grid operated by NLH in Cartwright currently relies on four (4) diesel generators (Gensets). This configuration is common for isolated communities where it would be too costly to interconnect to the main provincial grid. The gensets currently on site include the following units:

Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
<b>(G1)2036</b>	450	CAT	D-3412	1800	1992
<b>(G2)2086</b>	600	CAT	C-27	1800	2009
<b>(G3)2045</b>	450	CAT	D-3412	1800	1993
<b>(G4)2052</b>	720	CAT	D-3412	1200	1998

**Table 2 : Diesel Gensets on Site**



## 2.2 Generator Control Scheme

The gensets on site are managed by an automated control scheme. NLH explained that the control logic aims to minimize the number and size of the gensets running at any given time while also insuring sufficient spinning reserve to meet increases in load. To do so, whenever the unit running is operating at less than 75% load ratio, the system switches to a smaller unit, if available. Whenever the unit running is loaded at more than 85%, the system switches to a larger unit, if available, or starts a second generator to share the load.

The minimum load ratio for all gensets operated by NLH is 30%.

These control parameters are important for the modeling part of the process and will be discussed later.

## 2.3 Electric Load

The electric load at Cartwright varies a little between winter and summer months. NLH provided the 2014 monthly average hourly electrical load. This data is shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>Cartwright</b>	656	583	503	465	508	501	461	420	332	416	430	580

**Table 3 : Average Load (kW)**

Furthermore, a monitoring system was recently installed by NLH to record 15 minute electrical production from each genset. The data recorded by this system, which covers the period of December 2014 to April 2015, was made available for inclusion in the model. This dataset provided the basis of calculation for the production of a daily hourly load profile, an essential component of the modeling exercise.

It should be noted that the 15 minute dataset provided shows that more genset hours are required to produce the energy for the site compared to what is predicted by the modelling software.

## 2.4 Forecasted Load and Fuel Price

NLH provided information showing anticipated growth of peak hourly power demand and total yearly energy for the years 2015 to 2033 for Cartwright. The expected average fuel cost for each year was also supplied for the same period. The table below summarizes this information.

<b>Cartwright</b>	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Gross Peak (kW)	1,032	1,040	1,050	1,059	1,069	1,078	1,088	1,097	1,106	1,116	1,120	1,125	1,129	1,133	1,138	1,142	1,146	1,151	1,155
Net Peak (kW)	997	1,005	1,015	1,024	1,034	1,043	1,053	1,062	1,071	1,081	1,085	1,090	1,094	1,098	1,103	1,107	1,111	1,116	1,120
Gross Energy (MWh)	4,701	4,739	4,784	4,823	4,869	4,912	4,955	4,997	5,040	5,083	5,103	5,123	5,142	5,162	5,182	5,202	5,222	5,241	5,261
Net Energy (MWh)	4,500	4,536	4,580	4,617	4,661	4,702	4,743	4,784	4,825	4,866	4,885	4,904	4,923	4,942	4,961	4,980	4,998	5,017	5,036
Fuel Price (\$/L)	\$0.95	\$1.01	\$1.01	\$1.05	\$1.09	\$1.08	\$1.12	\$1.17	\$1.23	\$1.30	\$1.37	\$1.41	\$1.46	\$1.49	\$1.53	\$1.56	\$1.61	\$1.65	\$1.70

**Table 4 : Forecasted load and fuel price growth (2015-2033)**



The forecasted load growth and fuel price increase were important components in the evaluation of the various available system configurations as the objective was to find the most desirable system over the life of the project.

### 3. Design Methodology

#### 3.1 Software Used

The electrical system and integration of the wind turbines was modelled and simulated using HOMER (Hybrid Optimization of Multiple Electric Renewables). This software is specifically used to model and optimize the configuration of micro-grid systems composed of multiple components, which can include wind turbine generators, photovoltaic solar panels, hydroelectric generators, batteries as well as generators running on various types of fuel. Using inputs comprising electric load profile, electrical architecture of the system (DC vs AC, etc.), renewable resources as well as costs for the purchase, operation and replacement of each component, HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or fuel used by the system. In the context of the current assignment, the outputs of the software were integrated in MS Excel spreadsheets to include electrical load and fuel cost variations over time with the aim of selecting the most efficient solution over the life of the project.

#### 3.2 Model Building

NLH provided valuable information related to the historical operating performance of the existing system. The data provided included operations and maintenance (O&M) costs and overhaul costs, as well as data linking electrical production and fuel consumption. Each genset model was created in HOMER to accurately reflect these parameters, as well as the specific fuel curve provided by NLH.

The average monthly electrical load provided by NLH was used as the basis for the load profile included in the model. The 15 minute genset production dataset, covering a 5 month period, was used to establish a daily electric production profile. The assumption was made that the electric production at any given time was equal to the electric demand, so the daily load profile would be the same as the daily production profile. This daily load profile proved to be similar in shape for all 5 months of data provided, with differing magnitudes across months. As such, the assumption was made that the typical daily load profile shape would be the same for all 12 months but that it would be scaled to reflect the monthly averages provided by NLH. This daily load profile for each month was integrated as the electric load for the project. HOMER uses the base hourly profile and introduces hour to hour and day to day random variations based on parameters defined by the user. The result is a random time series for the load that has a pattern similar to the actual load.

At this point an iteration of the model was run in a configuration representing the equipment present on site to verify that HOMER would yield results similar to the numbers provided by NLH. The energy cost, generator run hours and quantity of fuel burned per year all came to within 5% of the numbers provided by NLH for project year 1. This provided validation that the model could be relied upon to accurately represent the system.



A preliminary turbine selection for the Cartwright project was completed as part of the Wind Resource assessment phase and two WTGs models from two different OEMs were selected; additional information on the turbine selection methodology is available in the WRA report. These turbines are the Northern Power Systems 100kW arctic version (NPS100) and the Emergya Wind Technologies 900kW (EWT900). Both WTGs were modeled in HOMER based on manufacturer provided specifications. The long term wind resource calculated in the wind resource assessment campaign was integrated in the model and the energy production predicted by the software WindFarmer for each turbine model was compared with the energy calculated by HOMER. WindFarmer is routinely used to optimize wind farm layouts with regard to energy, topography and restrictions and to estimate the energy production. WindFarmer outputs are considered more accurate than HOMER for this aspect. Following some minor model adjustments, the comparison showed that the HOMER results were similar to the WindFarmer results within a few percent, confirming that the simulation used realistic wind energy production numbers.

The following assumptions were made during the optimization process and in the simulation phase:

- The daily load profile was derived from time series and historical values provided by NLH
- Fuel costs and load growth were based on information provided by NLH, as presented in Section 2.4
- An inflation rate of 2.21% and average NLH long term marginal cost of debt (rounded) of 6.48% were used, according to historical values specified by NLH
- Construction costs have been defined based on information from manufacturers and historical values from past projects

### 3.3 System Sizing and Optimization

The sizing and optimisation of the proposed wind project for Cartwright was determined through an iterative process. HOMER simulations were run using varying numbers of each WTG model selected in the previous phase. The objective of the iterations was to determine the number of WTGs for each model that would result in the lowest calculated cost of energy (COE).

The outputs from Homer were integrated in Excel spreadsheets to evaluate the impact of increasing fuel costs, electrical demand, inflation and cost of borrowed capital. Some key metrics were identified to compare the various configurations and determine the most economically viable scenarios. The results are presented in the following section.



## 4. Results

### 4.1 Proposed Configuration

Based on the modeling performed in HOMER, the optimal number of turbines for integration in the Cartwright system is 5 when considering the NPS100 and 1 when considering the EWT900. Since the turbines are very different in scale, a qualitative comparison between the models is presented at the end of the current section. The table below shows a summary of the results for integration of various numbers of each WTG model.

