AURORA RESEARCH INSTITUTE
AURORA COLLEGE

Executive Progress Report for Wind Energy Monitoring in Six communities in the NWT

20 February 2007

By JP Pinard, P.Eng., MSc., PhD. Candidate
Editors: Pippa Seccombe-Hett, ARI
John Maissan, Leading Edge Inc.

For the Aurora Research Institute, Inuvik, NWT

EXECUTIVE SUMMARY

Following a pre-feasibility study (Pinard et al. 2003) the Aurora Research Institute initiated a program to measure wind statistics in four Beaufort Sea communities, Inuvik and Yellowknife. A summary of the wind data analyses is presented here. The rest of the executive report provides discussion and background information for each community report. The reports provide site descriptions, wind analysis of the wind monitoring site and the nearby airport station, and a discussion with recommendations for future work.

The annual mean wind speeds of the wind stations are correlated and projected to the six-year (2001-2006) airport wind speeds (Table 1). The wind speeds are summarized below with the projected mean wind speeds at 30 and 60 m above ground level (AGL). The errors associated with the wind speed measurements and projections combine variation from long-term mean, sensor accuracy, and error due to vertical projection. The corrected power ratio accounts for the higher density due to cooler mean temperatures which results in, for example a 9-10% higher turbine power output in most communities.

Table 1: Estimated mean wind speeds (m/s). The total errors are a combination of variation from long-term mean, sensor accuracy, and error due to vertical projection.

Summary of wind speeds in m/s		Measurement	Wind speed (m/s)		Corrected
		height	at 30 m	at 60 m	power ratio
Sachs Harbour - heated stn	July 05 to Dec 06	4.2 m	**7.57±1.2**	**8.17±1.49**	1.10
- 30 m tower	July 05 to Dec 06	10, 20, 30 m	**6.03±0.46**	**6.51±0.64**	1.10
Ulukhaktok 30-m tower	May to Oct 06	10, 20, 30 m	**6.54±0.49**	**6.84±0.66**	1.10
Paulatuk 30-m tower	June 05 to Oct 06	10, 20 m	**5.84±0.55**	**6.2±0.77**	1.09
Tuktoyaktuk 30-m tower	May to Dec 06	10, 20, 30 m	**5.05±0.4**	**5.44±0.58**	1.09
Yellowknife 38-m telco tower	July to Dec 06	10, 20, 38 m	**4.37±0.36**	**4.98±0.5**	1.04
Inuvik 60-m telco tower	Nov 05 to Dec 06	30, 60 m	**3.86±0.33**	**4.32±0.36**	1.08

From Maissan (2006), sites with wind speeds of above 7 m/s are most attractive, barring difficult development conditions. Between 6 and 7 m/s the site would need to be easily accessible and have low installation cost to be successful. Between 5 and 6 m/s the site will require easy community and site access, local technical labour and equipment available, very tight budgetary constraints, and will likely need subsidies. A proposed ReCWIP (Remote Community Wind Incentive Program) at the federal level (NRCan) and territorial and regional support will certainly help to make these projects more viable.

Ulukhaktok and Sachs Harbour have the most promising wind resources of the six communities. However, each has their development challenges. In Sachs Harbour a more exposed site that is closer to the local grid is desirable but may be difficult to obtain. The Ulukhaktok station on the ridge east of the hamlet has excellent wind but no road access. Either a road will need to be built to the site, or the monitoring station should be moved to a new location, where wind turbine installation is possible, for further monitoring.

The site of wind monitoring stations in both Paulatuk and Tuktoyaktuk may be sufficient for a wind farm with careful planning. Other locations adjacent to each of these communities may provide marginally better wind conditions. The wind resources at the Inuvik and Yellowknife sites would be considered uneconomical to develop unless heavy subsidies were provided. In Yellowknife consideration could be given to further wind resource investigation at higher elevations or in areas where the Canadian Wind Atlas identifies areas of potentially higher wind speeds.

1. Introduction

The following provides a preamble to methods and assumptions that are used in the reports. In the reports all of the stations that are associated with the airport are called **airport stations**. The stations that were installed for the purpose of measuring the wind speed for energy exploration are called **wind monitoring stations** (the acronym WM is sometimes used).

2. Site locations

The wind monitoring sites were all chosen to meet a number of criteria, being:

- maximum height limitations by NavCan and Transport Canada,
- best exposure to prevailing winds,
- proximity to local power line, and
- access to site by road.

Practically every remote community has an airport within one kilometre. Any nearby site with potential for wind farm development must fall below the height restrictions laid out by NavCan. A rule of thumb is that a 30-m tower should be at least five kilometres from the airstrip along the landing corridor (lengthwise to the strip). To the sides the limit is about four kilometres. If the tower is within four kilometres it may be bounded by a 45-m height restriction, or it may be allowed to be higher with a provision that it has marking and lighting. It is always advisable to consult with NavCan whenever a site is proposed for a tower.

For obvious reasons it is desirable to find the site most exposed to the prevailing wind. A hill or a ridge that is perpendicular to the predominant wind direction(s) would be ideal. It is also important to find a site with an upwind landscape that is as smooth as possible, water being the smoothest. If there is more than one predominant wind direction then a compromise is made for best overall exposure to those directions. The above decisions are made while keeping in mind that for the eventual building of a wind farm, the site must be easily accessible and close to power lines for the grid connection.

3. Data analysis in the reports

3.1. Identifying predominant wind directions

Wind turbines are typically placed in a row, preferably on a ridge top, perpendicular to the prevailing wind direction. A wind rose provides an excellent indication of the predominant direction of the wind energy. The wind roses in these studies have two shapes (e.g. see Figure 4, Appendix A). The solid shaded areas represent the relative wind energy. The wind energy by direction is calculated as the frequency of occurrence of the wind in a given direction sector multiplied by the cube of the mean wind speed in the same direction. There are 16 direction sectors and each sector is 22.5 degrees wide. The given wind energy in each direction is a fraction of the total energy for all directions. The transparent outlines represent the wind frequency of occurrence by direction as is typically shown in meteorological analyses. The wind frequency by direction can sometimes be misleading, showing a commonly occurring wind direction that is not significant for wind energy production. The outer numbers at the edge of each rose are the average wind speeds in each direction sector.

3.2. Compiling mean wind speed

The wind monitoring stations in the six communities have measurement periods that, to date, range from 6 to 18 months. Because of the relatively short period of measurement they will have a higher variability error from the long-term mean. By correlating the wind monitoring station to a longer term data set, such as an airport, we can reduce the variability error, or increase the confidence level. As noted before there are six years of wind data for the airport stations in each community that has been downloaded from the Environment Canada website. Each wind monitoring station is compared to the nearby airport station for the period defined by the time the wind monitoring station has been measuring. To estimate how well the two sites correlate a Pearson correlation is calculated for the short period. The ratio of the wind speeds at both sites is calculated from the average wind speed during the period of simultaneous operation. The wind speed at the monitoring station for the period divided by the airport wind speed for the same period multiplied by the six-year mean wind speed of the airport station projects a "long-term" mean wind speed for the wind monitoring station.

The vertical projection of wind speed at the wind monitoring station is made by fitting a logarithmic wind speed profile, Equation (1), to the measurements at the different elevations.

$$u_2 = u_1 \frac{\ln(z_2/z_0)}{\ln(z_1/z_0)} \qquad (1)$$

where u_1 is the known wind speed at elevation z_1 (usually 10 m AGL), and is projected to u_2 at the height z_2. The surface roughness z_o is usually found by fitting the wind speed at several known heights (eg. 10, 20, 30 m AGL) and is typically representative of the local surface roughness around the tower. A rule of thumb is that z_o is $^1/_{10}$ the height of the forest or grass surrounding the tower. Once the surface roughness is known the wind speed at levels such as 60 m above the ground can be estimated. Another profile equation that is sometimes used is the power law, or Archibald's Law. In most cases it can be made to fit the same curve derived by Equation (1) above.

4. Vertical Profiles from weather balloons

Weather balloon, or upper-air, stations are established in Inuvik, Norman Wells, Fort Smith, and Cambridge Bay. Among other things they measure wind speed throughout the atmosphere and are good indicators of the wider regional wind climate. The wind profile shows roughly how the wind speeds increased with height in the first few hundred metres above the surface (Figure 1). The wind speed measurements are typically made at the surface (10 m AGL), at 100, 300 m above sea level (ASL) and roughly every 300 m above this. It is evident in the linear interpolations of the measurements that there is a lack of measurements between the levels noted above. A logarithmic profile is fitted between the surface and 300 (or 100) m ASL to provide an estimate of the wind speed profile directly above the surface. We should note however, that the logarithmic (or power law, Archibald's law) profile is usually only useful in the lowest 60 m above the surface and above this they should be used with great care.

The logarithmic profiles show that winds of 6 m/s could be attained at roughly 100 m above the surface station. At open coastal sites such as Cambridge Bay where surface winds are already fairly high, the 6 m/s threshold is attained at a much lower elevation, in the case of Cambridge Bay it is at 30 m above the station. For the inland sites, although the surface station may only record 2-3 m/s it quite possible that a station on a hill nearby that is 100 m higher could be measuring winds of 6 to 6.5 m/s. To have confidence in such estimates it is important that the hill top site be well exposed to the prevailing wind direction. It should preferably be a ridge perpendicular to the main wind direction and have no upwind obstructions such as higher nearby hills.

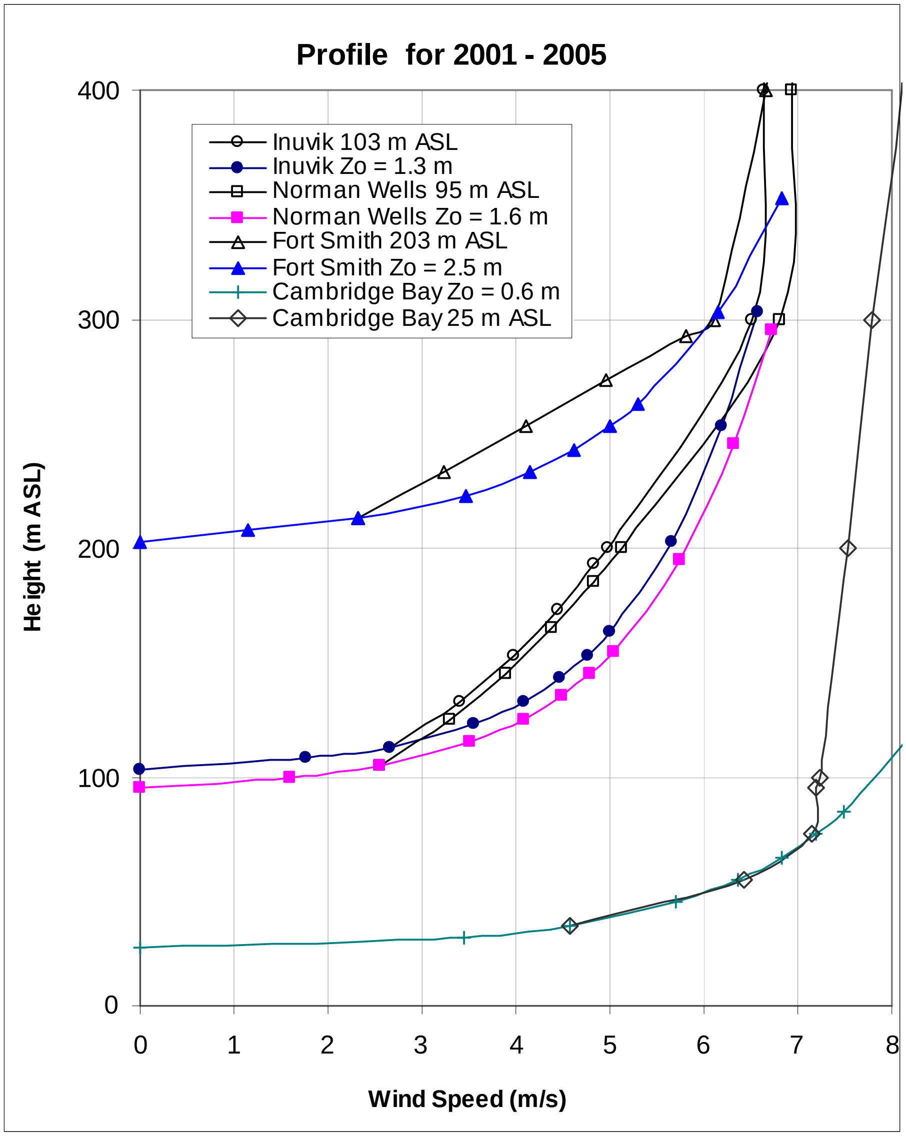

Figure 1: Vertical profiles of wind speeds at four weather balloon stations in the NWT.

