Snare Wind Monitoring Update 2016

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Executive Summary

This project is part of the assessment of potential sites for wind energy development in the Yellowknife area, particularly along the Snare grid powerline. This report provides an update on the wind monitoring that began in early December 2015 on the Northwestel tower located on one of the Snare hills, and outlines the expected long term annual mean wind speeds on the Snare hill complex.

Measurements from December, 2015 to March, 2016 show a mean wind speed of 6.28 m/s at 53 m above ground level (AGL) on the Snare tower (elevation of 365 m above sea level; ASL). This is compared to an average wind speed of 5.95 m/s at 400 m ASL, measured by the Fort Smith upper air (weather balloon) measurements for the same period. Using the Fort Smith upper air measurements for correlation, a four-year (2012-2015) long-term annual wind speed is estimated to be 7.15 m/s at 74 m AGL (turbine hub-height). This is compared to the upper air wind speed of 6.63 m/s (400 m ASL) for the same four-year period.

A RETScreen analysis was then conducted, using a wind farm scenario with the same configuration as the Diavik Diamond Mine, that is, four Enercon E70 2300 kW wind turbines (built at a cost of $3.6M/MW). The cost for Snare was assumed to be $5M/MW, or $46M for the project, and the operation and maintenance costs were assumed to be $1.15M annually. To provide an internal rate of return (IRR) on equity of 8.5% (5.77% interest on 60% debt; equity payback of 11.7 years), the wind energy would need to sell at a price of $0.23/kW.

Currently there is no market for wind energy on the Snare grid. In normal years the electrical system is met by about 95% hydro with the rest backed up by diesel-electric generation. The potential market of space heating in the Yellowknife area is currently priced at $0.08/kWh. A wind energy project on the Snare would only be viable if a major new customer was to emerge. A number of factors would need to change to make wind energy more viable: increased cost of fossil fuel, a carbon price, and a renewable energy incentive.

Introduction

This report is part of an assessment of potential sites for wind energy projects in the Yellowknife area.

The city of Yellowknife has a population of about 20,300 (2013 census from SSG 2015) people and is the capital of the Northwest Territories. The total annual electricity generation on the Snare Grid is currently about 195 GWh annually (David Mahon, manager energy projects at GNWT; pers. comm.). Diesel normally provides about 5% of the annual electricity on the grid, but in 2014 that number was expected to rise to 30% due to a water shortage[1]. From a report by SSG (2015) the heating demand on the Yellowknife-Snare grid system was about 314 GWh.

For most wind projects in the north, a long term annual mean wind speed of at least 6.0 m/s is desirable for considering their economics. Even more desirable is wind energy that is more plentiful during the winter months to meet the increased electricity demand. However, those stronger winter winds can be impacted by winter inversions at lower elevations, as has been observed in the Yellowknife area (Pinard and Maissan, 2008).

Inversions occur during the winter months when normal atmospheric conditions (cool air above, warm air below) become inverted. Inversions trap a dense layer of cold air under a layer of warm air. Even very shallow valleys can act like a bowl, with cold, dense air pooling at the bottom. The snow-covered valley floors reflect rather than absorb the heat from the sun, preventing the normal vertical mixing of warm and cold air. The cold heavy air tends to prevent the stronger winter winds above from reaching down toward the surface.

The ARI report by Pinard (2015) addressed the question of which hills near Yellowknife are above the heaviest influence of the temperature inversion effect (which reduce winter wind speeds at lower elevations), and what the expected long term mean wind speeds are on these hills. The report concluded that at elevations of at least 150 m above the surface of low-lying areas around Yellowknife one should expect annual mean wind speeds of 6 m/s or better. One of the report's recommendations was to set up wind instrumentations on the communication tower at the Snare hills complex in order to more accurately assess the economic feasibility of a wind project in the area.

The Snare hill complex has many peaks over 360 m ASL and is located about 130 km NW from Yellowknife and just south of the Snare River Dams (Figure 1). The surface elevation of the area around the hills are at around 200 m ASL. The hills start just 3.5 km from the southern dam and all of these hills are within 6 km of the powerline. Four or five hills in this area are within 1 km of the power line, and a few of them are even intersected by the powerline (Figure 2). Subject to the powerline capacity, there could be room for up to about two dozen large scale wind turbines on this hill complex.