	Fuel saved vs base case	Yearly Fuel Savings	Wind Penetration	WTG energy over 20 yrs (kWh)	Excess energy over 20 yrs (kWh)	Cost of Energy (\$/kWh)
No WTG	0%	\$0	0%	0	0	\$0.323
4 NPS100	24.5%	\$401,258	25.3%	24,954,620	735,458	\$0.318
5 NPS100	29.3%	\$480,421	30.4%	31,193,300	2,059,909	\$0.316
6 NPS100	33.2%	\$545,446	34.7%	37,432,060	4,256,070	\$0.317
7 NPS100	36.3%	\$538,852	38.0%	43,670,680	7,276,102	\$0.322
1 EWT900	40.3%	\$610,325	42.4%	57,969,780	17,376,152	\$0.279
2 EWT900	49.3%	\$769,412	52.2%	115,939,580	65,979,434	\$0.320

**Table 5 : Summary of Results**

The estimated energy production of each proposed configuration accounts for the possible losses in a wind farm, such as wake, aerodynamic, electrical, operational and power curve losses. The figures of availability should be defined with more accuracy at the detailed turbine selection stage, based on statistics for the turbine selected and after confirmation of the O & M strategy and review of the draft O&M contract if applicable. Based on preliminary manufacturer's discussions, other factors that will need to be considered for availability include the benefit of having a greater number of turbine units due to potential difficulties to execute repairs in the winter months. This will need to be analyzed as part of the turbine selection process.

As noted in Sections 4.2 and 4.3, the cost of energy does not include all applicable costs. As such, this preliminary cost of energy provides an indicator that, at this point, the project is viable and warrants further study. Additional costs not reflected include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization.

### 4.2 Construction Costs

The total estimated cost of building a wind farm at Cartwright includes development, turbine, construction and project management. Project contingency was also included, at 5% for WTG components and 10% for construction costs. Additional integration and pre-development costs include logistics study, integration study, electrical and mechanical stability studies have not been included. System integration costs have also been left out of the equation, as well as any associated integration and communication equipment costs since this scope were



not included in the present project. All of the aforementioned studies would need to be completed to fully assess the viability of the project. The following table shows a summary of the included project costs for various iterations:

Number of units	NPS 100				EWT 900	
	4	5	6	7	1	2
<b>Development costs</b>	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000
<b>Turbine costs</b>	\$1,760,000	\$2,200,000	\$2,640,000	\$3,080,000	\$2,375,000	\$4,750,000
<b>Construction costs</b>	\$1,136,553	\$1,270,304	\$1,404,054	\$1,537,805	\$1,343,550	\$2,271,050
<b>Project management</b>	\$327,155	\$384,530	\$441,905	\$499,281	\$409,355	\$739,605
<b>Contingency</b>	\$271,871	\$312,983	\$354,096	\$395,209	\$331,541	\$576,066
<b>Total project CapEx:</b>	<b>\$3,870,579</b>	<b>\$4,542,817</b>	<b>\$5,215,056</b>	<b>\$5,887,294</b>	<b>\$4,834,446</b>	<b>\$8,711,721</b>
<b>CapEx per installed MW:</b>	\$9,676,448	\$9,085,635	\$8,691,760	\$8,410,420	\$5,371,606	\$4,839,845

**Table 6 : Summary of Construction Costs**

For the detailed construction costs see Annex 1.

### 4.3 Further Study Required – System Integration

The installation of WTGs on the grid at Cartwright will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in the following section include no allocation for additional control and communication equipment.

### 4.4 Penetration and Energy Cost

The cost of energy for each option is calculated based on the total cost of producing the required quantity of energy during the life of the project and the total amount of energy produced. Costs are based on the cost of borrowed capital for CapEx, increasing fuel costs and energy demand as well as anticipated discount rate (inflation) over the duration of the project. All costs presented in this report are based on the average long term marginal cost of debt of 6.48% provided by NLH. However this historical value may not be representative of future interest rates and a different value could have a significant impact on the cost of energy for configurations using WTGs because of the large investment required. For information purposes, the resulting cost of energy associated with an interest rate of 4.5% was included in the Figure 1 : Average Cost of Energy.

The level of penetration of wind energy in the energy pool at Cartwright is proportional to the number of WTG installed on site. This value represents the total amount of power produced by wind turbines over the project life divided by the total amount of power used.

The results for average cost of energy and wind penetration over the expected project life of 20 years are shown in the figure below. From this figure, it can clearly be seen that there are



configurations using either WTG model that produce a COE lower than the base case. However, the EWT900 results in a much lower overall cost of energy and a much higher wind penetration level than the NPS100. The design methodology leading to these results was provided in Section 3.

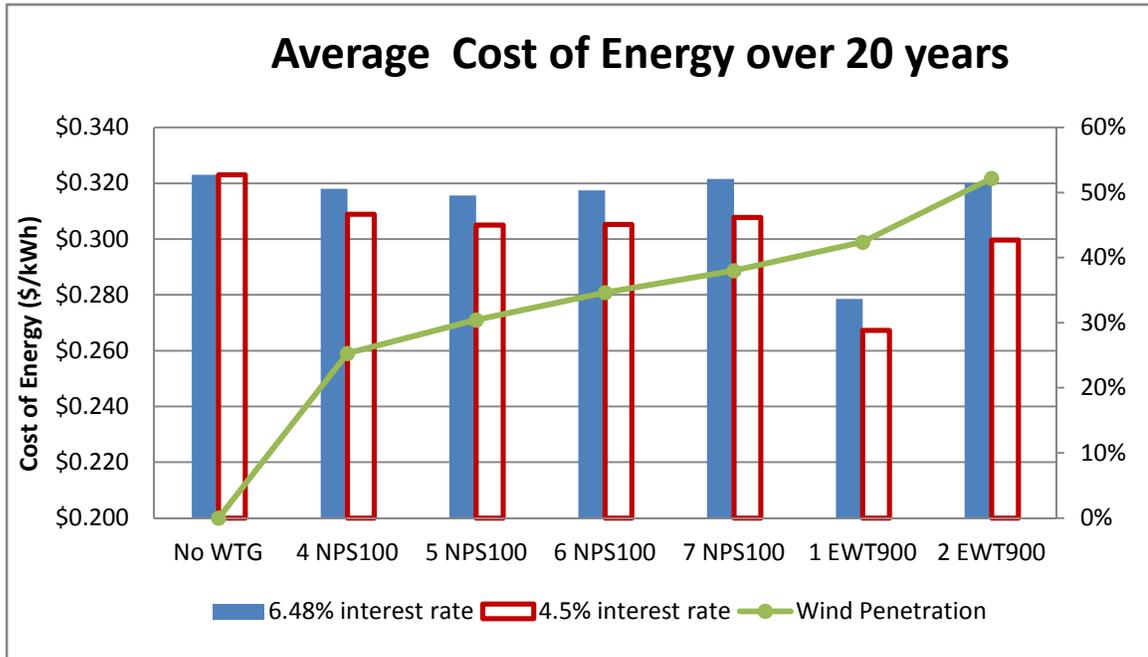


Figure 1 : Average Cost of Energy

#### 4.5 Evolution of Cost of Energy

Figure 2 : Evolution of Cost of Energy shows the evolution of the non-discounted cost of power over the 20 years of the project life. It illustrates that the inclusion of more WTGs or larger WTGs in the energy mix reduces the impact of rising fuel costs on the average cost of energy over the project life. The graph also indicates that scenarios with the EWT900 turbine result in much lower energy costs. Scenarios with the NPS100 also result in a lower energy cost than the base case, but the cost is significantly higher than the results with the EWT900.