5. Monthly mean wind speed, air density, and power correction

The airport station is used to calculate long-term monthly means of wind speed for each community. The monthly mean wind speed at 30-m (u_{30m}), shown in Equation (2), is estimated by multiplying the airport's monthly mean (u_{Am}) by the ratio (r) of the mean wind speed between the airport (u_{AP}) and the wind monitoring station (u_{30P}) at 30 m AGL. As noted above the ratio (r) of the wind speeds at both sites is calculated from the average wind speed during the period of simultaneous operation.

$$u_{30m} = u_{Am} r, \qquad \text{where} \quad r = \frac{u_{AP}}{u_{30P}} \tag{2}$$

The airport station also measures temperature and pressure which are used to calculate the monthly mean air density. The standard density used for wind turbine performance is 1.225 kg/m^3 and this is derived at the standard temperature and pressure of 288.15ºKelvin (15º Celsius) and 101.33 kPa. At any given location the density will deviate from this standard and so Equation (3) below is used to adjust the density (ρ_T) according to the locally measured air temperature (T = 273.15ºK + $T_{measured}$ºC) and pressure (B).

$$\rho_T = 1.225 \left[\frac{288.15}{T}\right]\left[\frac{B}{101.33}\right] \tag{3}$$

This equation is used in calculating the power output from stall-regulated wind turbines (see Burton et al. 2001). The air density can be used to adjust the estimated power output P_T for a given turbine and given in the form:

$$P_T = P_S \left[\frac{\rho_T}{1.225}\right] \tag{4}$$

where P_S is the measured power in standard conditions noted above. P_S is usually provided by the manufacturer. In each report the ratio of the air density in Equation (4) is calculated and tabulated along with the other variables above. For pitch-regulated turbines the above approach is applicable to 70 % of the rated power. Above this a different correction applies using the measured wind speed (U_T) and is given as:

$$U_S = U_T \left[\frac{\rho_T}{1.225}\right]^{1/3} \tag{5}$$

where U_S is the adjusted wind speed. This approach is not calculated in the reports but may become important in the economic feasibility phase where pitched regulated turbines will be considered.

6. Icing

Instrument icing is possible at all the sites during the fall and winter. It usually occurs in the form of rime icing in which supercooled (in liquid state below 0°C) water droplets freeze on impact with a solid object. This negatively affects the wind speed and direction sensors by reducing the measured wind speed compared to the ambient condition. In severe icing conditions this will sometimes freeze the wind sensors in place so that there is measurement of zero wind speed and a constant direction. Each sensor is usually affected to varying degrees and do not all freeze up at the same time. It is usually very difficult to detect and one must visually sift through the wind data to look for clues. Those clues being extended periods of zero wind speed on some sensors when temperatures are below freezing. We could filter the data to eliminate all winds with zero wind speed, however, this may over predict the mean wind speed because actual calm conditions may be filtered out. At the same time icing also affects wind turbines by building up on the leading of the blades causing a reduced wind power output. Some wind farm developers apply the ice-contaminated measurements untreated to power calculations, thus reducing the expected turbine output.

Steps can be taken to reduce icing effects on instruments by using heated sensors, this requires readily available power to a wind monitoring site and this is not usually possible. For this reason a separate (usually shorter) tower is located near a power supply and wind measurements are made in conjunction with the tall tower at the site of interest. This was done in Sachs Harbour where severe icing was known to occur regularly in the winter. In the other communities, the local weather personnel noted that icing occurred only occasionally.

Turbine blades can be treated with black ice-phobic or hydro-phobic coatings that help to reduce ice build-up and speed up subsequent de-icing. A more expensive option is to fit the blades with heating pads. This second method has been applied to larger turbines but not yet to those such as the AOC 15/50 (see Section: Economic Feasibility)

7. Instrumentation, error and variability

The wind speed analyses in the reports include airport wind speed measurements from 2001 to 2006 (Table 2). These were downloaded from Environment Canada's website. The airport measurements were made 24 hours a day from a standard 10-m tower, usually located near the airport terminal and the airstrip. Wind measurements are made during a two-minute period at the top of each hour. The 30-m tall wind monitoring stations measure wind speed, direction and temperature every 2 seconds and are averaged at 10-minute intervals. For the purpose of comparing to the airport measurements the wind monitoring station data are converted to hourly averages. It has been found (Pinard et al. 2005) that wind measurements from airport stations can be typically 60 to 70 % of those made by wind monitoring stations designed for the purpose of measuring wind energy potential.

The typical error in measurement from the wind (30-m towers) monitoring station is less than 0.1 m/s for wind speed ranging 5 to 25 m/s, and so it is less than 2% error. The airport measurements are also considered better than 2%. To reduce further errors due to shadow effect by towers the anemometers have been placed on 1.5-m booms away from the direction where the lowest frequency of wind occurs. The error from wind speeds projected to a higher level above ground was calculated by matching logarithmic profiles to the ±0.1 m/s extremes of the mean wind speeds at 10 and 30 m. In this study the projection error is estimated to be 0.25 m/s for the 60-m estimate. In the special case of the heated sensor at Sachs Harbour the error for projecting from 4.2 to 30 and 60 (0.75 and 1.0 m/s respectively) was based on limits used in the error for the 30-m wind monitoring station nearby.

A 6 to 18 month periodic mean wind speed can vary substantially from the long-term mean. Based on long-term wind measurements at the Whitehorse airport (Pinard et al. 2005) a six-month period of measurement will be within ±25 % (minimum and maximum) of the long-term mean. The variation (maximum-minimum) reduces to ±14 % at one year and ±6 % or less at five years or more. For a six-month and a six-year mean wind speed of 5 m/s this represents ±1.25 and ±0.3 m/s variation respectively. To reduce the variation of the short monitoring period we correlate the wind monitoring station to the airport station. We then assume that the projected six-year mean wind speed of the wind monitoring station improves to within 6 % of the long-term mean.

Table 2: Estimated mean wind speed (m/s) using 2001 to 2006 as the basis. The total errors are a combination of variation from long-term mean, sensor accuracy, and error due to vertical projection.

Summary of wind speeds in m/s			Wind speed (m/s) at 30 m				Wind speed (m/s) at 60 m			
		Measurement	6-year	Error			6-year	Error		
		height	Mean	Projection	Variation	Total	Mean	Projection	Variation	Total
Sachs Harbour - heated stn	July 05 to Dec 06	4.2 m	**7.57**	0.75	0.45	1.20	**8.17**	1.00	0.49	1.49
- 30 m tower	July 05 to Dec 06	10, 20, 30 m	**6.03**	0.10	0.36	0.46	**6.51**	0.25	0.39	0.64
Ulukhaktok 30-m tower	May to Oct 06	10, 20, 30 m	**6.54**	0.10	0.39	0.49	**6.84**	0.25	0.41	0.66
Paulatuk 30-m tower	June 05 to Oct 06	10, 20 m	**5.84**	0.20	0.35	0.55	**6.20**	0.40	0.37	0.77
Tuktoyaktuk 30-m tower	May to Dec 06	10, 20, 30 m	**5.05**	0.10	0.30	0.40	**5.44**	0.25	0.33	0.58
Yellowknife 38-m telco tower	July to Dec 06	10, 20, 38 m	**4.37**	0.10	0.26	0.36	**4.98**	0.20	0.30	0.50
Inuvik 60-m telco tower	Nov 05 to Dec 06	30, 60 m	**3.86**	0.10	0.23	0.33	**4.32**	0.10	0.26	0.36

8. A note on climate change

At Cambridge Bay, Baker Lake, Forth Smith, Inuvik and Whitehorse the weather balloon stations have all measured wind speed increases over nearly five decades of measurements. The long term variability can be summed in the upper-air data from the Inuvik soundings. It is apparent that a rise of approximately 1 m/s has occurred over nearly five decades (Figure 2). The same has been noted for the Whitehorse station.

This increase is occurring at two atmospheric scales (see Pinard, 2007). On a large scale there is the increased intensity of cyclonic activity due to the global climate warming. At the surface the annual temperatures have increased and are causing a less stable local atmosphere. As a result the depth of the inversion layer has become shallower. The inversion occurs when the coldest air is at the surface and temperature increases to a maximum at the inversion top, usually a few hundred metres above the surface. The inversion typically prevents the winds aloft from mixing down to the surface. The less stable atmosphere (a shallow inversion, warmer surface temperature) allows more downward mixing of the winds aloft to the surface thus causing higher surface wind speeds. The temperature increases that have measured in the last 50 fifty are much more pronounced in the winter and so are the winter wind speed increases.

The annual wind speed of the airport stations at the six communities are shown (Figure 2). Although the annual means are variable most of them show an increase over the six-year period.

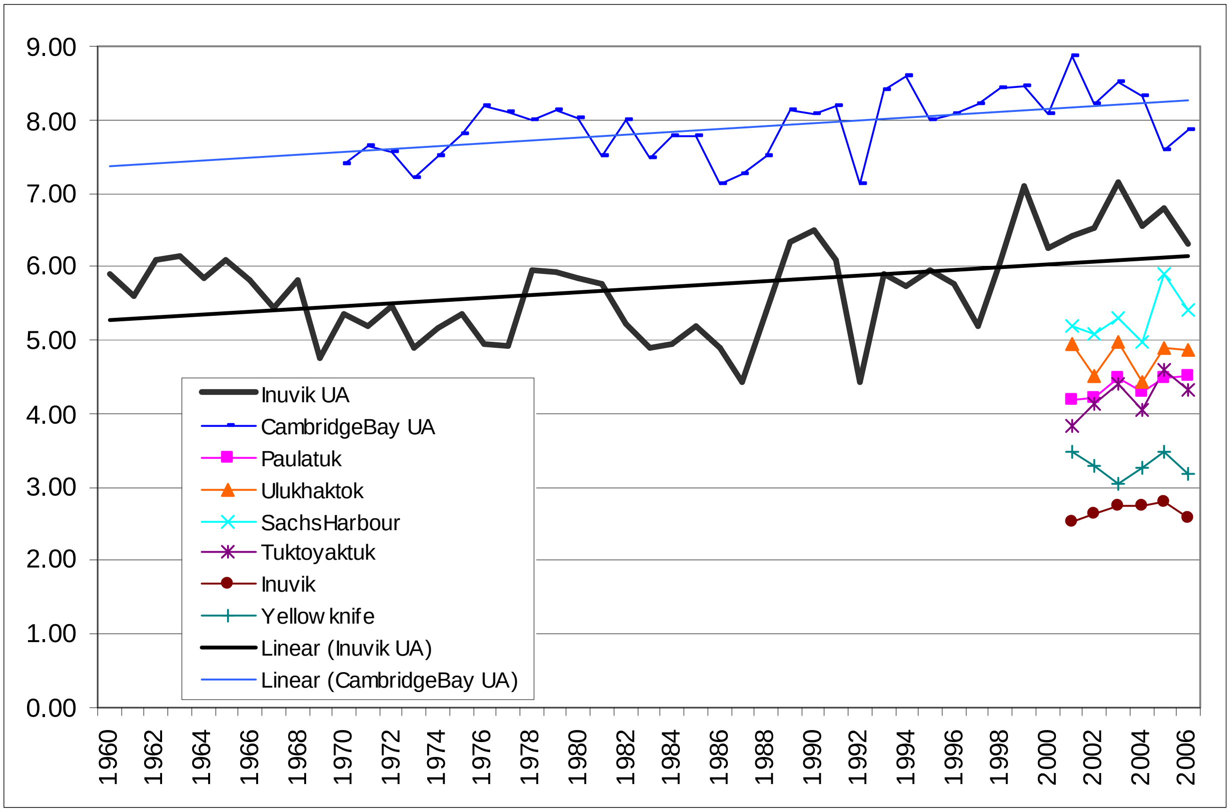

Figure 2: Time series of annual mean wind speed at 500 m above sea level (ASL) over Inuvik (58 m ASL) and Cambridge Bay (25 m ASL) and the airport stations in six communities. The mean wind speed at 500 m ASL for the period is 5.7 and 7.8 m/s in Inuvik and Cambridge Bay respectively. The rate of wind speed increase is about 0.2 m/s per decade. The acronym UA is short for upper-air or weather balloon measurements.