CN Hill is the site of a Northwestel communication tower, which has a powerline and a road leading to the site. The tower is sitting at the top of the hill at an estimated elevation of 365 m ASL, above the

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[1] See article "Record low water levels raise NWT power costs" in Northern Journal: http://norj.ca/2014/09/record-low-water-levels-raise-nwt-power-costs/.

influence of the inversion layer. The tower was instrumented with heated wind sensors (to eliminate instrument icing) to measure wind speeds and determine whether Snare has strong enough winds to provide economically viable wind energy on the grid, particularly in the winter. This analysis will also examine existing upper air wind measurements and terrain elevation data covering the Snare Grid connecting to Yellowknife as part of the assessment.

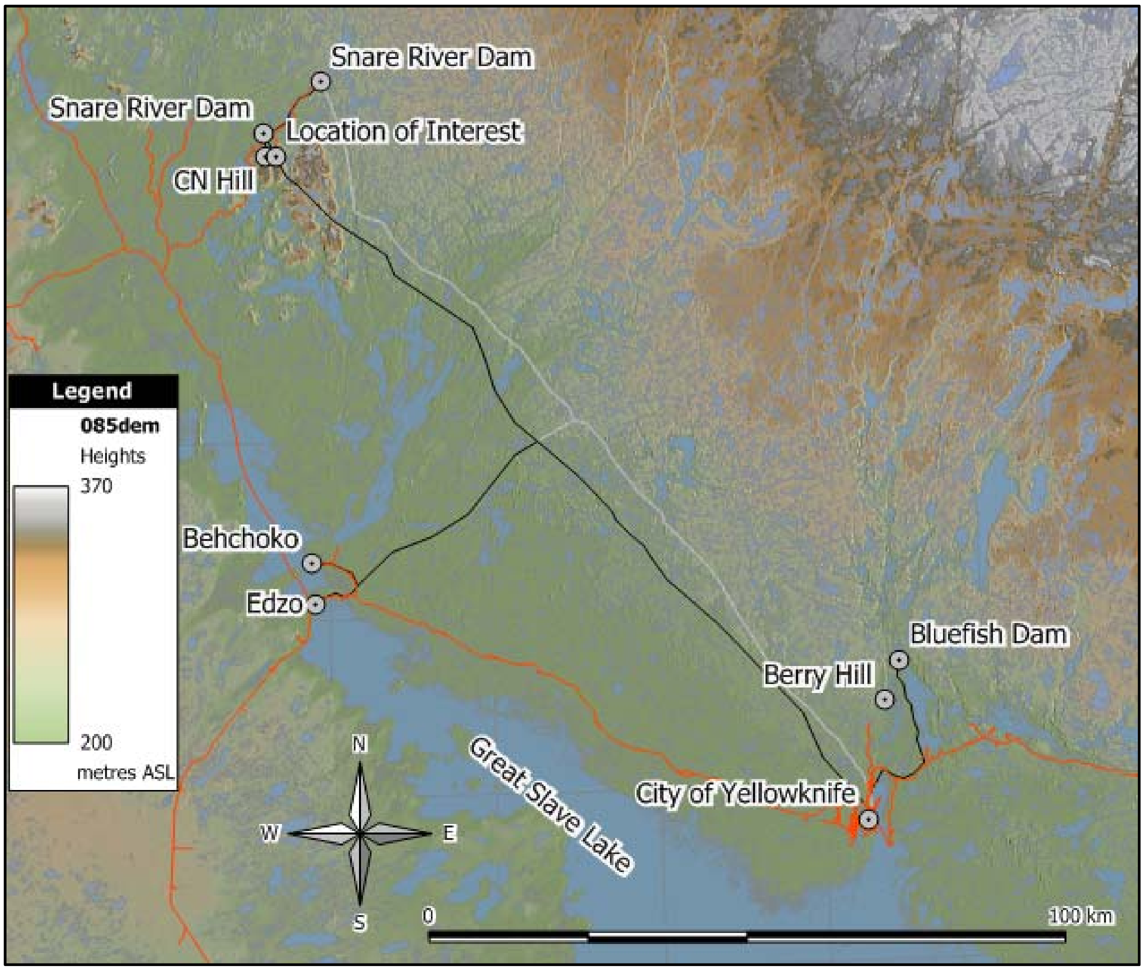

Figure 1: Map of Yellowknife area showing the extent of the Snare Grid (black line), which extends from the Bluefish Dam to the Snare River Dams. The gray line shows a previously used powerline, and roads are in red. The road from Edzo to Snare is an ice road. Powerlines currently in use are in black.