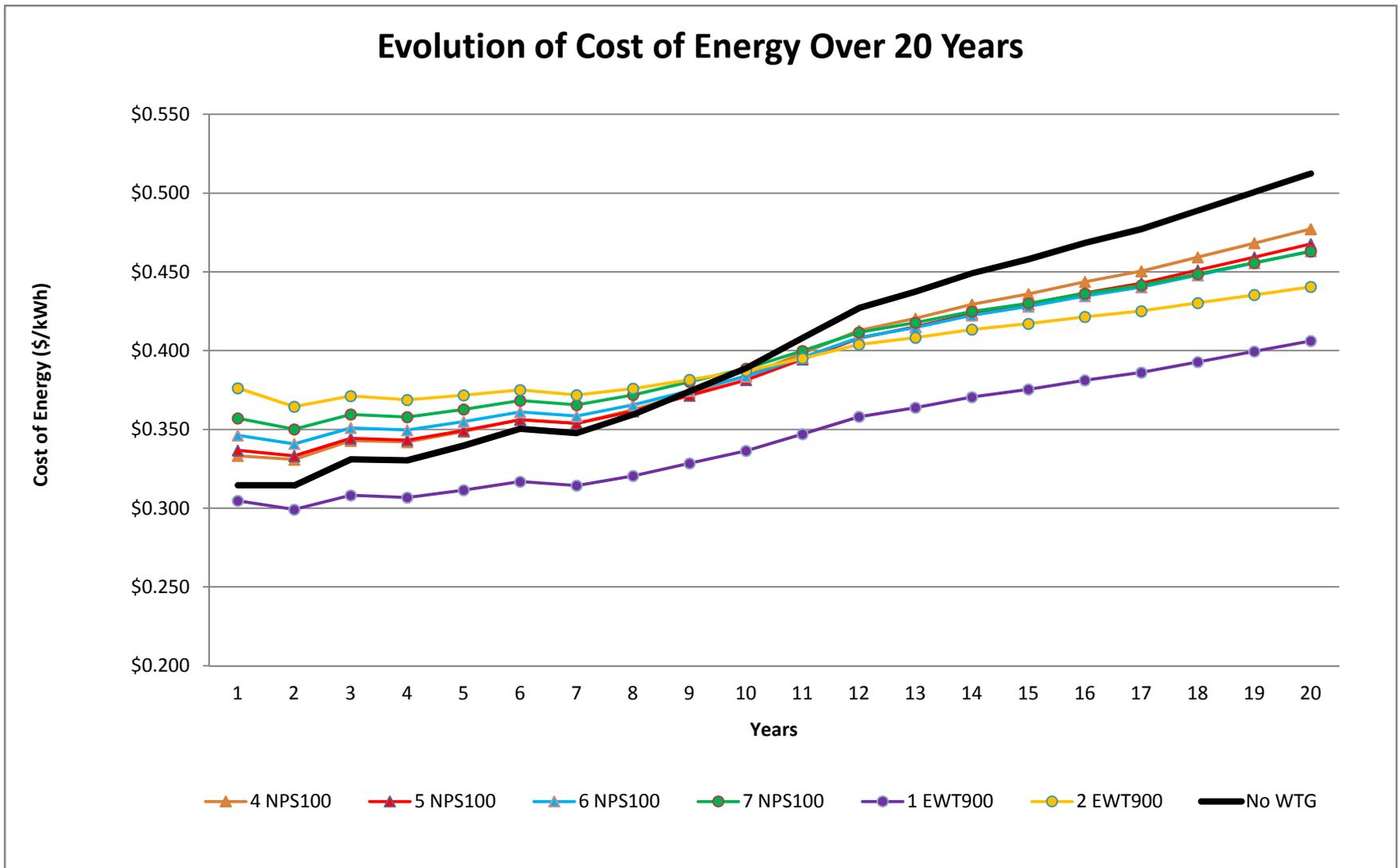


Figure 2 : Evolution of Cost of Energy

#### 4.6 Fuel Costs and Excess Wind Energy

The average yearly fuel costs provide a good indication of the system reliance on fossil fuels for operation. The greater the installed wind capacity, the lower the annual fuel costs. However because of the magnitude and variability of electrical load on site, above a certain quantity of turbines, not all the energy produced by the turbines can be used by the system, causing the WTG to be less efficient.

The following figure shows the average yearly fuel costs for each configuration as well as the associated percentage fuel saved. The percentage of wasted WTG energy is also shown.

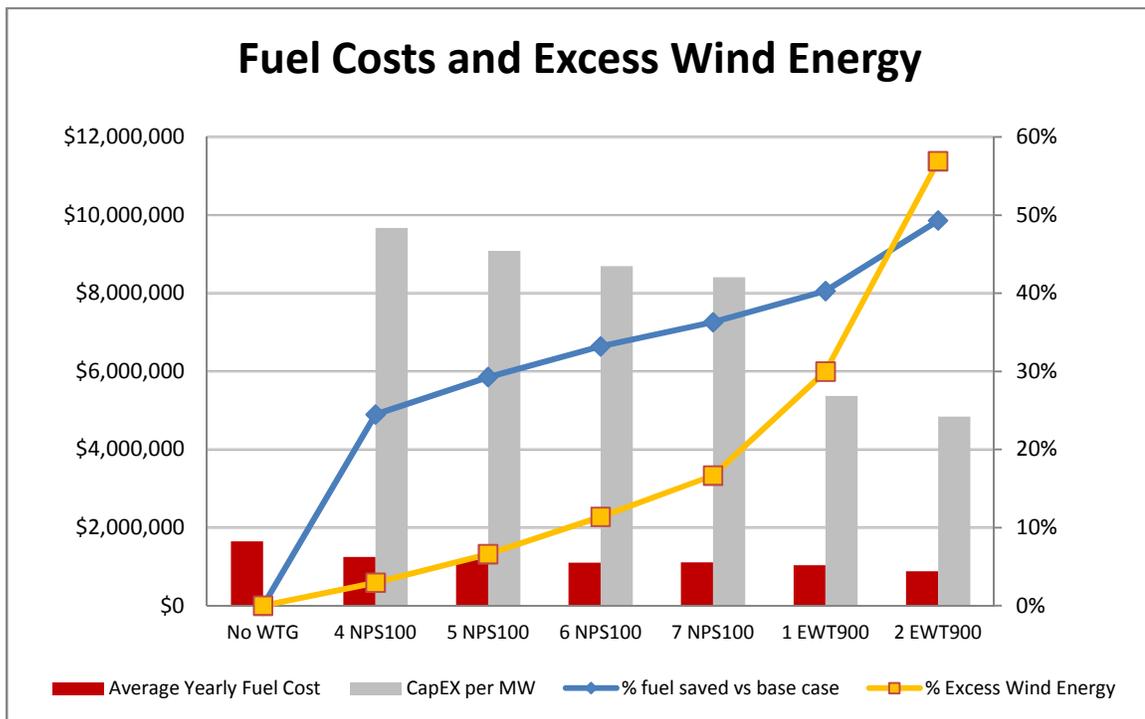


Figure 3 : Fuel Costs and Excess Wind Energy

#### 4.7 Avoided Greenhouse Gas Emissions

The addition of renewable energy to the Cartwright electrical grid would have an impact on the amount of Greenhouse Gas (GHG) emissions resulting from energy production. NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each liter of diesel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration is as follows:

Case	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
No WTG	0	0
4 NPS100	868	17,366
5 NPS100	1,038	20,766
6 NPS100	1,177	23,548
7 NPS100	1,287	25,746
1 EWT900	1,429	28,586
2 EWT900	1,749	34,988

**Table 7 : Avoided Emissions of CO<sub>2</sub>**

Note: As of 2010, total Newfoundland and Labrador Green house gas emissions were 8.9 million tonnes per year, so 0.016 % of total Provincial emissions would be avoided by the installation of 1 EWT900 WTG at Cartwright.

#### 4.8 Qualitative Comparison of WTG Models

The results presented in Section 4.1 clearly highlight the difference in wind penetration and energy cost between the two turbines being considered. The NPS100 is a small wind turbine that is easier to deploy yet has limited control capabilities, while the EWT900 is a full-size turbine with a large rotor diameter and the full control package associated with a utility scale turbine. Both turbines have an excellent track record in arctic conditions, making both potential candidates for the application. On the economic aspect, though the cost estimates will need to be validated in the next phase of the project, the cost per installed kW is much lower for the larger turbine which is generally common within the wind industry.

Consequently, the energy produced comes at a lower price for the EWT900 than the NPS100. On the electrical side, the EWT is oversized for the application and produces much more energy than the NPS. Accordingly, the amount of excess energy by the EWT WTG is far above the NPS model, however the overall cost of useful energy remains lower for the EWT. The excess energy is expected to be easier to manage on the EWT as well, since it has active curtailment and derating management capabilities. From an environmental perspective, the EWT allows for more avoided emissions than the NPS. The practical O&M aspect also favors the EWT, as the manufacturer offers O&M options through long term contracts and, under certain circumstances, will even offer an availability warranty.

The size of the EWT900 makes for a more complex deployment, construction and installation. The logistical capabilities, including the remoteness, of the Cartwright port and community are not well documented and may make the delivery, unloading, transport and installation of the



EWT turbine much more expensive than budgeted at present. This could be a fatal flaw associated with the EWT900 WTG. A full logistic analysis is strongly recommended to confirm whether the installation of the EWT900 WTG is feasible. It needs to be noted that turbine models between 100 KW to 900 KW are not commonly available from many OEMs especially for use in arctic conditions. A more detailed turbine selection process should be initiated in following phases of the project.

The table below shows a comparison between the two models with “X” indicating superiority in each category:

Category	NPS100	EWT900
Track Record	X	X
Turbine Cost		X
Energy Production		X
Control Capabilities		X
Avoided Emissions		X
O&M		X
Logistics	X	

**Table 8 : WTG qualitative comparison**

Figure 4 : Turbines Size highlights the size differences between the NPS100 and the EWT900.