9. Economic feasibility

The economic viability of a wind project in a remote community depends on four important variables:

- Capital cost of the wind project,
- Operating and maintenance cost of the project,
- Cost of fuel to the diesel plant, and
- Annual mean wind speed.

The first three variables are addressed in Maissan (2006) and for the sake of presenting economic feasibility we shall follow Maissan's proposition of three AOC 15/50 totalling a 180 kW of wind power production capacity for a diesel community. Refer to Section 9 and Appendix A for further discussion.

All minor variables such as wind turbine efficiency losses and amortization are fixed and are described in Maissan. The capital cost based on the Alaskan experience and Hydro

Quebec estimates range between $4,000 and $10,000 per kW installed. The annual operating costs could cost from $5,000 to $15,000/year. The fuel costs to the diesel plants in remote communities are assumed to be in the range $0.80 to $1.25 per litre.

For the purpose of this study we will use medium values of the costs presented in Maissan, summarized above. For a three-turbine wind farm we'll assume a capital cost of $7,000/kW installed and an operating cost of $30,000 annually. The interest rate for amortization is 8%. Let us also assume that the price of fuel to the diesel plant is $1/litre. At these costs a farm would require a minimum annual mean wind speed of about 7.5 m/s. If this is the case then Sachs Harbour maybe the only candidate with a viable project. A combination of cost reductions and subsidies will likely lower the limit. If we can reduce the capital cost to $4,000/kW then a minimum annual mean wind speed of 6.5 m/s would be required to make the project viable. If the price of diesel goes up to $1.25/litre then the minimum wind speed is 6 m/s.

As pointed out by Maissan a reduction of interest rate from 8 to 5% has the effect of reducing the capital cost from $5,000 to $4,000, which amounts to about 0.5 m/s in the wind speed requirement. An incentive program such as ReCWIP that is being proposed by CanWEA would provide $0.15/kWh, this would reduce the wind speed limit by about 1 m/s.

References

Burton, T., D. Sharpe, N. Jenkins, E. Bossanyi, 2001. Wind Energy Handbook. Wiley.

Maissan, J.F., "A Report on the State-of-the-art and Economic Viability of Wind Power Development in Arctic Communities." Aurora Research Institute, Jan. 2006.

Pinard, J.-P., T. Weis, and Bak Chauhan (Ed.) "Pre-Feasibility Analysis of Wind Energy for Inuvialuit Region in Northwest Territories." Aurora Research Institute Mar. 2003.

Pinard, J. D. J.-P., R. Benoit, and W. Yu, 2005. A WEST wind climate simulation of the mountainous Yukon. Atmosphere-Ocean, 43, 259–282.

Pinard, J.-P., 2007, Wind Climate of the Whitehorse Area, Arctic. In press, due in September.

Appendix A – Inuvik

Progress Report for Wind Energy Monitoring in Inuvik, NWT

Summary

The long term wind speed in Inuvik was projected to be 3.86 m/s and 4.32 m/s at 30 m and 60 m above ground level (AGL) respectively using 2001 to 2006 airport data as a basis. The measurements were made from a telecommunication tower just east of the town. The predominant wind direction there was shown to be from the north-northwest but there was also a less dominant easterly wind direction. The wind climate is considered less than marginal for wind development is this area.

Site Description

The wind monitoring station began collecting data on 14 November, 2005. The sensors were installed on a telecommunications tower just east of downtown Inuvik (Figure 1). The site is 11 km northwest of the air strip centre and is near a power line that serves the community of Inuvik (Figure 2). The site is accessible by road.

The wind speed sensors are located at 30 m and 60 m AGL, the wind vane is at 30 m AGL, and a temperature sensor is located at approximately 2 m AGL. The site elevation is approximately 100 m above sea level (ASL).

Figure 1: View of the wind monitoring station facing towards the northeast. The Sir Alexander Mackenzie Elementary School is the building on the left, the Aurora Research Institute is behind the photographer to the left.

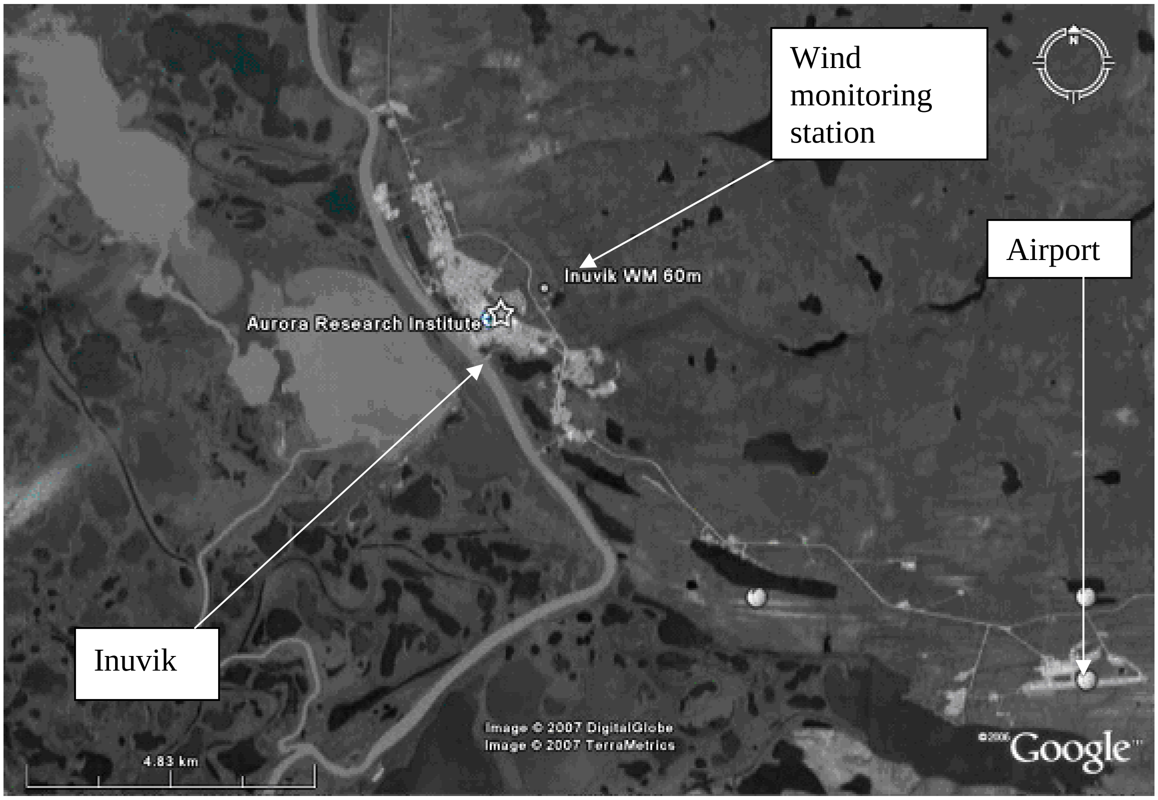

Figure 2: Satellite image of the area around Inuvik. Note that North is up.

Data Analysis

Wind Direction

The airport station shows two dominant wind energy modes: the largest from the northwest, and a second from the east (Figure 3) . The wind monitoring station shows predominant winds from the north-northwest with the easterly component being much less important.

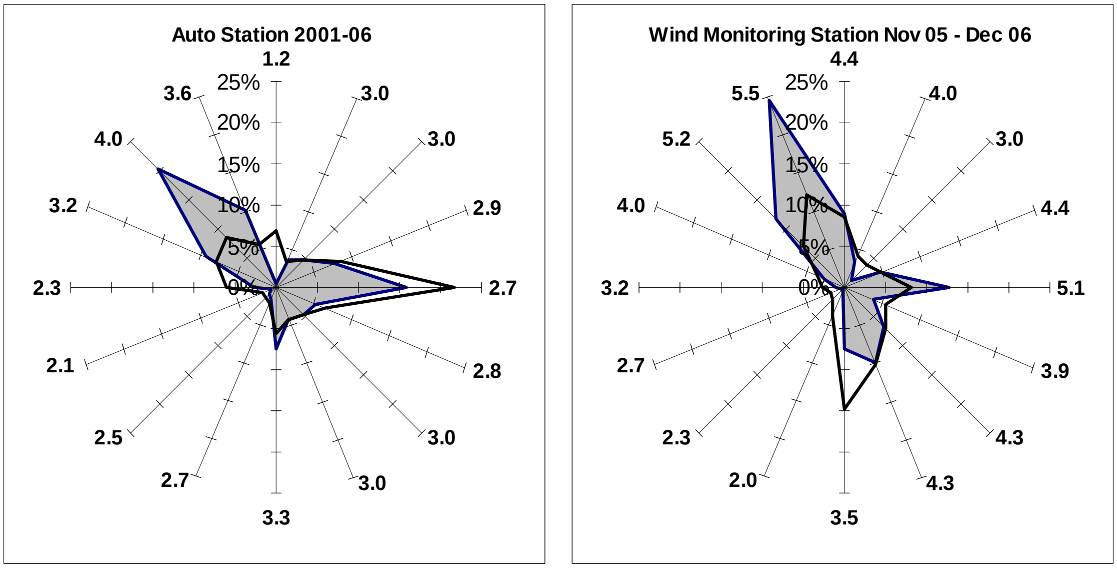

Figure 3: Wind roses for the airport and the 60 m wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

Wind Speed

Both the airport and the wind energy monitoring stations are analyzed and compared. The wind monitoring sensor at 30 m AGL has a correlation with an r-value of 0.77 with the airport measurements. Icing may occur occasionally at this site. For the period of measurement about 11 % of the wind conditions were reported to be calm, a minority of this period may be attributed to icing. By eliminating the calm period accounts for a increase of 1 % in the wind monitoring station mean wind speed. This correction will be ignored and not applied to the following calculations.

The mean wind speed at the wind monitoring site is 16 % higher (when projected down to 10 m height for comparison) than the airport (Table 1). The six year average at the airport is 107 % of the November 2005 to December 2006 average so the wind speeds measured at the wind monitoring site should be proportionally higher when projected to a 2001-2006 mean. The six year annual mean wind speed at the wind monitoring site is estimated to be 3.86 m/s at 30 m AGL and 4.32 m/s at 60 m AGL. A surface roughness of 0.1 m (dense tall grass or sparse short forest.) was applied in the vertical projection.

Table 1: Wind speed calculations for the airport and the wind monitoring sites.

Location and measurement period	Height	Wind speed	
Inuvik Airport 14 Nov 05 to 7 Dec 06	10 m AGL	2.51	m/s
WM 14 Nov 05 to 7 Dec 06	30 m AGL	3.62	m/s
	60 m AGL	4.07	m/s
Inuvik A 2001-06 average	10 m AGL	2.67	m/s
Ratio of 6-year to Nov 05-Dec06 means		1.07	
WM wind projected to 2001-06 at	10 m AGL	**3.11**	m/s
	20 m AGL	**3.58**	m/s
	30 m AGL	**3.86**	m/s
	40 m AGL	**4.05**	m/s
	50 m AGL	**4.20**	m/s
	60 m AGL	**4.32**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2). A graphical representation of the wind monitoring station wind speed and the corrected power ratio is shown (Figure 4). The wind speed for the monitoring station (the unheated 30-m tower at the west end) is projected to 30-m AGL using a multiplier of 1.44 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001-06. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.44.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	2.06	2.97	-24.9	100.9	1.42	1.16
February	2.07	2.99	-23.8	101.1	1.41	1.15
March	2.67	3.85	-23.0	101.5	1.41	1.15
April	2.88	4.15	-11.5	101.0	1.35	1.10
May	3.21	4.63	-0.2	100.9	1.29	1.05
June	3.48	5.02	11.3	100.7	1.23	1.01
July	3.19	4.60	13.4	100.3	1.22	1.00
August	2.93	4.22	10.6	100.4	1.23	1.01
September	2.89	4.16	4.7	100.2	1.26	1.03
October	2.61	3.77	-5.1	100.3	1.30	1.06
November	2.11	3.04	-18.3	100.7	1.37	1.12
December	1.95	2.81	-20.9	100.2	1.39	1.13
Annual	2.67	3.86	-7.2	100.7	1.32	1.08

The highest monthly mean wind speed is 5.02 m/s in June with a sustained average of above 4 m/s from April to September (Figure 4). The drop in the wind speed in

November to March can be attributed to the high atmospheric stability, as noted in the table above these are the months with the lowest temperatures. The corrected power ratio increases to a maximum of 1.15 in February-March and diminishes to 1.00 in July. Mean annual corrected power ratio is 1.08.