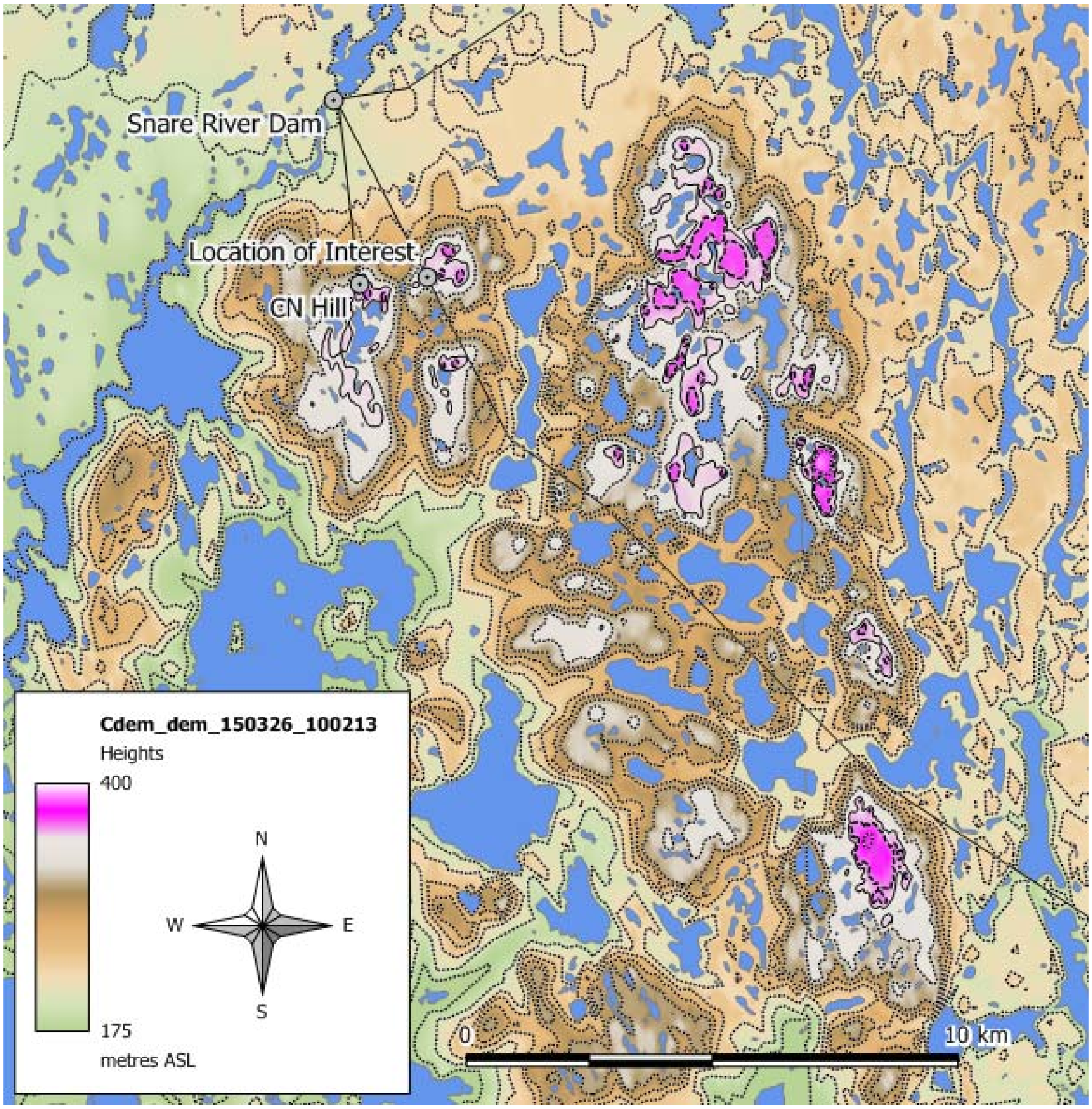

Figure 2: Map of the hill complex south of the Snare River Dams. The contour interval for all of dotted lines are 25 m starting at 200 m ASL. The solid line is at 350 m ASL, and an intermediate dashed contour line is at 360 m ASL, also indicated by the pink area.