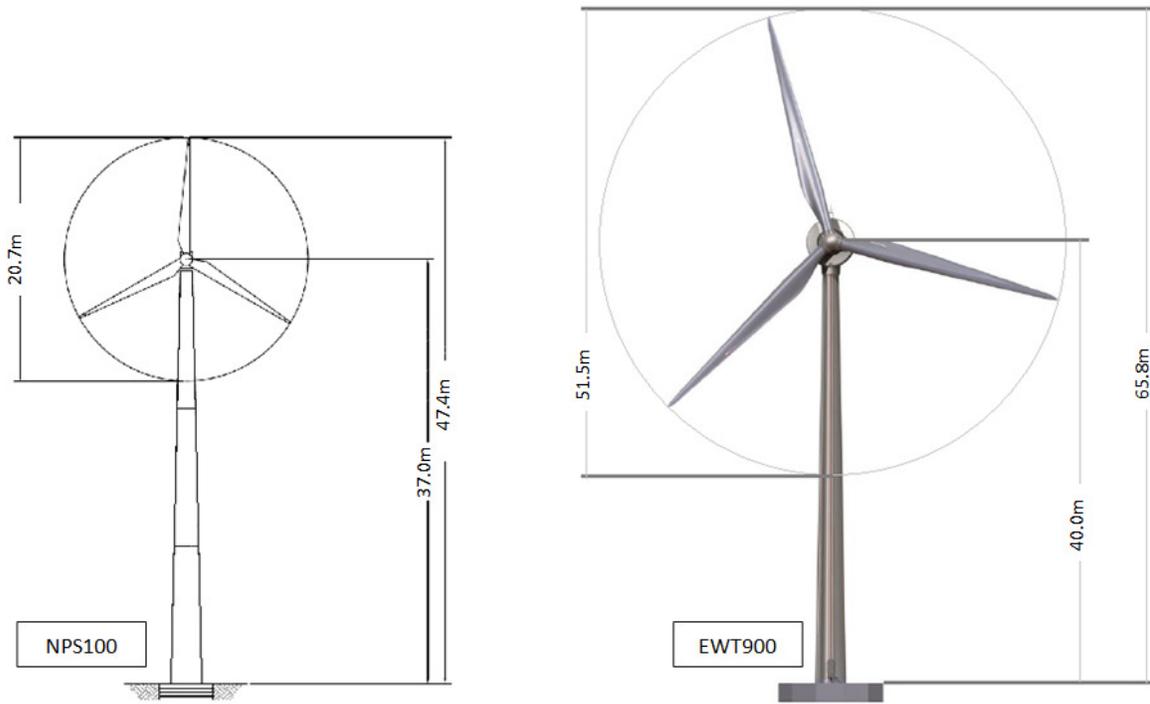


Figure 4 : Turbines Size

## 5. Conclusion and Recommendations

Based on the system modeling and preliminary economic analysis performed by Hatch, the optimal system design for Cartwright is the installation of one EWT900 WTGs. This result is based on the anticipated energy production of the existing gensets and the future wind turbines, according to the functional specifications of the local grid as provided by NLH. It should be noted that several components were excluded from this analysis, including the value of avoided GHG emissions, the level of community acceptance and government policy implications. It is recommended that NLH gather more information on these topics prior to moving forward with further assessments of project viability.

It is important to note that a detailed mechanical and electrical stability study was not performed at this stage. It is critical that such a study be performed in advance of the detailed design stage to determine the impacts of adding WTGs to the existing system, as well as the actual limitations of the current grid. Furthermore, a logistics analysis needs to be completed to determine whether the local capabilities allow for the installation of the EWT900 turbine.

ELB

Attachment(s)/Enclosure :

Annex 1 - Construction Costs.pdf

H340923-0000-05-124-0005\_rev2.pdf (Cartwright Final Wind Resource Assessment Report)



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## Annex 1 – Construction Costs Used in HOMER Model

Costs to add turbines at various sites	NPS100	EWT900
WTG O&M (\$/y)	\$ 20,000	\$ 60,000
Project development (lump sum)	\$ 200,000	\$ 200,000
Engineering and studies (lump sum)	\$ 175,000	\$ 175,000
Deployment cost (lump sum)	\$ 75,000	\$ 175,000
New electrical line (\$/km)	\$ 250,000	\$ 250,000
New road (\$/km)	\$ 300,000	\$ 300,000
Interconnection to local grid	\$ 50,000	\$ 50,000
Rock blasting (per turbine)	\$ 20,000	\$ 250,000
Concrete batch plant deployment	\$ 25,000	\$ 25,000
Foundation concrete content (cubic yards)	29.09	250.00
Concrete cost (\$/cubic yard)	\$ 900	\$ 900
Other foundation material and labor	\$ 25,000	\$ 125,000
Total foundation cost (per turbine)	\$ 71,180	\$ 600,000
Turbine purchase cost (per turbine)	\$ 325,000	\$ 2,000,000
Extra turbine cost for arctic version (per turbine)	\$ 20,000	\$ -
Turbine transportation to site (per turbine)	\$ 45,000	\$ 250,000
Turbine installation (per turbine)	\$ 50,000	\$ 125,000
Turbine peak power output (kW)	100	900
Project management (% of total project cost)	10%	10%
Construction management (% of construction costs)	6%	6%
Contingency for turbine components	5%	5%
Contingency for construction costs	10%	10%

# Appendix J: Hybrid system modelling and optimisation report – L'Anse au Loup



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H340923-0000-05-124-0012, Rev. B

Project Report

November 9, 2015

# Coastal Labrador Wind Monitoring Program L'Anse au Loup Hybrid System Modeling and Optimization

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## 1. Introduction, Objectives and Scope of Work

As part of the project titled, Coastal Labrador Wind Monitoring Program, Newfoundland and Labrador Hydro (NLH) mandated Hatch to complete a wind monitoring campaign to determine the feasibility of adding Wind Turbine Generators (WTG) to Labrador isolated communities of Nain, Hopedale, Makkovik, Cartwright and L'Anse au Loup. This report presents the methodology and results related to L'Anse au Loup.

The wind monitoring periods are listed in the table below and additional information on the wind monitoring campaigns can be found in the respective WRA reports completed for each community.

	Date of first data recorded	Date of last data recorded
<b>Nain (mast 2601)</b>	30 October 2013	19 July 2015
<b>Hopedale (mast 2602)</b>	27 October 2013	19 July 2015
<b>Makkovik (mast 2603)</b>	25 October 2013	19 July 2015
<b>Cartwright (mast 2605)</b>	5 November 2013	13 July 2015
<b>L'Anse au Loup (mast 2604)</b>	5 October 2013	27 April 2015

**Table 1 : Sites and Monitoring Periods**

The specific objectives of the mandate were to provide the potential wind turbine capacity that can be installed on these 5 communities, the potential wind penetration and the associated cost breakdown for development, construction and operations (CapEx and OpEx).

## 2. Overview of Existing Diesel Grid on Site

L'Anse au Loup has an electrical demand quite large compared to other communities being evaluated under this mandate. The electrical equipment on site as well as electrical load and future forecast are defined below, based on the information provided by NLH.

### 2.1 Installed Power Generation Equipment

The power grid operated by NLH in L'Anse au Loup currently relies on two different sources of power. Firstly, this community is interconnected to the Hydro-Quebec (HQ) grid, which currently provides over 90% of the electricity being used. The remaining power is being supplied by six (6) diesel generators (gensets). It is important to note that based on information provided by NLH the maximum grid inertia with Hydro Quebec is limited to 4 MW.

The gensets currently on site supply less than 10% of the electrical demand and include the following units:

Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
<b>(G1)2005</b>	800	CAT	D-3512	1800	1988
<b>(G2)2012</b>	1100	CAT	3516	1800	1984
<b>(G3)2041</b>	1000	CAT	D-3512	1800	1971
<b>(G4)246</b>	600	CAT	D-398	1200	1975



Unit Number	Unit kW	Brand	Model	RPMs	Purchase Year
(G5)2091	1825	CAT	B-3516	1800	2015
(G6)2082	1825	CAT	B-3516	1800	2009

**Table 2 : Diesel Gensets on Site**

## 2.2 Generator Control Scheme

The gensets on site are managed by an automated control scheme. NLH explained that the control logic, aims to minimize the number and size of the gensets running at any given time while also insuring sufficient spinning reserve to meet increases in load. To do so, whenever the unit running is operating at less than 75% load ratio, the system switches to a smaller unit, if available. Whenever the unit running is loaded at more than 85%, the system switches to a larger unit, if available, or starts a second generator to share the load. The minimum load ratio for all gensets operated by NLH is 30%.