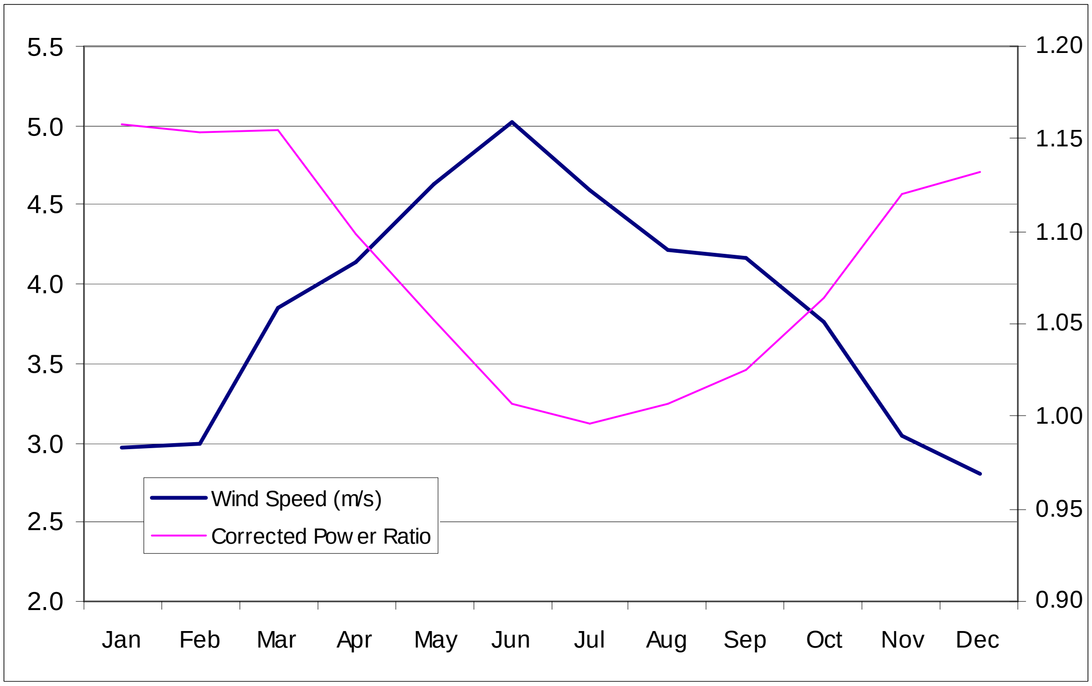

Figure 4: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the left side and the air density to the right.

Recommendations

The measurements to date indicate that the wind climate in this area is not adequate for the generation of electricity with wind power with the present technology.

Appendix B – Paulatuk

Progress Report for Wind Energy Monitoring in Paulatuk, NWT

Summary

The long term wind speed in Paulatuk was projected to be 5.84 m/s at 30 m above ground level (AGL) using 2001 to 2006 airport baseline data. The measurements were made in a flat field just southeast of the water reservoir southeast of the Hamlet. The predominant wind direction there was from the south-southwest.

The site is recommended for further studies for wind development.

Site Description

The wind monitoring station began collecting data on 22 June, 2005 (Figure 1). The tower was erected 4.5 km southeast of the airport centre (Figure 2). The wind monitoring site is approximately 1.4 km from the power line to the water reservoir. The site is accessible by an existing road that leads further towards the east-southeast.

The tower is 30 m tall and has a wind speed sensor at each of 10, 20, and 30 m AGL, a wind vane at 30 AGL, and a temperature sensor at approximately 2 m AGL. The ground is mostly sand, and at the time of installation the frozen layer was found at approximately 1 m below the surface.

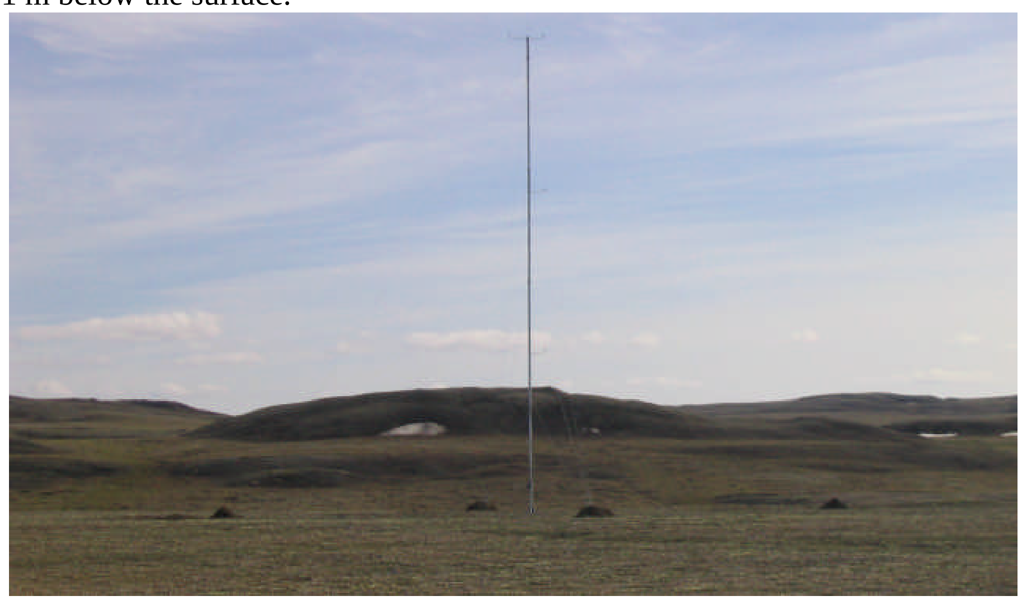

Figure 1: View of the wind monitoring station facing towards the south-southwest. The hill centered in the background is approximately 3 km away.

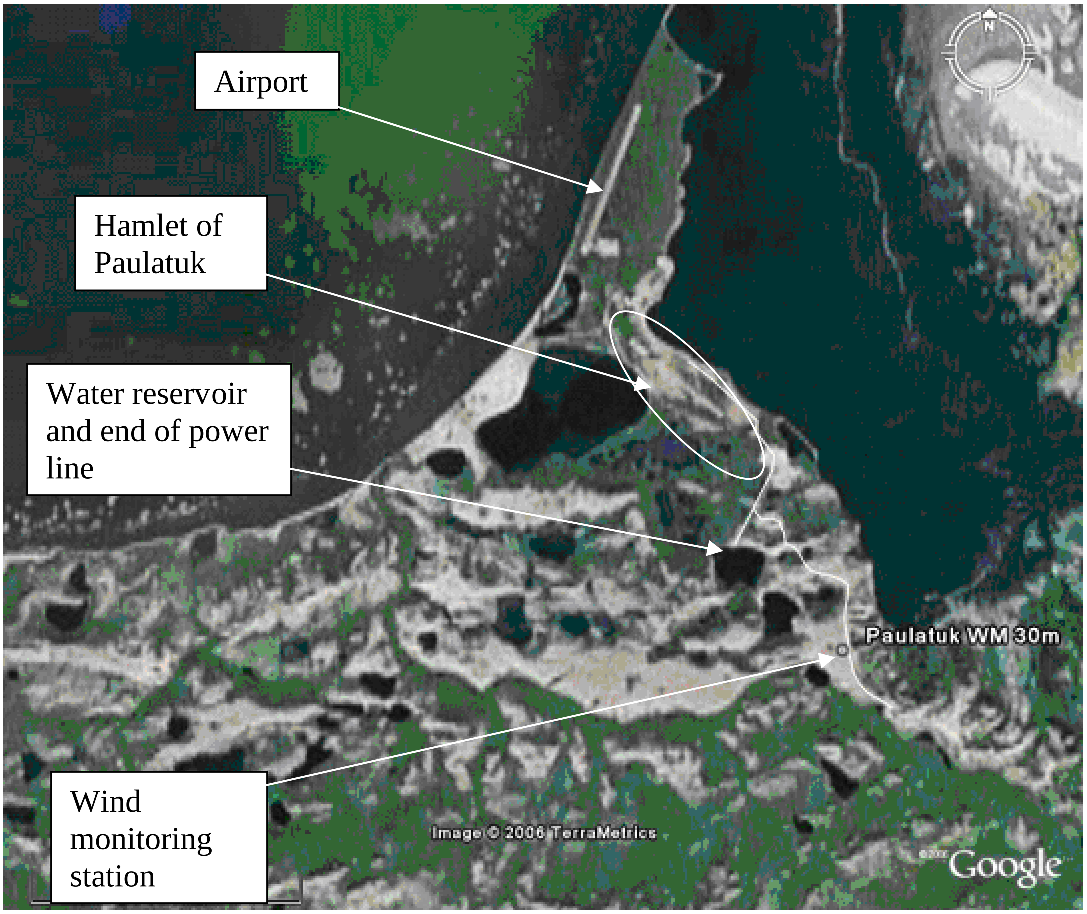

Figure 2: Satellite image of the area around Paulatuk.

Data Analysis

Wind Direction

Wind roses for both the airport and the wind energy monitoring station are both showing the direction of predominant wind energy is from the south-southwest (Figure 3). The distribution frequency of wind by direction is spread out more evenly giving the impression that perhaps the westerly wind might be more important. This is misleading and is why a wind energy rose should be calculated.

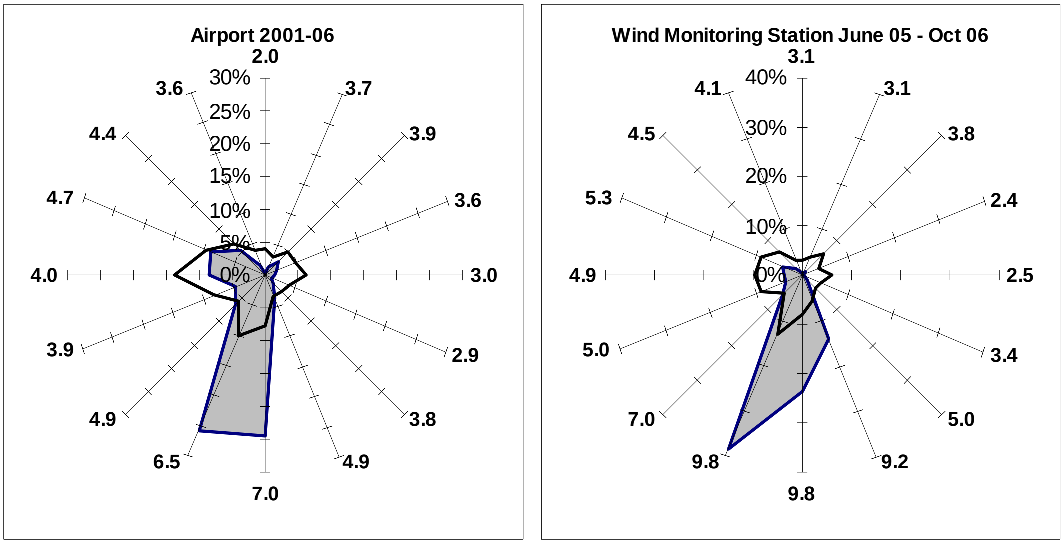

Figure 3: Wind roses for the airport and the wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

Wind Speed

Both the airport and the wind energy monitoring stations are analyzed and compared. The correlation between the wind monitoring sensors and the airport station has an r value of 0.87. For the period of measurement about 3 % of the wind conditions were reported to be calm, a minority of this period may be attributed to icing. By eliminating the calm period accounts for no increase in the wind monitoring station mean wind speed.

The mean wind speed at the wind monitoring site is 20 % higher (at 10 m height comparison) than the airport (Table 1). The six-year average at the airport is 96 % of the June 2005 to October 2006 average so the wind speeds measured at the wind monitoring site should be proportionally lower when projected to a long term mean. The annual mean wind speed at the wind monitoring site is estimated to be 5.84 m/s at 30 m AGL and 6.20 m/s at 60 m AGL. The vertical projection was made using a surface roughness of 0.0004 m, representative of a smooth flat sandy surface.

It should be noted, however, that there appears to be a problem with the anemometer located at 30 m, its wind speed readings are showing a lower mean wind speed compared to the 20 m reading. The vertical projection is based on the 10 and 20 wind speeds only. This increases the error in the vertical projection that is shown in the executive report.