Analysis of Snare Tower Wind Measurements

Two heated wind sensors were installed on Northwestel's Snare tower at 25 and 53 m above ground level (AGL) and started measuring on December 11, 2015. An unheated sensor was also installed at 53 m AGL a wind vane at 25 m AGL, and a temperature sensor at 2 m AGL. The Snare tower is at approximately 365 m ASL and so the total elevation of uppermost wind speed sensor is at about 418 m ASL. The period of measurement for this study is from December 11, 2015 to March 31, 2016.

The wind speeds at the Snare site were compared to upper air wind speed data from Environment Canada meteorological stations in Fort Smith and Norman Wells. Weather balloon data from these sites include wind speed and direction recorded at 400 m ASL. The Norman Wells upper air station is located 550 km northwest and its measurements at 400 m ASL have a cross correlation coefficient R^2 of 0.140 with the Snare site measurements. The Fort Smith upper air station is located 440 km southeast and its measurements at 400 m ASL has a R^2 of 0.266 with the Snare measurements.

Alternatively, the Yellowknife airport and Inner Whaleback meteorological stations are located at 140 km and 210 km southeast of Snare, and have a cross correlation coefficient R^2 of 0.292 and 0.274, respectively, with the Snare wind speeds. Note that the correlation between two sites that are closer to each other in terms of height and horizontal distance will have a value that is closer 1. Both the Yellowknife and the Inner Whalebacks stations are 10 m towers and are at 206 and 165 m ASL, respectively. These two stations are at least 160 m lower in elevation than the Snare station and so can be more influenced by the temperature inversion than the Snare site. The winter inversion will decrease the wind speeds at lower elevations whereas just above the inversion (e.g. Snare site) the winter winds will increase. Using these stations at lower elevations to project the winds on a hilltop such as at Snare will require more measurements from the winter and summer months and more careful attention to the monthly variation. For this reason, the correlation analysis is focused on the Fort Smith upper air measurements.

The average wind speed for Fort Smith upper air measurements were found to be 6.63 m/s (400 m ASL) over a four-year period from 2012 to 2015. The wind speeds that were measured at the Snare tower for the 11 December 2015 to 31 March 2016 period was 5.44 and 6.28 m/s at 25 and 53 m AGL, respectively. During the same monitoring period, the Fort Smith upper air measurements were 5.95 m/s (400 m ASL) and the four-year mean was 11% faster than this four-month average. A MCP (Measure-Correlate-Predict) correlation using a matrix time series (a more reliable correlation method than the Linear Least square method, both available in the Windographer wind analysis tool used for this study) calculated that the four-year mean at the Snare site is estimated to be 6.75 m/s at 53 m AGL.

Wind Speed in Relation to Height

The wind speed measured at 53 m AGL needs to be projected to higher levels to estimate the mean wind speed for wind turbines with taller towers. The heights for the wind turbines used in this analysis are at 74 m (Enercon E-70 2.3 MW).

Turbulent air flow over rough surfaces tends to generate a vertical profile of horizontal winds that are fairly predictable. The wind speed profile near the ground is dependent on neutral well mixed air conditions and the roughness of the ground surface. This vertical profile can be defined by the natural log law equation (Stull, 2000):

$$u_2 = u_1 \frac{\ln(z_2/z_o)}{\ln(z_1/z_o)}$$

Where u_1 is the known wind speed at z_1 (typically at 10 m AGL), and is projected to u_2 at the height z_2. The surface roughness is defined by z_o which as a rule of thumb is 1/10 the height of the grass, brush, or ground undulations surrounding the site where the measurements are made. This equation is considered most accurate up to approximately 100 m above the surface. The surface roughness z_o can be categorised by the type and size of vegetation as well as the hilliness of the ground itself.