Because of the specificity of L'Anse au Loup, prior to modelling and optimizing, NLH indicated that the specific case of L'Anse au Loup should be modelled without any minimum load for the gensets, while the Hydro-Quebec grid should provide at least 30% of the energy demand.

## 2.3 Electric Load

The electric load at L'Anse au Loup varies significantly between winter and summer months. NLH provided the 2014 monthly average hourly electrical load. This data is shown in the table below:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L'Anse au Loup	4,202	4,167	3,532	2,822	2,384	2,482	1,905	2,039	2,032	2,140	3,492	4,311

**Table 3 : Average Load (kW)**

The electrical production from the diesel plant and the supply from Hydro-Quebec was monitored on a 10 minute timestamp. The data recorded, which covers the period of January 2014 to January 2015, was made available for inclusion in the model. This dataset provided the basis of calculation for the production of a daily hourly load profile, an essential component of the modeling exercise.

## 2.4 Forecasted Load and Energy Price

NLH provided information showing anticipated growth of peak hourly power demand and total yearly energy for the years 2015 to 2033 for L'Anse au Loup. The expected average fuel cost for each year was also supplied for the same period. The equation used to determined the price of the electricity delivered by Hydro-Quebec was made available by NLH. This price has been calculated accordingly for each year of the project life. The table below summarizes these information.

L'Anse au Loup	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Gross Peak (kW)	6,396	6,456	6,281	6,324	6,365	6,402	6,435	6,465	6,494	6,519	6,541	6,560	6,579	6,601	6,620	6,635	6,650	6,666	6,681
Net Peak (kW)	6,276	6,336	6,161	6,204	6,245	6,282	6,315	6,345	6,374	6,399	6,421	6,440	6,459	6,481	6,500	6,515	6,530	6,546	6,561
Gross Energy (MWh)	27,379	27,903	27,147	27,336	27,511	27,671	27,812	27,945	28,069	28,178	28,273	28,355	28,438	28,533	28,613	28,679	28,745	28,812	28,878
Net Energy (MWh)	26,919	27,443	26,687	26,876	27,051	27,211	27,352	27,485	27,609	27,718	27,813	27,895	27,978	28,073	28,153	28,219	28,285	28,352	28,418
Diesel Price (\$Cdn/Litre)	\$0.84	\$0.91	\$0.91	\$0.94	\$0.98	\$0.97	\$1.01	\$1.06	\$1.11	\$1.18	\$1.24	\$1.28	\$1.32	\$1.35	\$1.38	\$1.41	\$1.45	\$1.49	\$1.53
HQ grid (\$/kWh)	\$0.11	\$0.12	\$0.12	\$0.12	\$0.13	\$0.13	\$0.13	\$0.14	\$0.15	\$0.16	\$0.17	\$0.17	\$0.18	\$0.18	\$0.19	\$0.19	\$0.20	\$0.20	\$0.21

**Table 4 : Forecasted load, and price growth of fuel and electricity (2015-2033)**

The forecasted load growth and energy price increase (fuel and electricity) were important components in the evaluation of the various available system configurations as the objective was to find the most desirable system over the life of the project.

### 3. Design Methodology

#### 3.1 Software Used

The electrical system and integration of the wind turbines was modelled and simulated using HOMER (Hybrid Optimization of Multiple Electric Renewables). This software is specifically used to model and optimize the configuration of micro-grid systems composed of multiple components, which can include wind turbine generators, photovoltaic solar panels, hydroelectric generators, batteries as well as generators running on various types of fuel. Using inputs comprising electric load profile, electrical architecture of the system (DC vs AC, etc.), renewable resources as well as costs for the purchase, operation and replacement of each component, HOMER can investigate multiple configurations and produce insight as to how to minimize the Levelized Cost of Energy (LCOE) or fuel used by the system. In the context of the current assignment, the outputs of the software were integrated in MS Excel spreadsheets to include electrical load, fuel cost and HQ price variations over time with the aim of selecting the most efficient solution over the life of the project. Due to the restriction of HOMER to properly integrate and model utility supply generation, the HQ supply electricity was simulated as four gensets of 1000kW each.

#### 3.2 Model Building

NLH provided valuable information related to the historical operating performance of the existing system. The data provided included operations and maintenance (O&M) costs and overhaul costs, as well as data linking electrical production and fuel consumption. Each genset model was created in HOMER to accurately reflect these parameters, as well as the specific fuel curve provided by NLH. The Hydro-Quebec grid was also represented in HOMER and simulated as four 1000kW gensets, due to the HOMER restrictions as identified in section 3.1.



The average monthly electrical load provided by NLH was used as the basis for the load profile included in the model. The 10 minute electrical supply dataset, covering a year period, was used to establish a daily electric production profile. The assumption was made that the electric production at any given time was equal to the electric demand, so the daily load profile would be the same as the daily production profile. This daily load profile proved to be similar in shape for all 12 months of data provided, with differing magnitudes across months. As such, the assumption was made that the typical daily load profile shape would be the same for all 12 months but that it would be scaled to reflect the monthly averages provided by NLH. This daily load profile for each month was integrated as the electric load for the project. HOMER uses the base hourly profile and introduces hour to hour and day to day random variations based on parameters defined by the user. The result is a random time series for the load that has a pattern similar to the actual load.

At this point, an iteration of the model was run in HOMER in a configuration representing the equipment present on site. This iteration is the base case to which the other iterations, which use wind turbines, are compared in regards to fuel savings and energy cost.

It should be noted that according to the specifications provided by NLH for L'Anse au Loup (i.e. no minimum load for the gensets and a minimum of 30% of the load covered by the HQ grid) the base case system modelled does not produce energy from diesel as much as reported and forecasted by NLH. HOMER models that only 3% of the energy would be produced by the diesel gensets, instead of around 7% as per the NLH forecast. This difference is due to NLH having to produce more energy from the diesel generators during the periods where HQ is undergoing maintenance on their grid (which are not modelled in Homer).

A preliminary turbine selection for the L'Anse au Loup project was completed as part of the Wind Resource assessment phase. Given the major load at L'Anse au Loup, and considering the potential benefit of a bigger wind turbine, only one of the WTGs, identified as potentially interesting for the hybrid projects in Labrador communities, was selected for modelling at L'Anse au Loup; additional information on the turbine selection methodology is available in the WRA report. The turbine is the Emergya Wind Technologies 900kW (EWT900). This WTG was modeled in HOMER based on manufacturer provided specifications. The long term wind resource calculated in the wind resource assessment campaign was integrated in the model and the energy production predicted by the software WindFarmer was compared with the energy calculated by HOMER. WindFarmer is routinely used to optimize wind farm layouts with regard to energy, topography and restrictions and to estimate the energy production. WindFarmer outputs are considered more accurate than HOMER for this aspect. Following some minor model adjustments, the comparison showed that the HOMER results were similar to the WindFarmer results within a few percent, confirming that the simulation used realistic wind energy production numbers.

The following assumptions were made during the optimization process and in the simulation phase:



- The daily load profile was derived from time series and historical values provided by NLH
- Fuel costs, electricity prices and load growth were based on information provided by NLH, as presented in Section 2.4
- An inflation rate of 2.21% and average NLH long term marginal cost of debt (rounded) of 6.48% were used, according to historical values specified by NLH
- Construction costs have been defined based on information from manufacturers and historical values from past projects

### 3.3 System Sizing and Optimization

The sizing and optimisation of the proposed wind project for L'Anse au Loup was determined through an iterative process. HOMER simulations were run using varying numbers of WTG model selected in the previous phase. The objective of the iterations was to determine the number of WTGs that would result in the lowest calculated cost of energy (COE).

The outputs from Homer were integrated in Excel spreadsheets to evaluate the impact of increasing fuel costs, electrical demand, inflation and cost of borrowed capital. Some key metrics were identified to compare the various configurations and determine the most economically viable scenarios. The results are presented in the following section.