Table 1: Wind speed calculations for the airport and the wind monitoring sites.

Location and measurement period	Height	Wind speed	
Paulatuk Airport 22 June 05 to 29 Oct 06	10 m AGL	4.54	m/s
Paulatuk WM 22 June 05 to 29 Oct 06	10 m AGL	5.47	m/s
	20 m AGL	5.84	m/s
	30 m AGL	5.72	m/s
Paulatuk A 2001-06 average	10 m AGL	4.37	m/s
Ratio of 2005-06 to 6-year mean		0.96	
Paulatuk WM wind projected to 2001-06 at	10 m AGL	**5.26**	m/s
	20 m AGL	**5.63**	m/s
	30 m AGL	**5.84**	m/s
	40 m AGL	**5.99**	m/s
	50 m AGL	**6.10**	m/s
	60 m AGL	**6.20**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2) . A graphical representation of the wind monitoring station wind speed and the power ratio is shown (Figure 4). The wind speed for the monitoring station is projected to 30-m AGL using a multiplier of 1.33 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001-06. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.33.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	4.71	6.29	-24.9	101.8	1.43	1.17
February	4.50	6.01	-25.6	102.0	1.44	1.17
March	4.11	5.49	-25.1	102.3	1.44	1.17
April	3.86	5.15	-15.3	101.9	1.38	1.12
May	4.16	5.54	-4.0	101.9	1.32	1.08
June	3.51	4.68	4.3	101.5	1.27	1.04
July	3.86	5.15	9.0	101.2	1.25	1.02
August	4.20	5.61	7.8	101.2	1.26	1.02
September	4.66	6.22	4.1	101.1	1.27	1.04
October	5.32	7.10	-4.9	101.2	1.31	1.07
November	4.88	6.50	-16.8	101.5	1.38	1.13
December	4.61	6.15	-19.8	101.3	1.39	1.14
Annual	4.38	5.84	-9.2	101.6	1.34	1.09

The highest monthly mean wind speed is 7.10 m/s in October with a sustained average of over 6 m/s from September to February (Figure 4). The corrected power ratio also increases to a maximum of around 1.17 from January to March and diminishes to 1.02 in July and August.

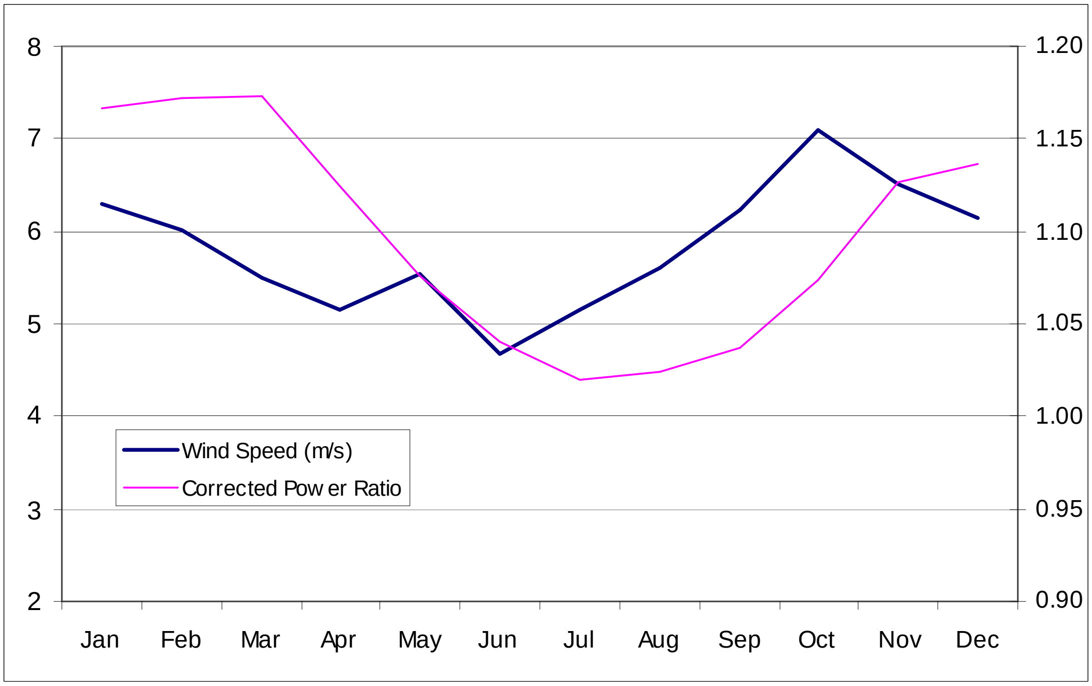

Figure 4: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the left side and the air density to the right.

Conclusions and Recommendations

This site has potential for a wind farm development to generate electricity. Further monitoring should be carried out. An additional anemometer should be placed on the tower at 30 m and the existing 30-m anemometer should be replaced.

Although this is an ideal site because of its large flat terrain, it is 1.4 km from the nearest power line. It would be ideal to locate it closer to the grid. Other areas are suggested in the image below (Figure 5). Here the westernmost proposed area is 150 m from the power line that follows the road.

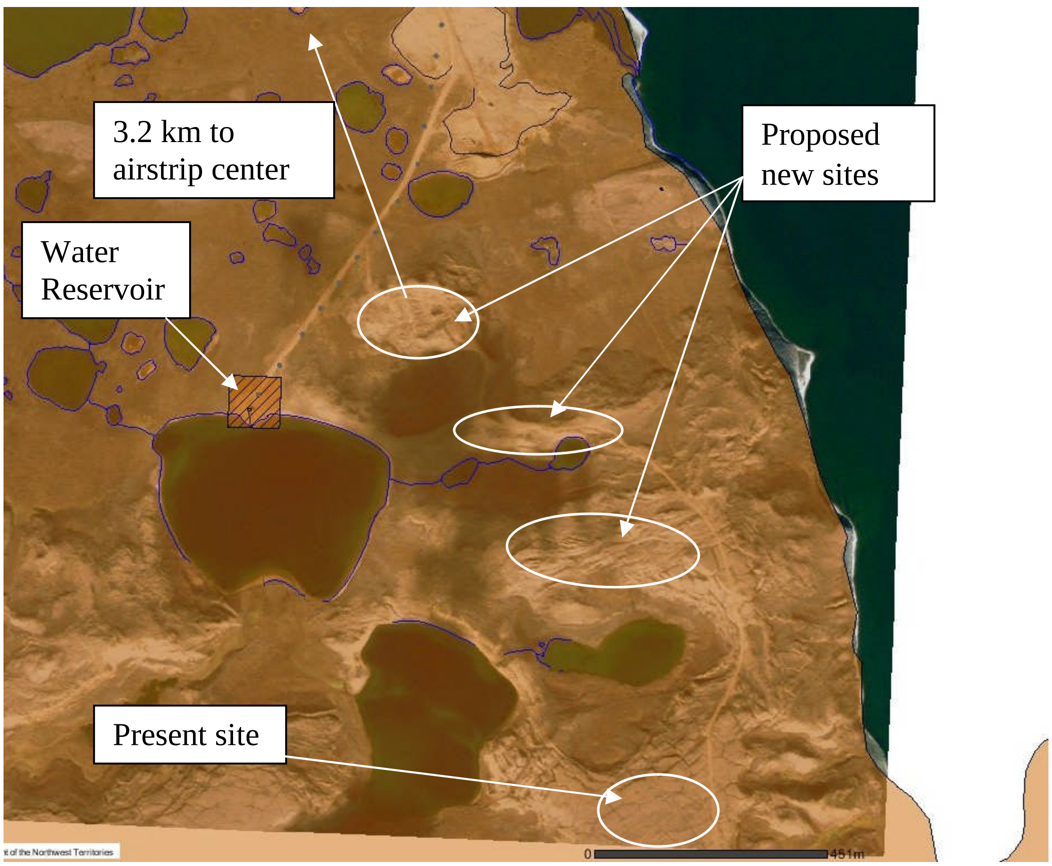

Figure 5: Suggested new locations for further wind monitoring. The power line poles are shown following the road to the reservoir.

Appendix C – Sachs Harbour

Progress Report for Wind Energy Monitoring in Sachs Harbour, NWT

Summary

The long term wind speed in Sachs Harbour was projected to be 6.03 m/s at 30 m above ground level (AGL), using 2001 to 2006 airport data as a baseline, for a location 6 km west of the Hamlet. A wind speed of 7.57 m/s (at 30 m height) at the original wind turbine location by the Hamlet was also projected from a separate heated wind speed sensor installation. The predominant wind direction was from the southeast with a smaller component from the north.

Among other areas, the east side of the Hamlet by the gravel quarry is recommended for further wind resource assessment studies for wind project development.

Site Description

The wind monitoring station began collecting data on 8 July, 2005 (Figure 1 and Figure 2). The 30 m tower was erected 6.1 km west of the west end of the air strip (Figure 3). The wind monitoring site is approximately 5.4 km from the Ice Palace where the power line is believed to terminate. The site is accessible by an existing road that leads further towards the west. The tower is 30 m tall and has a wind speed sensors at each of 10, 20, and 30 m above ground level (AGL), a wind vane at 30 m AGL, and a temperature sensor at approximately 2 m AGL. The site elevation is approximately 45 m above sea level (ASL). The ground is mostly sand, and at the time of installation the frozen layer was found at approximately 1 m below the surface.

Figure 1: View of the wind monitoring station facing towards the west. The landfill is just beyond the station to the left.

Rime icing, or frost build-up on stationary objects, was observed in Sachs Harbour and therefore a heated sensor was also included in the monitoring. To access power the heated wind speed and direction sensors were located at the site where an AOC 15/50 wind turbine was originally established (Figure 2). The wind vane and anemometer are at

4.2 m above the ground. This site is at 87 m ASL, approximately 42 m higher than the other monitoring site to the west.

Figure 2: Looking southeast at the site of the wind turbine foundation (to the left) and the heated sensor (to the right). This site is located between the Hamlet and the airport.

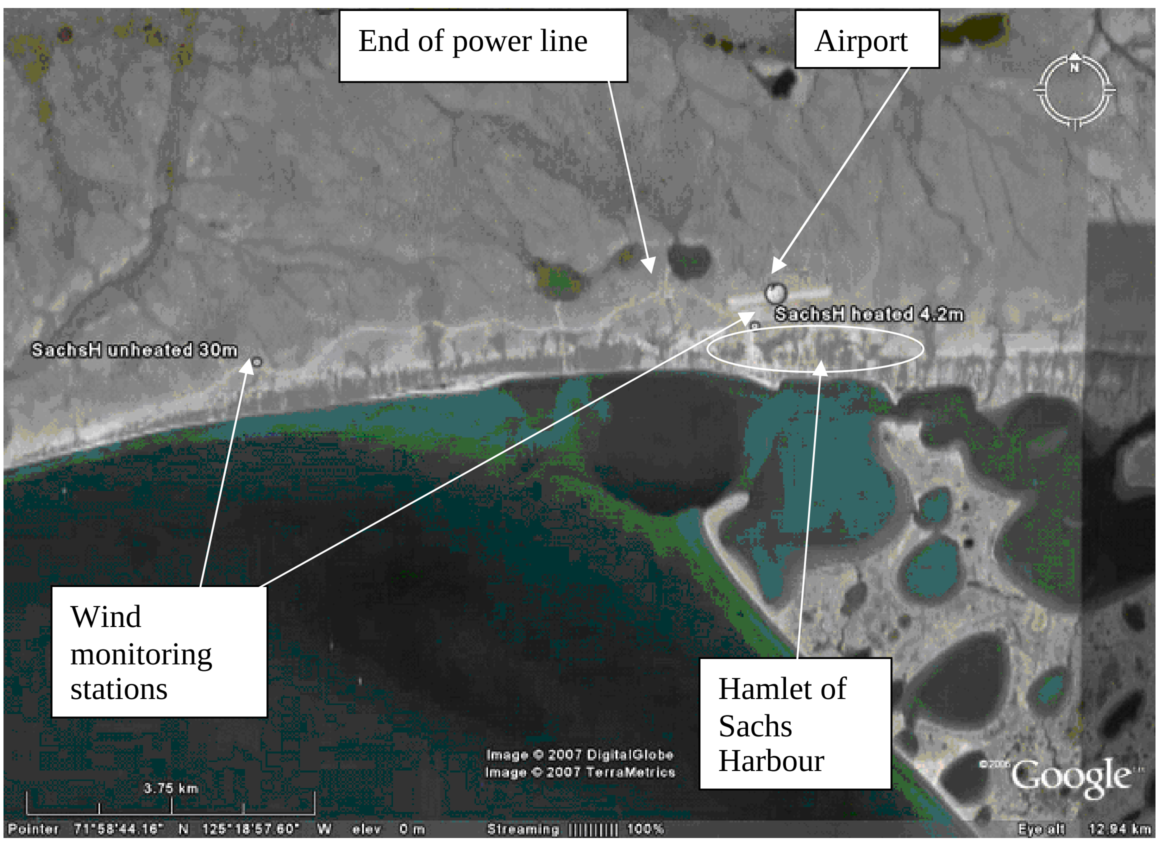

Figure 3: Satellite image of the area around Sachs Harbour.