At the Snare Hill site, the ground is relatively flat with small bushes. At the site the surface roughness was estimated to be z_o = 0.19 m using measurements at 25 and 53 m AGL, which is typical of an area with some trees and low brush but it may also be likely due to being at the top of the temperature inversion. With summer measurements the surface roughness number may change.

The results of the vertical projection model are shown in Table 1 and Figure 3. The annual mean wind speed is expected to be 6.84 and 7.15 m/s at heights of 57 and 74 m, respectively.

Table 1: Details of measurements and their projection to longer term and to higher elevations. Bold values indicate the estimated long-term (four years, 2012 to 2015) mean wind speed at the Snare hill site.

Location and measurement period	Height	Wind speed	
Fort Smith UA, 11th Dec, 2015 to 31th Mar, 2016:	400 m ASL	5.95	m/s
Snare hill, 11th Dec, 2015 to 31st March, 2016:	53 m AGL	6.28	m/s
	25 m AGL	5.44	m/s
Fort Smith UA, 4-year 2012-2015:	400 m ASL	6.63	m/s
Ratio of 4-month to 4-year mean at Fort Simth UA:		1.11	
Snare hill site projected to four years:	10 m AGL	**4.75**	m/s
	20 m AGL	**5.58**	m/s
	25 m AGL	**5.85**	m/s
	40 m AGL	**6.41**	m/s
	50 m AGL	**6.68**	m/s
	53 m AGL	**6.75**	m/s
	57 m AGL	**6.84**	m/s
	60 m AGL	**6.90**	m/s
	70 m AGL	**7.08**	m/s
	74 m AGL	**7.15**	m/s
	80 m AGL	**7.24**	m/s
	90 m AGL	**7.38**	m/s
	100 m AGL	**7.51**	m/s

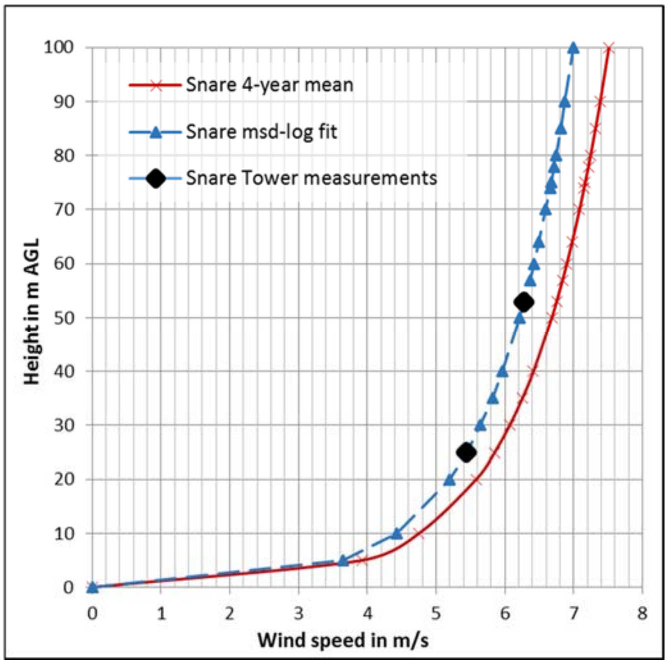

Figure 3: Vertical profile of horizontal wind speed versus height above sea level (ASL) at the Snare tower near the Snare hydro dams in the NWT.

Monthly Mean Wind Speed

Figure 4 shows the monthly mean wind speed measured at the Snare tower, and at 400 m ASL for Fort Smith station. The graph shows that the monthly wind speeds at 74 m AGL should range from 6.9 m/s in July to 8.2 m/s in January. Stronger winter winds compliment the city's increased winter demand for energy.