## 4. Results

### 4.1 Proposed Configuration

Based on the modeling performed in HOMER and based on the cost of energy as the main criteria, there is no optimal number of turbines for integration in the L'Anse au Loup system. Each configuration tested has a higher cost of energy than the base case system consisting of the diesel gensets and the HQ grid. This is mainly due to the low cost of the energy provided by HQ. The table below shows a summary of the results for integration of various numbers of WTG.

	Fuel saved vs base case	Yearly Fuel Savings	Wind Penetration	WTG energy over 20 yrs (kWh)	Excess energy over 20 yrs (kWh)	Cost of Energy (\$/kWh)
No WTG	0%	\$0	0%	0	0	\$0.130
1 EWT900	20.5%	\$483,928	10.6%	58,253,120	3	\$0.133
2 EWT900	49.1%	\$983,197	21.1%	116,506,240	102,145	\$0.132
3 EWT900	60.7%	\$1,417,467	30.7%	174,758,920	5,227,505	\$0.132
4 EWT900	67.2%	\$1,620,894	38.6%	233,012,480	19,964,417	\$0.135
5 EWT900	71.5%	\$1,906,305	44.7%	291,262,860	44,645,138	\$0.134
6 EWT900	74.9%	\$2,108,707	49.0%	349,517,840	79,275,475	\$0.141

Table 5 : Summary of Results



The estimated energy production of each proposed configuration accounts for the possible losses in a wind farm, such as wake, aerodynamic, electrical, operational and power curve losses. The figures of availability should be defined with more accuracy at the detailed turbine selection stage, based on statistics for the turbine selected and after confirmation of the O & M strategy and review of the draft O&M contract if applicable. Based on preliminary manufacturer's discussions, other factors that will need to be considered for availability include the benefit of having a greater number of turbine units due to potential difficulties to execute repairs in the winter months. This will need to be analyzed as part of the turbine selection process.

As noted in Sections 4.2 and 4.3, the cost of energy does not include all applicable costs. Additional costs not reflected include mechanical and electrical stability studies, system integration costs, control and communications system costs, as well as detailed logistic studies, plant detailed design and optimization. On the other hand, given the accessibility of this community, savings could be made for some costs categories compared to the other communities, but that was not considered in the present assessment.

## 4.2 Construction Costs

The total estimated cost of building a wind farm at L'Anse au Loup includes development, turbine, construction and project management. Project contingency was also included, at 5% for WTG components and 10% for construction costs. Additional integration and pre-development costs include logistics study, integration study, electrical and mechanical stability studies have not been included. System integration costs have also been left out of the equation, as well as any associated integration and communication equipment costs since this scope were not included in the present project. Each of the hybrid projects in Labrador communities has been assessed independently, however there may be benefits from economies of scale if more than one project is retained (e.g. for purchasing the turbines, or renting a crane).

For example, for L'Anse au Loup, assuming economies due to more than one project moving forward and considering a 5% savings on the WTGs price and a reduction of 10% on the construction costs, the cost of energy produced by a hybrid system configured with 3 wind turbines would be the same as without wind turbine using mainly the HQ grid.

All of the aforementioned studies would need to be completed to fully assess the viability of the project. The following table shows a summary of the included project costs for various iterations:



	EWT 900					
Number of units	1	2	3	4	5	6
Development costs	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000	\$375,000
Turbine costs	\$2,375,000	\$4,750,000	\$7,125,000	\$9,500,000	\$11,875,000	\$14,250,000
Construction costs	\$1,868,250	\$2,708,300	\$3,548,350	\$4,388,400	\$5,228,450	\$6,068,500
Project management	\$461,825	\$783,330	\$1,104,835	\$1,426,340	\$1,747,845	\$2,069,350
Contingency	\$389,258	\$624,163	\$859,069	\$1,093,974	\$1,328,880	\$1,563,785
<b>Total project CapEx:</b>	<b>\$5,469,333</b>	<b>\$9,240,793</b>	<b>\$13,012,254</b>	<b>\$16,783,714</b>	<b>\$20,555,175</b>	<b>\$24,326,635</b>
<b>CapEx per installed MW:</b>	<b>\$6,077,036</b>	<b>\$5,133,774</b>	<b>\$4,819,353</b>	<b>\$4,662,143</b>	<b>\$4,567,817</b>	<b>\$4,504,932</b>

**Table 6 : Summary of Construction Costs**

For the detailed construction costs see Annex 1.

### 4.3 Further Study Required – System Integration

The installation of WTGs on the grid at L'Anse au Loup will require further electrical and mechanical studies, which are not part of the current scope of work and should be performed at a later stage to fully assess the project viability. The results of these studies will determine whether additional control and communication equipment needs to be added to the system. It should be noted that since it is not currently known if any additional equipment will be required, no cost was included for such components in any of the simulations at this stage. The energy costs presented in the following section include no allocation for additional control and communication equipment.

### 4.4 Penetration and Energy Cost

The cost of energy for each option is calculated based on the total cost of producing the required quantity of energy during the life of the project and the total amount of energy produced. Costs are based on the cost of borrowed capital for CapEx, increasing fuel costs and energy demand as well as anticipated discount rate (inflation) over the duration of the project. All costs presented in this report are based on the average long term marginal cost of debt of 6.48% provided by NLH. However this historical value may not be representative of future interest rates and a different value could have a significant impact on the cost of energy for configurations using WTGs because of the large investment required. For information purposes, the resulting cost of energy associated with an interest rate of 4.5% was included in the Figure 1 : Average Cost of Energy.

The level of penetration of wind energy in the energy pool at L'Anse au Loup is proportional to the number of WTG installed on site. This value represents the total amount of power produced by wind turbines over the project life divided by the total amount of power used.

The results for average cost of energy and wind penetration over the expected project life of 20 years are shown in the figure below. From this figure, it can clearly be seen that there are configurations that produce a COE lower than the base case, but this is true only with an interest rate of 4.5%. The design methodology leading to these results was provided in Section 3.

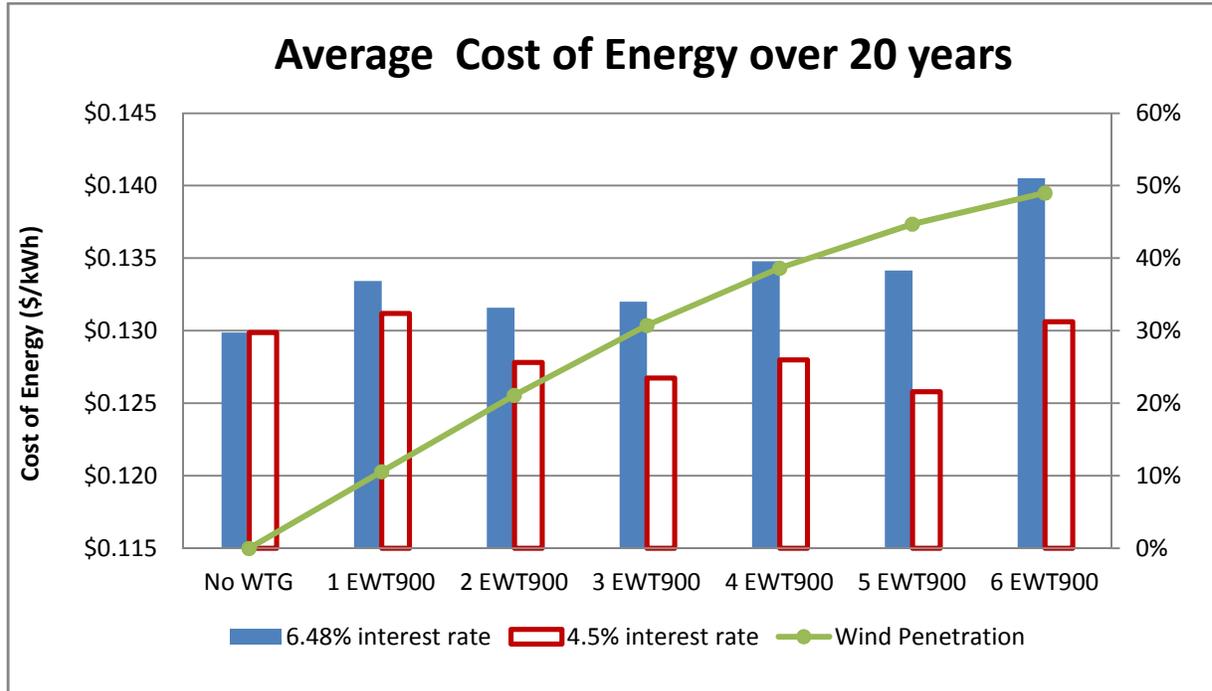


Figure 1 : Average Cost of Energy

#### 4.5 Evolution of Cost of Energy

Figure 2 : Evolution of Cost of Energy shows the evolution of the non-discounted cost of power over the 20 years of the project life. It illustrates that the inclusion of more WGTs in the energy mix reduces the impact of rising fuel costs on the average cost of energy over the project life.