Data Analysis

Wind Direction

Wind roses for both the airport and the wind energy monitoring stations are showing the direction of predominant wind energy is from the southeast (Figure 4). The heated station however is showing that a second direction mode from the north is also important (Figure 5).

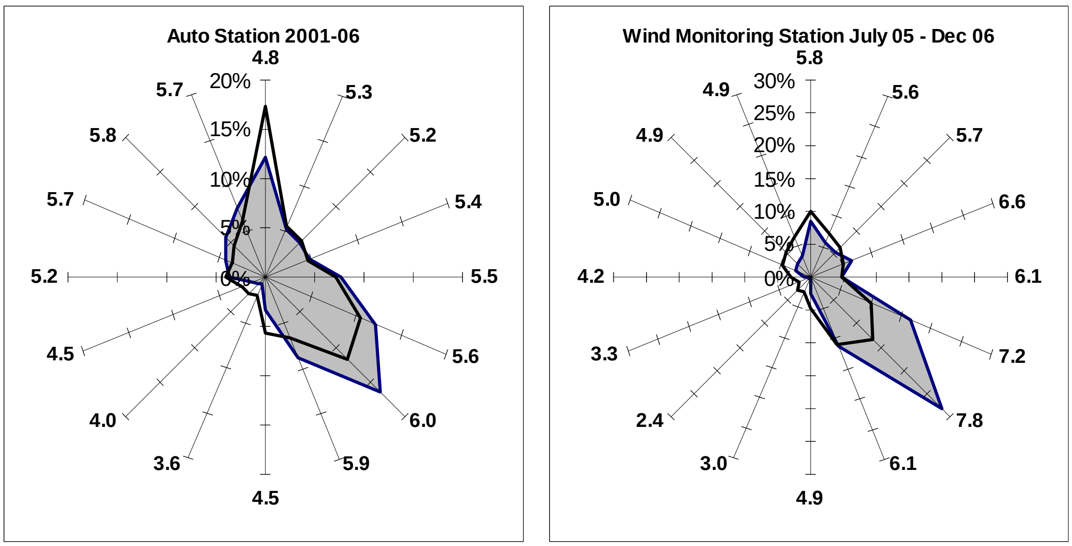

Figure 4: Wind roses for the airport and the 30 m wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

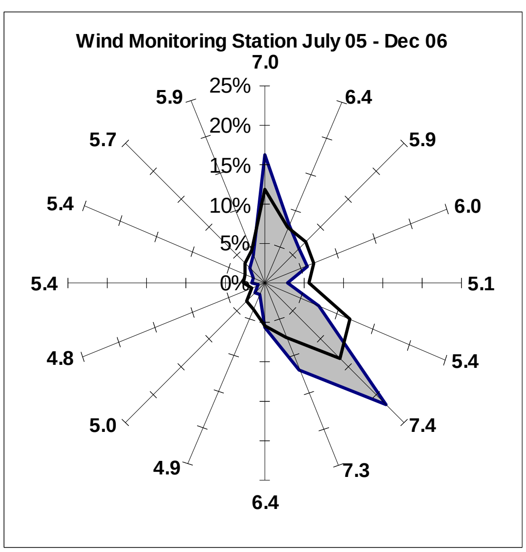

Figure 5: Wind rose for the heated wind sensors at the wind turbine site.

Icing

A comparison of the heated and unheated wind speed shows that over the monitoring period there have been indications of severe icing for 7.6 % of the time. The heated sensor recorded zero wind speed for only 0.8 % of the period while the unheated sensor (at 10 m) recorded 8.4 % calm wind conditions. Icing is suspected to have occurred for longer, for example, for 15% of the time the unheated 10-m sensor measured less than half of the those of the heated sensor. The longest period of suspected icing occurred from 8 January to 10 February 2006 where wind speed at the 10-m level were nearly calm for the period. During the same time the heated sensor recorded a mean wind speed of 5.6 m/s. Eliminating the 15 % suspected icing period results in an increase of 12 % in the unheated wind speed, which is applied in the projected wind speed for the unheated station in the table below.

Wind Speed

Both the airport and the wind energy monitoring stations are analyzed and compared. The correlation between the wind monitoring (WM) sensors and the airport station has an r value of 0.86.

The mean wind speed at the wind monitoring site is about 90 % (at 10 m) of the mean at the airport (Table 1). At the wind turbine site the projected wind speed to 10 m is 25 % higher than the airport. The six-year average at the airport is 95 % of the July 2005 to December 2006 average so the wind speeds measured at the wind monitoring site should be proportionally less when projected to a long term mean. The long term (based on 6 years of airport data) annual mean wind speed at the (unheated) wind monitoring site is estimated to be 6.03 m/s at 30 m AGL and 6.51 m/s at 60 m (including 1.12 % factor accounting for icing). At the wind turbine site however, the long term mean is estimated to 7.57 m/s and 8.17 m/s at 30 m AGL and 60 m respectively. A surface roughness of 0.005 m (typical of snow surface) was used to fit the vertical profile to the 10-, 20- and 30-m wind speeds.

Table 1: Wind speed calculations for the airport and the wind monitoring (WM) sites.

Location and measurement period	Height	Wind speed	
Sachs Harbour Airport 8 July 05 to 31 Dec 06	10 m AGL	5.61	m/s
Sachs WM 8 July 05 to 31 Dec 06	10 m AGL	5.00	m/s
	20 m AGL	5.43	m/s
	30 m AGL	5.71	m/s
Sachs Heated WM 8 July 05 to 31 Dec 06	4.2 m AGL	6.16	m/s
Sachs Harbour A 2001-06 average	10 m AGL	5.34	m/s
Ratio of 2005-06 to 6-year mean		0.95	
Sachs H. WM wind projected to 2001-06 at	10 m AGL	**5.27**	m/s
Based on unheated 30-m tower sensors	20 m AGL	**5.75**	m/s
adjusted for icing period.	30 m AGL	**6.03**	m/s
	40 m AGL	**6.23**	m/s
	50 m AGL	**6.39**	m/s
	60 m AGL	**6.51**	m/s
Sachs H. WM wind projected to 2001-06 at	10 m AGL	**6.61**	m/s
Based on the heated sensors at 4.2 m	20 m AGL	**7.22**	m/s
	30 m AGL	**7.57**	m/s
	40 m AGL	**7.82**	m/s
	50 m AGL	**8.01**	m/s
	60 m AGL	**8.17**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2). A graphical representation of the wind monitoring station wind speed and the power ratio is shown (Figure 4). The wind speed for the monitoring station (the unheated 30-m tower at the west end) is projected to 30-m AGL using a multiplier of 1.13 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001 to 2006. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.13.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	4.32	4.88	-26.5	100.6	1.42	1.16
February	4.65	5.25	-28.1	100.9	1.43	1.17
March	5.24	5.92	-26.9	101.2	1.43	1.17
April	5.33	6.03	-17.7	100.8	1.37	1.12
May	5.27	5.96	-6.9	100.8	1.32	1.08
June	5.28	5.97	2.3	100.5	1.27	1.04
July	5.42	6.13	4.9	100.2	1.25	1.02
August	5.22	5.90	3.4	100.0	1.26	1.03
September	5.98	6.76	-0.4	100.2	1.28	1.04
October	6.45	7.30	-9.3	100.1	1.32	1.08
November	5.36	6.07	-19.4	100.5	1.38	1.13
December	5.17	5.85	-22.3	100.1	1.39	1.14
Annual	5.36	6.06	-12.1	100.5	1.34	1.10

The highest monthly mean wind speed is 7.30 m/s in October with a sustained average of nearly 6 m/s or more from March to November (Figure 4). The drop in the wind speed in December to February can be attributed to the high atmospheric stability, as noted in the table above these are the months with the lowest temperatures. The corrected power ratio increases to a maximum of 1.17 in February-March and diminishes to 1.02 in July. Mean annual corrected power ratio is 1.10.

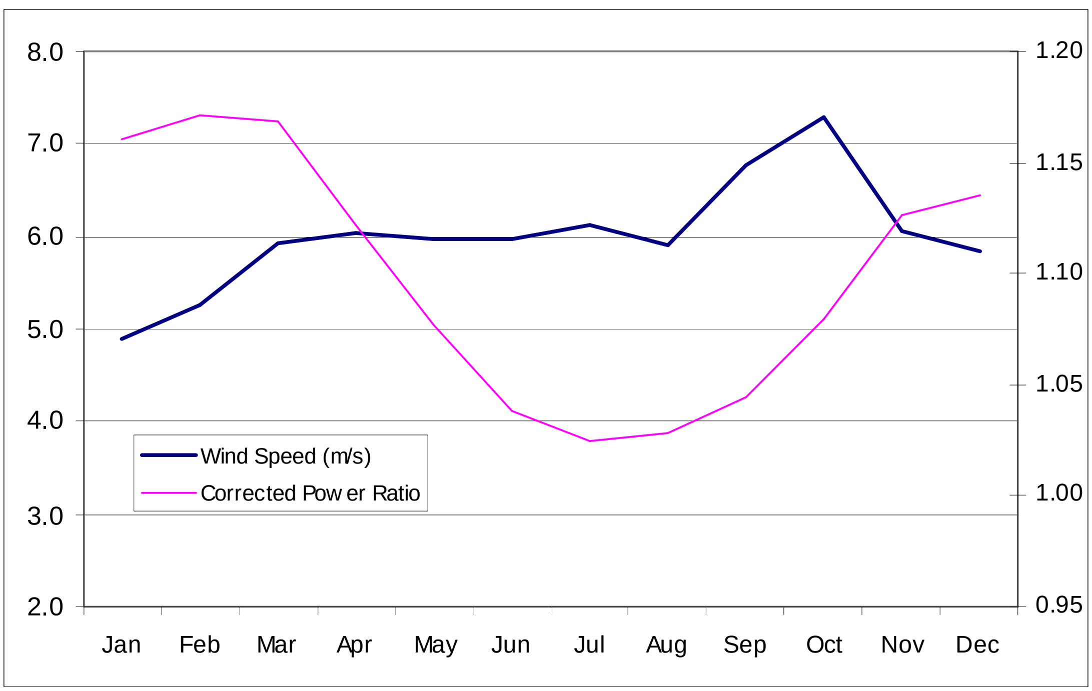

Figure 6: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the left side and the air density to the right.

Conclusions and Recommendations

The wind monitoring site west of the Hamlet is relatively far from the power line. It is also lower in elevation than the original wind turbine site. The anemometer at the turbine site shows higher wind speeds suggesting that this site may still be a better candidate as it is more elevated and more exposed to the dominant southeast winds.

Another area should perhaps be explored; this area is 1 to 1.5 km east of the wind turbine site in what looks like a gravel quarry. The site is about 1 km from the nearest power line. Concerns had been raised about the proximity of tower near the airport. A dedicated lighting system might alleviate this problem and should be discussed with the airport authorities.

Figure 7: Proposed new site for wind monitoring.

Appendix D – Tuktoyaktuk

Progress Report for Wind Energy Monitoring in Tuktoyaktuk, NWT

Summary

The long term wind speed in Tuktoyaktuk was projected to be 5.05 m/s at 30 m above ground level (AGL) using the 2001 to 2006 airport data as a baseline . The measurements were made in a flat field just east of the sewage lagoon south of the Hamlet. The predominant wind directions were from the west-northwest and also from the east.

A new site is recommended for further wind resource assessment studies for wind development. This new site is more exposed to prevailing winds and will likely experience higher average wind speeds.