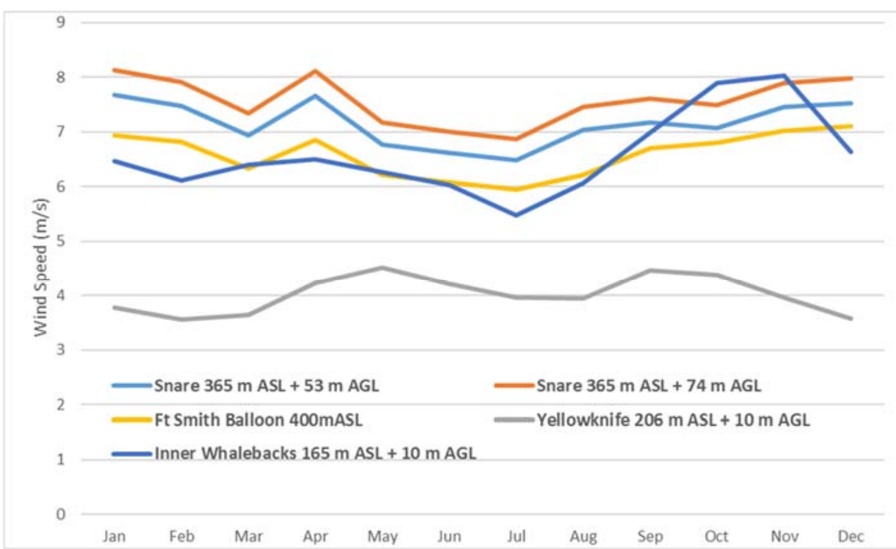

Figure 4: Monthly mean wind speeds at 400 m AGL at the Fort Smith station, at the Snare hill site, and also compared to the Yellowknife and Inner Whalebacks.

Wind Direction Analysis

No wind direction analysis was made as the wind vane was not heated and was subject to icing. Once summer data is available a clearer picture of wind direction will be made. However, on the report by Pinard (2015) it is likely that the winds at the Snare hill complex experiences the same dominant northwesterly winds.

A Simple RETScreen Analysis of Wind Economics at Snare

A simple economic analysis was made using RETScreen and using a wind farm scenario with the same configuration as the Diavik Diamond Mine, that is, with four Enercon E70 2300 kW wind turbines totalling 9.2 MW. There is a hill that is less than 2 km east of the Northwestel Snare tower and the hill is also within 1 km of the powerline. There is also an existing road that extends to within 2 km of the hill of interest, shown in Figure 2. The above wind project configuration was estimated to cost about $4,200/kW for a hill about 13 km east of Inuvik (Pinard and Maissan, 2015). Snare is further south and closer to big centers like Yellowknife and Edmonton, however accessible only by winter ice road. With these parameters in mind the author estimates that this project could cost $5,000/kW to install, totalling $46M. This is higher than the Diavik project which was $3,600/kW, however, Diavik has equipment and skills onsite to build this project at lower cost, and the Snare site is remote and accessible only by ice road in the winter. The annual operation and maintenance was assumed to be $125/kW (Pinard and Maissan, 2015), and so $1.15M annually.

The debt ratio used in this analysis was 60% at a borrowing cost of 5.77% and inflation of 2% and the term for debt and project is 25 years. The turbine losses are estimated to be a total of 20%, which includes turbine availability and all other losses. Using the wind speed of 7.15 m/s at a hub height of 74 m, the expected plant capacity factor is 23.5% and the project would have an annual production of 18.9GWh, or about 10% of the grid annual load.

For a return on equity of 8.5%, the wind energy would need to sell at a price of $0.23/kW. The equity payback would be 11.7 years. The RETScreen parameters and results are shown in Figures 5 and 6. If the project could be built at a cost of $4M/MW (i.e. with tighter cost controls, with subsidies, or with a scaled up project) then the price would $0.20/kW for the same return on equity and payback period.

While in normal water flow years this would displace some of the diesel it could also provide for a space heating and electric transportation market.