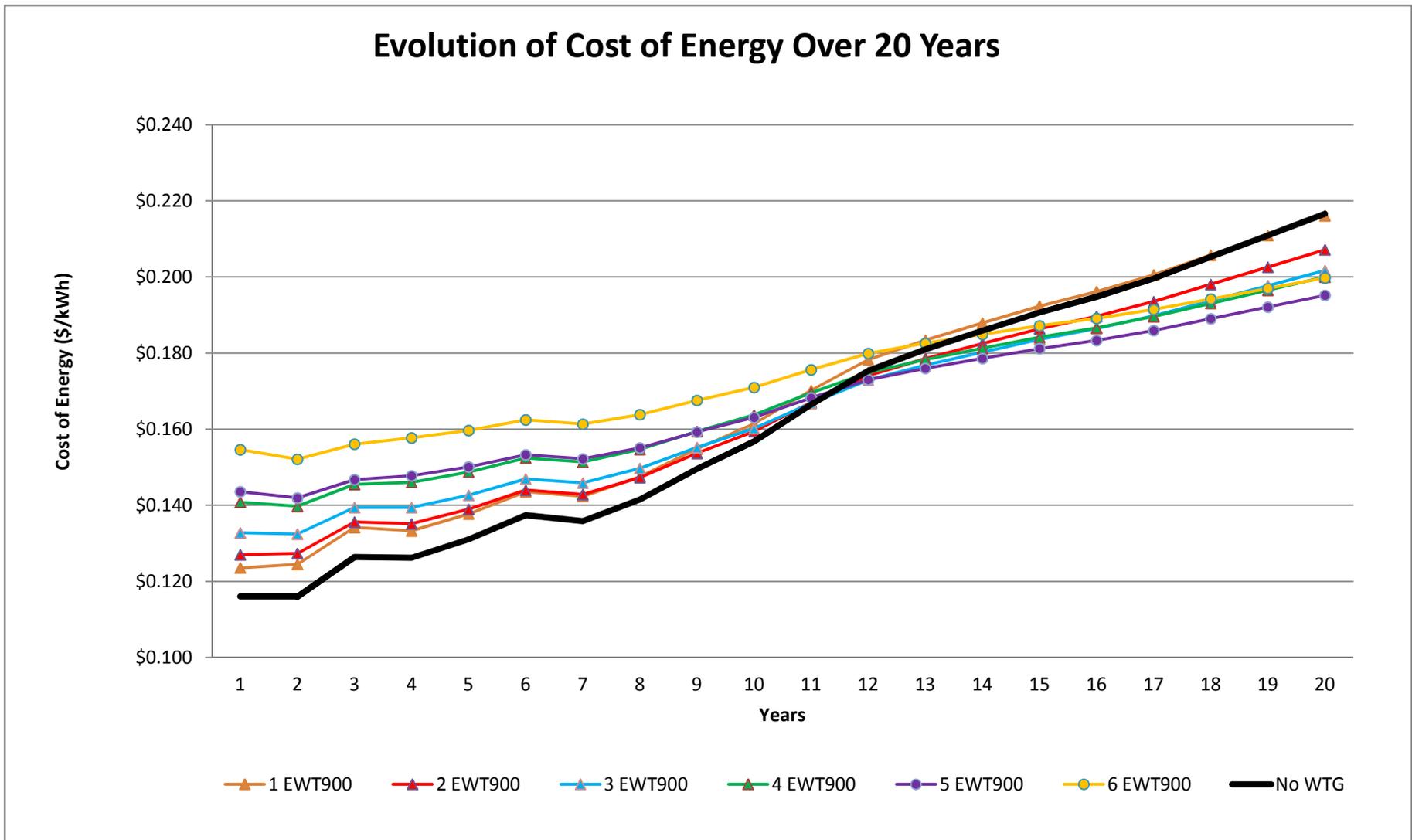


Figure 2 : Evolution of Cost of Energy



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#### 4.6 Energy Costs and Excess Wind Energy

The average yearly energy costs provide a good indication of the system reliance on fossil fuels and HQ grid for operation. The greater the installed wind capacity, the lower the annual energy costs. However because of the magnitude and variability of electrical load on site, above a certain quantity of turbines, not all the energy produced by the turbines can be used by the system, causing the WTG to be less efficient.

The following figure shows the average yearly fuel costs for each configuration as well as the associated percentage fuel saved. The percentage of wasted WTG energy is also shown.

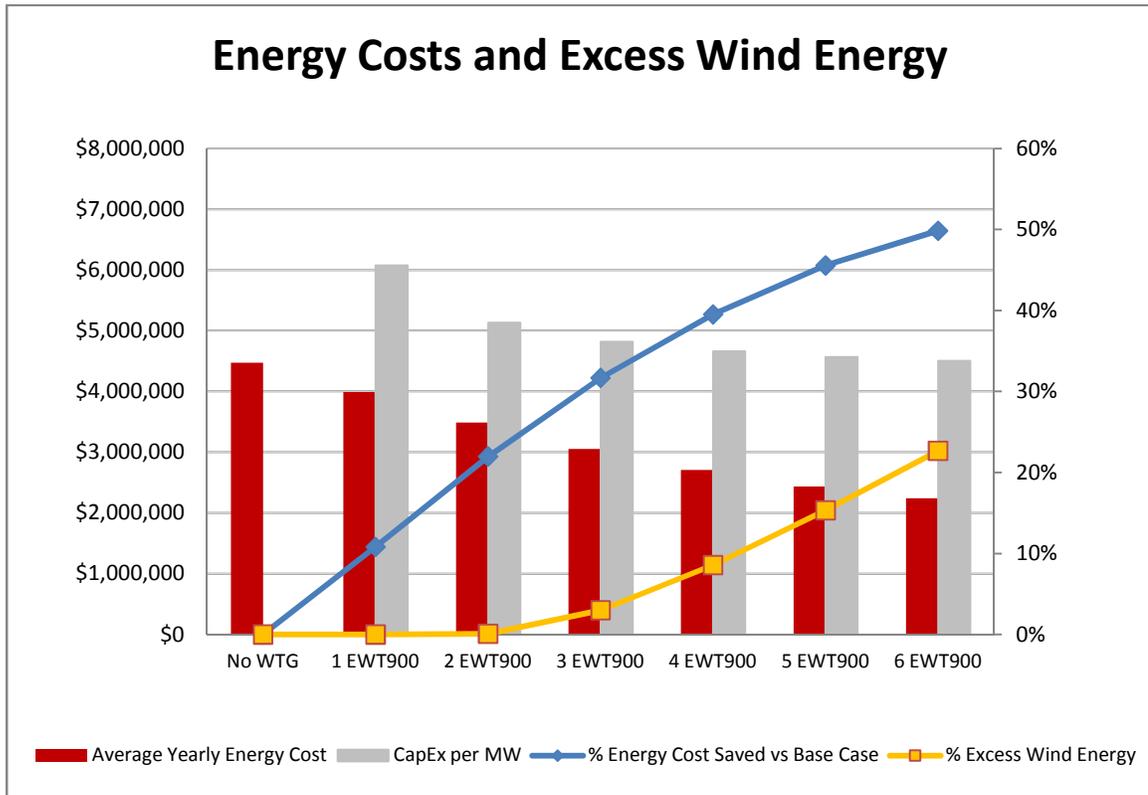


Figure 3 : Energy Costs and Excess Wind Energy

#### 4.7 Avoided Greenhouse Gas Emissions

The addition of renewable energy to the L'Anse au Loup electrical grid would have an impact on the amount of Greenhouse Gas (GHG) emissions resulting from diesel energy production, but not as much as for the other communities, since most of the energy demand is met by the HQ grid. NLH specified that it uses a value of 2.791 kg of CO<sub>2</sub> for each liter of diesel burned in the gensets it operates. Based on this number, Hatch calculated that the amount of avoided GHG emissions for each project configuration is as follows:



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Case	Avoided Emissions of CO <sub>2</sub> (tonnes) over 1 Year	Avoided Emissions of CO <sub>2</sub> (tonnes) over 20 years
No WTG	0	0
1 EWT900	144	2,885
2 EWT900	346	6,911
3 EWT900	428	8,553
4 EWT900	473	9,466
5 EWT900	504	10,074
6 EWT900	527	10,549

**Table 7 : Avoided Emissions of CO<sub>2</sub>**

Note: As of 2010, total Newfoundland and Labrador Green house gas emissions were 8.9 million tonnes per year. However, since the system configuration modelled for L'Anse au Loup rely on the diesel gensets only for 3% of the energy demand, only 0.005 % of total Provincial emissions would be avoided by the installation of 3 EWT900 WTG at L'Anse au Loup.