Site Description

The wind monitoring station began collecting data on 26 May, 2006. The 30 m tower was erected in a field east of the sewage lagoon at the south end of the Hamlet (Figure 1). The site is four kilometres south of the air strip centre and is two kilometres along the access road from the nearest power line that serves residences at the south end of the Hamlet (Figure 2). The site is accessible by road and sits in a field near a shooting range.

The tower is 30 m tall and has a wind speed sensor at each of 10, 20, and 30 m, a wind vane at 30 m, and a temperature sensor at approximately two metres. The site elevation is approximately four metres above sea level (ASL). The ground is sandy clay in the tundra. There is a small hill 100 m to the northwest of the tower. The hill is approximate 10-15 m high and may act as an obstruction to the northwest winds that are measured by the airport.

Figure 1: View of the wind monitoring station facing towards the south.

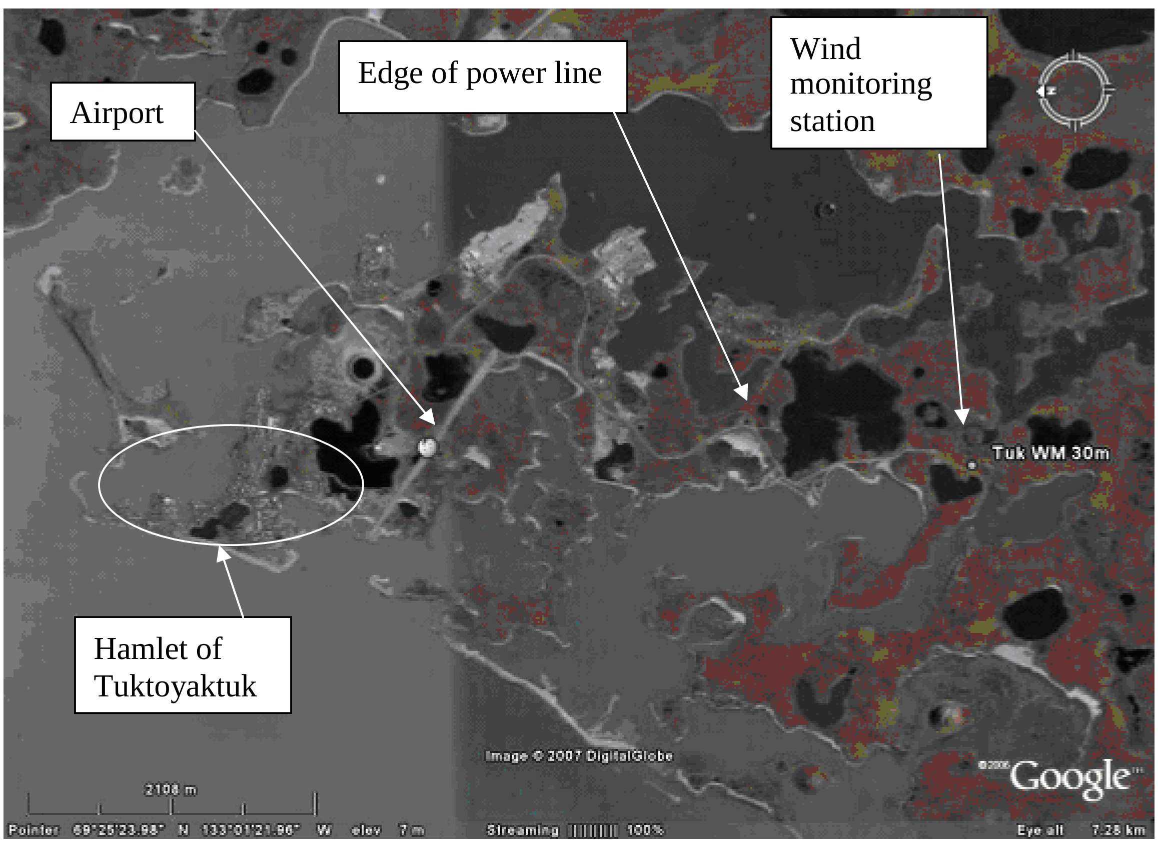

Figure 2: Satellite image of the area around Tuktoyaktuk. Note that North is to the left.

Data Analysis

Wind Direction

Both wind monitoring stations show two dominant wind modes: the largest from the west-northwest, and a second from the east (Figure 3).

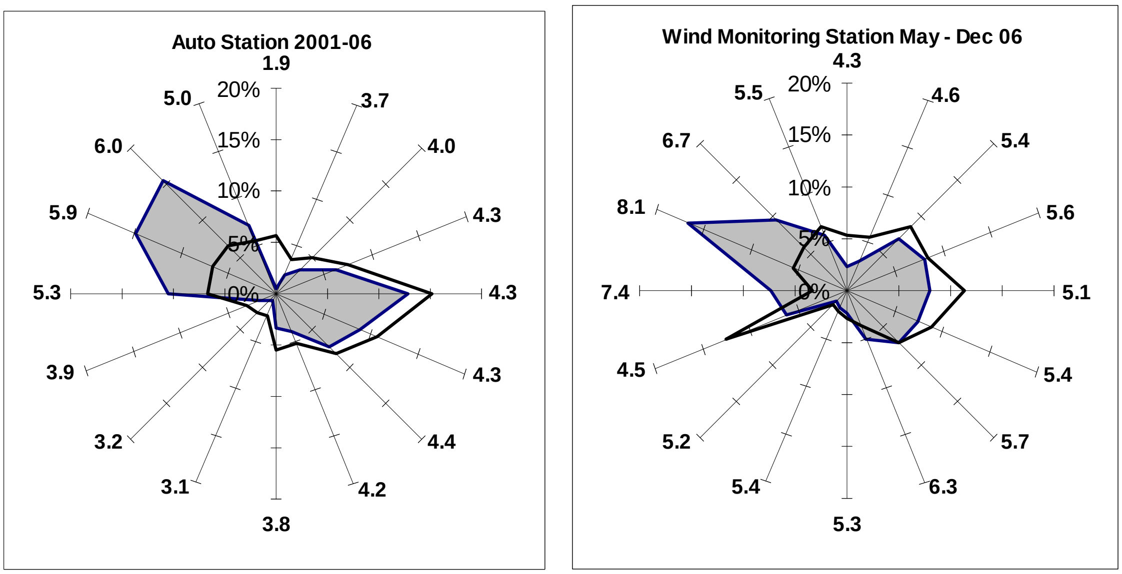

Figure 3: Wind roses for the airport and the 30 m wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

Wind Speed

Both the airport and the wind energy monitoring stations were analyzed and compared. The wind monitoring (WM) sensors have an excellent correlation with the airport measurements with an r value of 0.93. Icing may occur occasionally at this site. During the period of measurement about 3 % of the wind conditions were reported to be calm, some of this period may be attributed to icing. By eliminating the calm period accounts for an increase of 1 % in the wind monitoring station mean wind speed. This correction will be ignored and not applied to the following calculations.

The mean wind speed at the wind monitoring site is about 10 % higher (10 m) than the airport (Table 1). The six-year average at the airport is 92 % of the May-Dec 2006 average so the wind speeds measured at the wind monitoring site should be proportionally less when projected to a long term mean. The long term annual mean wind speed at the wind monitoring site is estimated to be 5.05 m/s at 30 m AGL and 5.44 m/s at 60 m AGL (based on 2001 to 2006 airport data). A surface roughness of 0.004 m (snow surface) was applied in the vertical projection.

Table 1: Wind speed calculations for the airport and the wind monitoring sites.

Location and measurement period	Height	Wind speed	
Tuktoyaktuk Airport 26 May 06 to 31 Dec 06	10 m AGL	4.64	m/s
WM 26 May 06 to 31 Dec 06	10 m AGL	4.89	m/s
	20 m AGL	5.27	m/s
	30 m AGL	5.47	m/s
Tuktoyaktuk A 2001-06 average	10 m AGL	4.25	m/s
Ratio of 6-year to May-Dec 06 means		0.92	
WM wind projected to 2001-06 at	10 m AGL	**4.43**	m/s
	20 m AGL	**4.82**	m/s
	30 m AGL	**5.05**	m/s
	40 m AGL	**5.21**	m/s
	50 m AGL	**5.34**	m/s
	60 m AGL	**5.44**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2). A graphical representation of the wind monitoring station wind speed and the corrected power ratio is shown (Figure 4). The wind speed for the monitoring station (the unheated 30-m tower at the west end) is projected to 30-m AGL using a multiplier of 1.19 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001-2006. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.19.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	4.04	4.80	-25.9	101.8	1.43	1.17
February	4.02	4.78	-26.3	101.9	1.44	1.17
March	3.72	4.42	-25.5	102.4	1.44	1.18
April	4.19	4.98	-15.2	101.8	1.38	1.12
May	4.35	5.18	-3.5	101.8	1.32	1.07
June	4.44	5.28	6.1	101.5	1.27	1.03
July	4.72	5.62	10.5	101.1	1.24	1.01
August	4.39	5.22	8.8	101.2	1.25	1.02
September	4.68	5.57	4.1	101.0	1.27	1.04
October	4.49	5.34	-5.3	101.1	1.32	1.07
November	3.89	4.63	-18.6	101.5	1.39	1.13
December	3.73	4.44	-21.6	101.2	1.40	1.14
Annual	4.25	5.05	-9.3	101.5	1.34	1.09

The highest monthly mean wind speed is 5.62 m/s in July with a sustained average of above 5 m/s from April to October (Figure 4). The drop in the wind speed from November to March can be attributed to the high atmospheric stability, since these are the months coinciding with the lowest temperatures. The corrected power ratio increases to a maximum of 1.18 in March and diminishes to 1.01 in July. Mean annual corrected power ratio is 1.09.

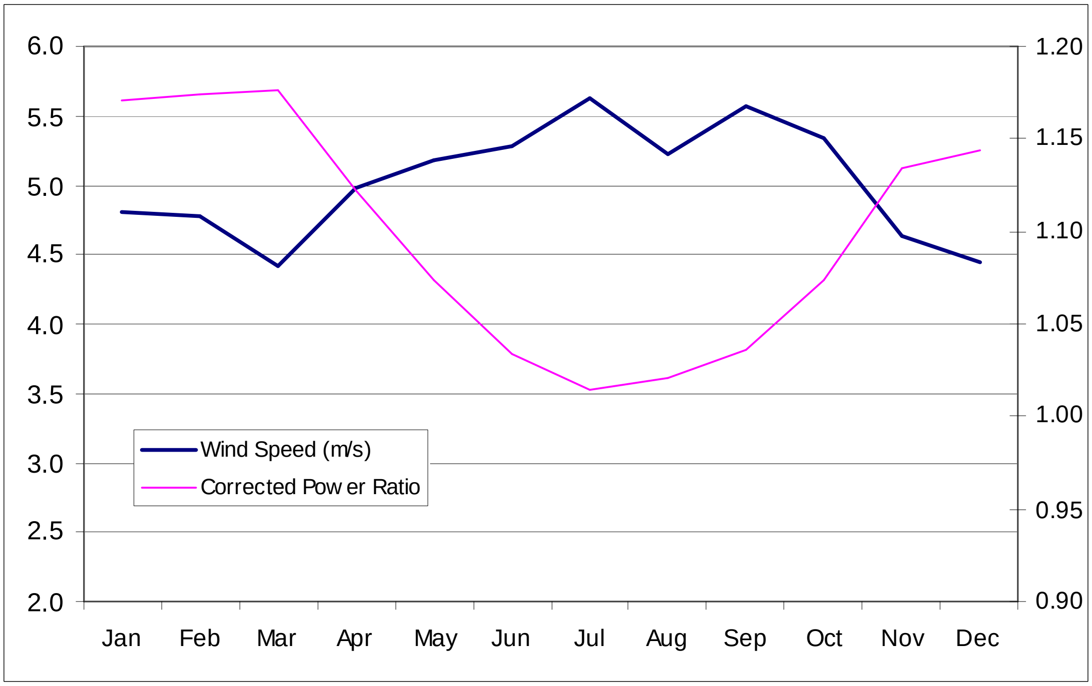

Figure 4: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the left side and the air density to the right.

Recommendations

The wind energy potential in Tuktoyaktuk is marginal but could be examined further. The community has a rather large energy load, winter road access and local heavy equipment, and trained local personnel, which would give it an advantage over the other Inuvialuit communities. Further monitoring should be carried out. Given that the predominant of the two major wind directions is from the west-northwest, it may be wise to move the tower north of the present site to another location (Figure 5 and 6). This proposed new site has high exposure over the smooth water surface to both predominant west-northwest and easterly winds. Moving the tower to this new site may show that the mean wind speed is 0.5 m/s higher at this location.