RETScreen Energy Model - Power project

Proposed case power system				Incremental initial co
Analysis type		○ Method 1 ⊙ Method 2 ○ Method 3		
Resource assessment				
Resource method		Wind speed	☑ Show data	
			Lac La Martre	
Wind speed - annual	m/s	7.2	2.9	
Measured at	m	74.0	10.0	
Wind shear exponent		0.14		
Air temperature - annual	°C	-4.2	-4.2	
Atmospheric pressure - annual	kPa	96.5	98.2	
Wind turbine				
Power capacity per turbine	kW	2,300.0		
Manufacturer		Enercon		
Model		E70 E4		
Number of turbines		4		
Power capacity	kW	9,200.0		$ 46,000,000
Hub height	m	74.0	7.2 m/s	
Rotor diameter per turbine	m	71		
Swept area per turbine	m²	3,959		
Energy curve data		Custom		
Shape factor		2.1		
	☐ Show data		☐ Show data	
Array losses	%	5.0%		
Airfoil losses	%	5.0%		
Miscellaneous losses	%	5.0%		
Availability	%	95.0%		
Summary				
Capacity factor	%	23.5%		
Electricity exported to grid	MWh	18,938		
Electricity export rate	$/MWh	232.00		

Figure 5: RETScreen analysis showing the proposed energy system for a wind project.

Financial Analysis

Financial parameters			
Inflation rate	%	2.0%	
Project life	yr	25	
Debt ratio	%	60%	
Debt interest rate	%	5.77%	
Debt term	yr	25	
Initial costs			
Power system	$	46,000,000	100.0%
Other	$		0.0%
Total initial costs	$	46,000,000	100.0%
Incentives and grants	$		0.0%
Annual costs and debt payments			
O&M (savings) costs	$	1,150,000	
Fuel cost - proposed case	$	0	
Debt payments - 25 yrs	$	2,112,099	
	$		
Total annual costs	$	3,262,099	
Annual savings and income			
Fuel cost - base case	$	0	
Electricity export income	$	4,393,599	
	$		
Total annual savings and income	$	4,393,599	
Financial viability			
Pre-tax IRR - equity	%	8.5%	
Pre-tax IRR - assets	%	1.0%	
Simple payback	yr	14.2	
Equity payback	yr	11.7	

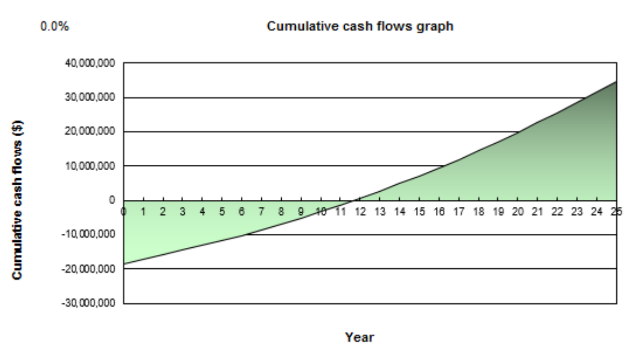

Figure 6: RETScreen analysis showing the financial results.

Conclusions

1. The Snare tower measurements for four winter months in 2015-16 reveal wind speeds of 6.28 m/s at 53 m AGL at a surface elevation of 365 m ASL in the Yellowknife area along the grid.
2. Based on correlations with the Fort Smith upper air measurements, annual mean wind speeds of 7.15 m/s at a hub height of 74 m AGL are estimated at the Snare hill site.
3. The wind speeds are expected to be stronger during the winter.
4. Using the RETScreen tool, and the same wind project scale and configuration as Diavik Mines, but at an estimated cost of $5000/kW installed cost, results in an estimated cost of $0.23/kWh.

Next Steps

The next steps that would be involved in developing a wind project in Yellowknife are:

1. Continue monitoring the wind at the Snare site (CN Hill).
2. Investigate conditions under which wind development would take place.
3. If further development is merited then commission wind map of the Snare hills area and determine sites of interest for a wind project development, evaluate these locations for economics, and establish a wind monitoring station there.

References:

Pinard, J.P., John F. Maissan, and Pippa Seccombe-Hett (Ed.) 2008, **Yellowknife Wind Energy Pre-Feasibility Report.** Prepared for Aurora Research Institute, Inuvik, NT.

Pinard, JP, and Annika Trimble (Ed.), 2015, **Potential Wind Farm Locations for the Yellowknife Area.** Prepared for Aurora Research Institute, Inuvik, NT.

Sustainability Solutions Group (SSG), 2015, **City of Yellowknife Community and Corporate Energy and Greenhouse Gas Emissions Inventory.**

This and other NWT renewable energy reports can be found at http://www.nwtresearch.com