#### 4.8 Qualitative Appreciation of WTG Model

The EWT900 is a full-size turbine with a large rotor diameter and the full control package associated with a utility scale turbine. This turbine has an excellent track record in arctic conditions, making it a potential candidate for the application. On the economic aspect, though the cost estimates will need to be validated in the next phase of the project, the cost per installed kW is much lower for larger turbines which is generally common within the wind industry. Consequently, the energy produced comes at a lower price for the EWT900 than it would be with a smaller wind turbine. The excess energy is expected to be easy to manage on the EWT, since it has active curtailment and derating management capabilities. The EWT has also a practical O&M aspect, as the manufacturer offers O&M options through long term contracts and, under certain circumstances, will even offer an availability warranty.

Compared to smaller wind turbines, the size of the EWT900 makes for a more complex deployment, construction and installation. However, since L'Anse au Loup is not as remote as some other Labrador communities, and since it seems to have good logistical capabilities, the delivery, unloading, transport and installation of the EWT turbine might not be much more expensive than budgeted at present. A full logistic analysis is, though, strongly recommended to confirm whether the installation of the EWT900 WTG is feasible. It needs to be noted that turbine models between 100 KW to 900 KW are not commonly available from many manufacturers especially for use in arctic conditions. A more detailed turbine selection process should be initiated in following phases of the project.

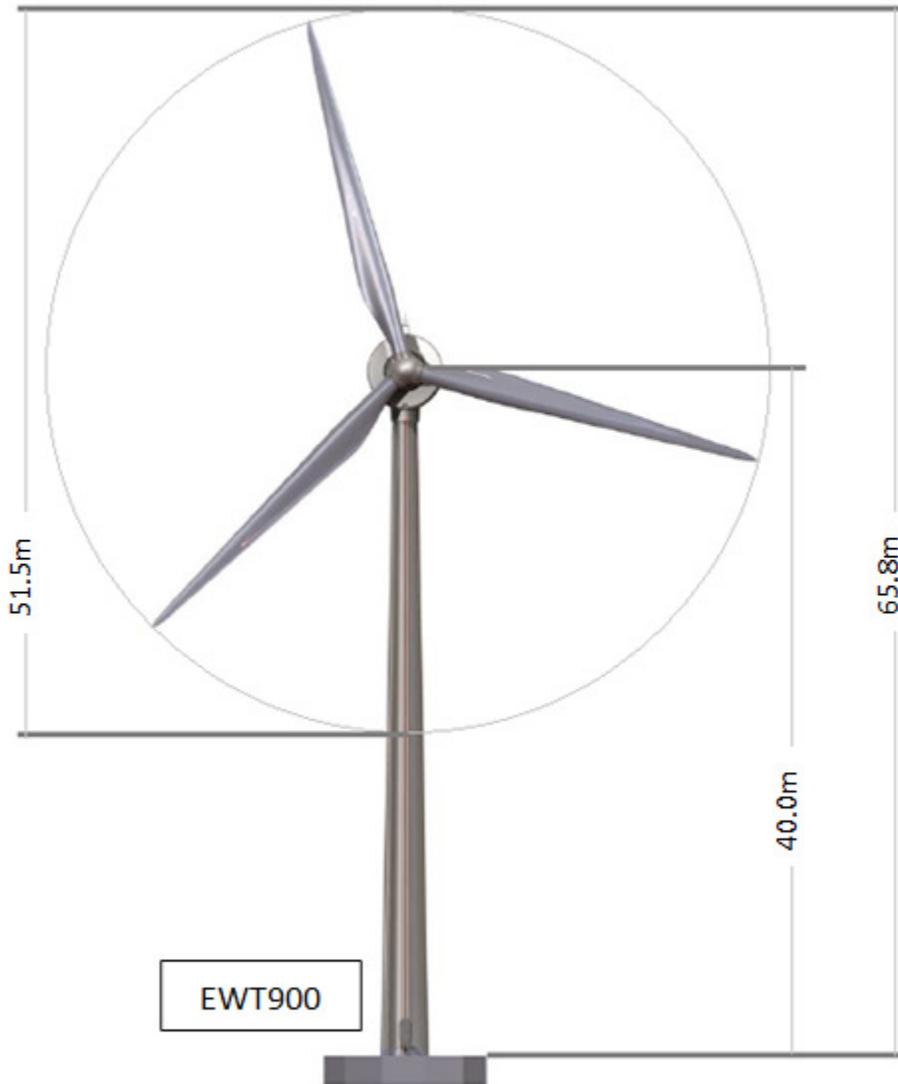


Figure 4 : Turbine Size

## 5. Conclusion and Recommendations

Based on the system modeling and preliminary economic analysis performed by Hatch, the optimal system design for L'Anse au Loup is to maximize the use of electricity provided by the Hydro-Quebec grid. None of the tested configurations, integrating wind turbines in the system, was economically competitive with the base case system consisting of the diesel gensets and the HQ grid. This is mainly due to the low cost of the energy provided by HQ.

This result is based on the anticipated energy production of the existing gensets, HQ grid and the future wind turbines, according to the functional specifications of the local grid as provided by NLH. It should be noted that several components were excluded from this analysis, including the value of avoided GHG emissions, the level of community acceptance and government policy implications. Each of the hybrid projects in Labrador communities has been assessed independently, however they might benefit from economies of scale if more than one project is retained. In addition, given the accessibility of this community, savings could be made for some costs categories compared to the other communities. A more detailed cost analysis might conclude to an economically competitive hybrid project in L'Anse au Loup. It is recommended that NLH gathers more information on these topics prior to exclude this community for a potential hybrid energy project.

It is important to note that a detailed mechanical and electrical stability study was not performed at this stage. It is critical that such a study be performed in advance of the detailed design stage to determine the impacts of adding WTGs to the existing system, as well as the actual limitations of the current grid. Furthermore, a logistics analysis needs to be completed to determine whether the local capabilities allow for the installation of the EWT900 turbine.

ELB

Attachment(s)/Enclosure :

Annex 1 - Construction Costs.pdf

H340923-0000-05-124-0004\_rev2.pdf (L'Anse au Loup Final Wind Resource Assessment Report)



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## Annex 1 – Construction Costs Used in HOMER Model

Costs to add turbines at various sites	NPS100	EWT900
WTG O&M (\$/y)	\$ 20,000	\$ 60,000
Project development (lump sum)	\$ 200,000	\$ 200,000
Engineering and studies (lump sum)	\$ 175,000	\$ 175,000
Deployment cost (lump sum)	\$ 75,000	\$ 175,000
New electrical line (\$/km)	\$ 250,000	\$ 250,000
New road (\$/km)	\$ 300,000	\$ 300,000
Interconnection to local grid	\$ 50,000	\$ 50,000
Rock blasting (per turbine)	\$ 20,000	\$ 250,000
Concrete batch plant deployment	\$ 25,000	\$ 25,000
Foundation concrete content (cubic yards)	29.09	250.00
Concrete cost (\$/cubic yard)	\$ 900	\$ 900
Other foundation material and labor	\$ 25,000	\$ 125,000
Total foundation cost (per turbine)	\$ 71,180	\$ 600,000
Turbine purchase cost (per turbine)	\$ 325,000	\$ 2,000,000
Extra turbine cost for arctic version (per turbine)	\$ 20,000	\$ -
Turbine transportation to site (per turbine)	\$ 45,000	\$ 250,000
Turbine installation (per turbine)	\$ 50,000	\$ 125,000
Turbine peak power output (kW)	100	900
Project management (% of total project cost)	10%	10%
Construction management (% of construction costs)	6%	6%
Contingency for turbine components	5%	5%
Contingency for construction costs	10%	10%



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