Approval from NavCan and the Hamlet is required before moving forward with the proposed new site.

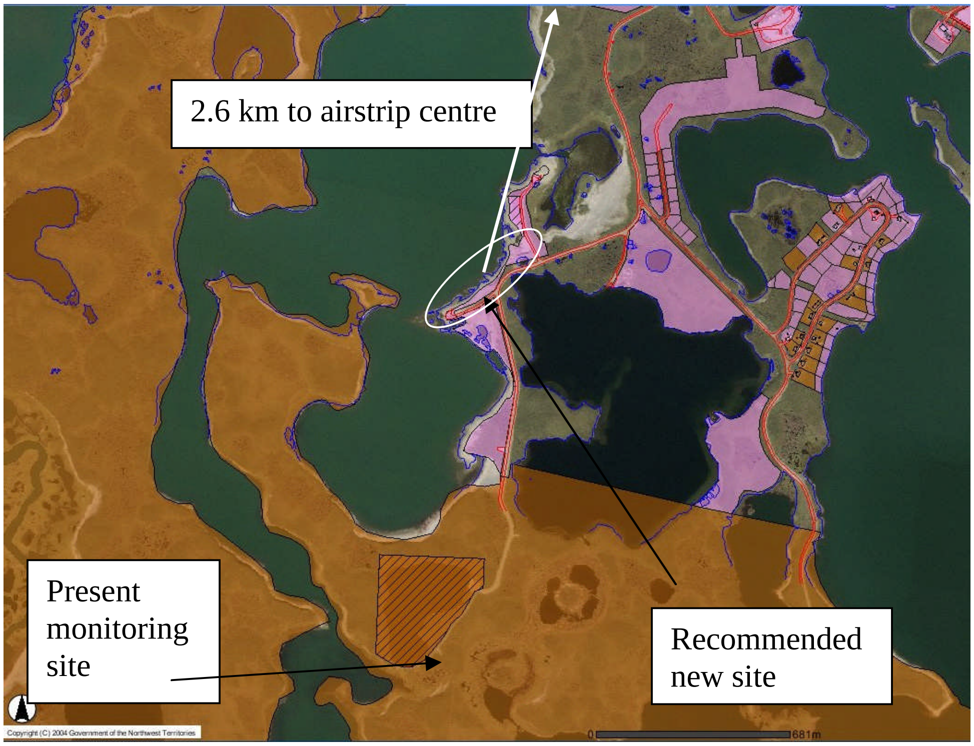

Figure 5: Map showing a recommended new site for further wind monitoring.

Figure 6: Close-up of the site of interest. The pink parcel is Commissioner's land.

Appendix E – Ulukhaktok

Progress Report for Wind Energy Monitoring in Ulukhaktok, NWT

Summary

The long term wind speed in Ulukhaktok was projected to be 6.57 m/s at 30 m above ground level (AGL) using the 2001 to 2006 airport data as a baseline. The measurements were made on a high ridge just east of the Hamlet and the predominant winds were from the east-southeast.

The site is recommended for further studies for wind development. Studies into road access and/or a more accessible site are recommended.

Site Description

The wind monitoring station began collecting data on 22 May, 2006. The 30 m tower was erected on a ridge to the east of the Hamlet (Figure 1). The site is 3.9 km east-southeast of the air strip centre and is 1.2 km from the power line that runs to the pump house (Figure 2). The site is not accessible by any existing road, however is accessible in the winter by snow machine via a 5 km long round-about route starting from the pump house north of the Hamlet

The tower is 30 m tall and has a wind speed sensor at each of 10, 20, and 30 m, a wind vane at 30 m, and a temperature sensor at approximately 2 m. The site elevation is approximately 183 m above sea level (ASL).. The ground is smooth bare fractured bedrock that is mostly intact.

Figure 1: View of the wind monitoring station facing towards the south-southeast.

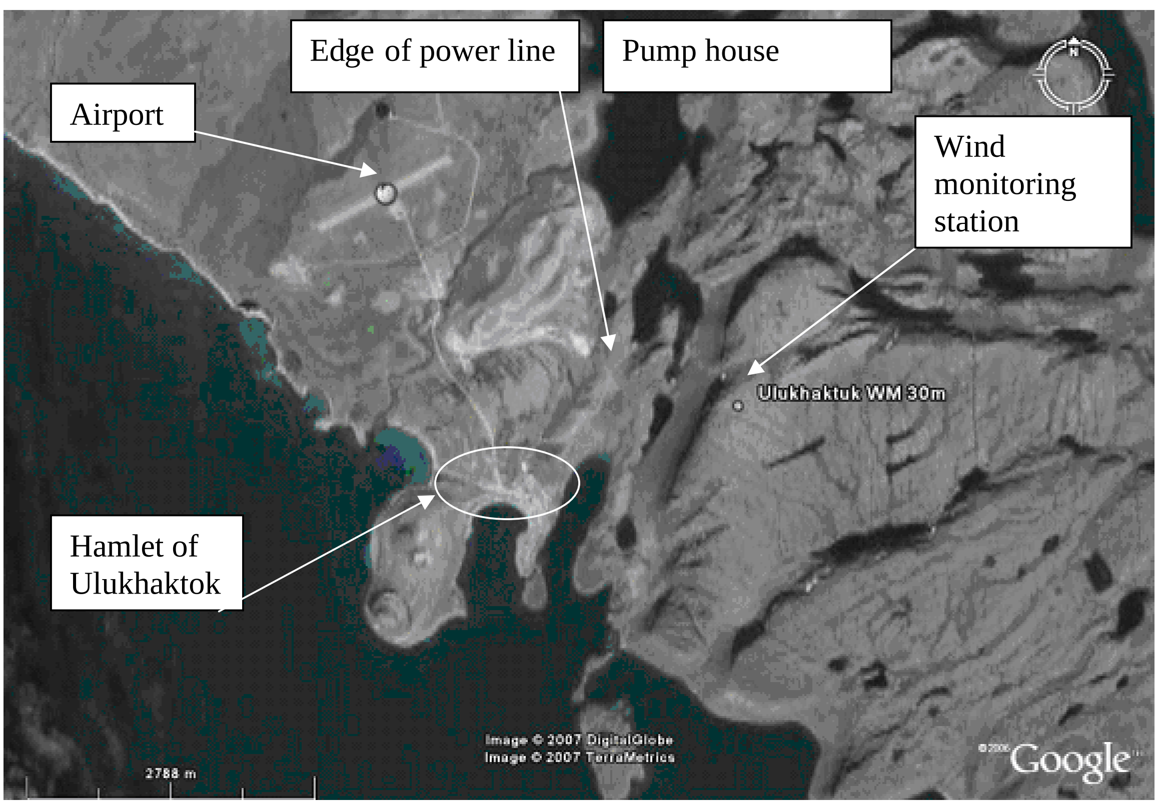

Figure 2: Satellite image of the area around Ulukhaktok .

Data Analysis

Wind Direction

The predominant wind at the airport is from the east whereas on the east ridge it is east-southeast (Figure 3).

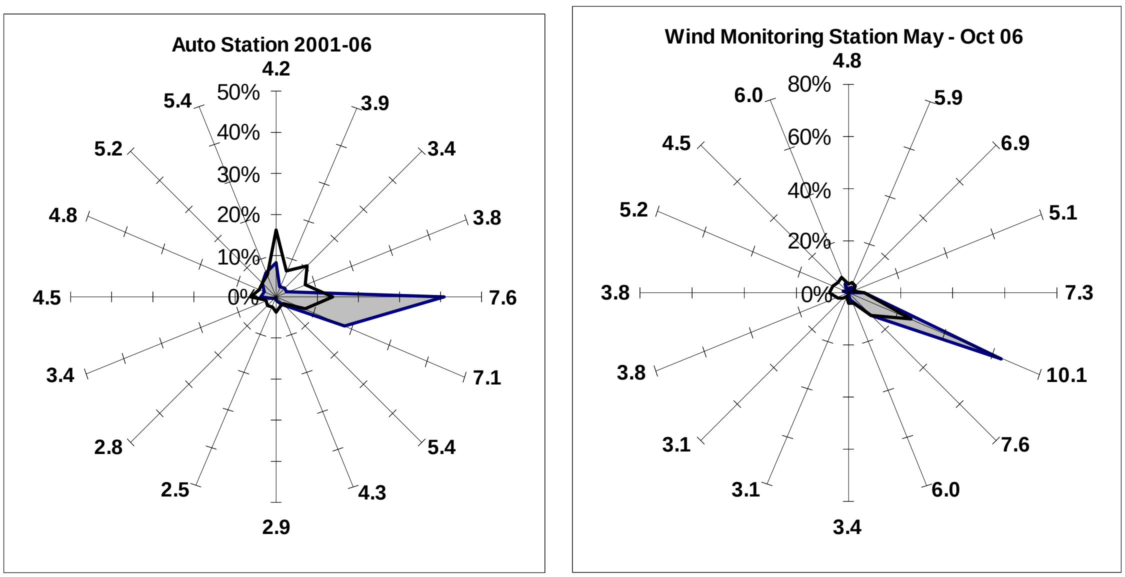

Figure 3: Wind roses for the airport and the 30 m wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

Wind Speed

Both the airport and the wind energy monitoring stations were analyzed and compared (Table 1). The wind monitoring sensors have an excellent correlation with the airport measurements and an r value of 0.85. Icing may occur occasionally at this site. For the period of measurement about 4 % of the wind conditions were reported to be calm, a minority of this period may be attributed to icing. By eliminating the calm period accounts for an increase of 2 % in the wind monitoring station mean wind speed. This correction will be ignored and not applied to the following calculations.

The wind speed average at the wind monitoring site is about 30% higher (10 m) than the airport. The six-year average at the airport is the same as the May-October 2006 average so the wind speeds measured at the wind monitoring site should be similar to the 2001-2006 mean. The long term annual mean wind speed at the east ridge site is estimated to be 6.57 m/s at 30 m AGL and 6.97 m/s at 60 m AGL. A surface roughness of 0.0003 m was used to fit the vertical profile to the 20-m and 30-m wind speeds.

Table 1: Wind speed calculations for the airport and the wind monitoring sites.

Location and measurement period	Height	Wind speed	
Ulukhaktok Airport 2 May 06 to 21 Oct 06	10 m AGL	4.77	m/s
East Ridge WM 2 May 06 to 21 Oct 06	10 m AGL	6.22	m/s
	20 m AGL	6.36	m/s
	30 m AGL	6.55	m/s
Ulukhaktok A 2001-06 average	10 m AGL	4.79	m/s
Ratio of 2005-06 to 6-year mean		1.00	
East Ridge WM wind projected to 2001-06 at	10 m AGL	**5.94**	m/s
	20 m AGL	**6.34**	m/s
	30 m AGL	**6.57**	m/s
	40 m AGL	**6.74**	m/s
	50 m AGL	**6.86**	m/s
	60 m AGL	**6.97**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2). A graphical representation of the wind monitoring station wind speed and the power ratio is shown (Figure 4). The wind speed for the monitoring station is projected to 30-m AGL using a multiplier of 1.37 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001-2006. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.37.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	4.24	5.82	-26.6	101.3	1.43	1.17
February	3.92	5.38	-28.8	101.6	1.45	1.18
March	4.02	5.52	-26.3	101.7	1.44	1.17
April	5.08	6.97	-17.3	101.6	1.38	1.13
May	4.81	6.60	-6.7	101.5	1.33	1.08
June	4.60	6.31	3.7	101.1	1.27	1.04
July	4.05	5.55	7.5	100.7	1.25	1.02
August	4.25	5.83	6.1	100.8	1.26	1.03
September	5.27	7.23	1.9	100.8	1.28	1.04
October	5.96	8.18	-7.8	100.9	1.32	1.08
November	5.71	7.84	-18.1	101.1	1.38	1.13
December	5.31	7.28	-22.6	100.9	1.40	1.15
Annual	4.79	6.57	-11.2	101.2	1.35	1.10

The highest monthly mean wind speed is 8.18 m/s in October with a sustained average of over 6 m/s from September to December and April to June. The drop in the wind speed in January to March may be due to high atmospheric stability, coinciding the months with the lowest temperatures. The corrected power ratio increases to a maximum of 1.18 from in February and diminishes to 1.02 in July.

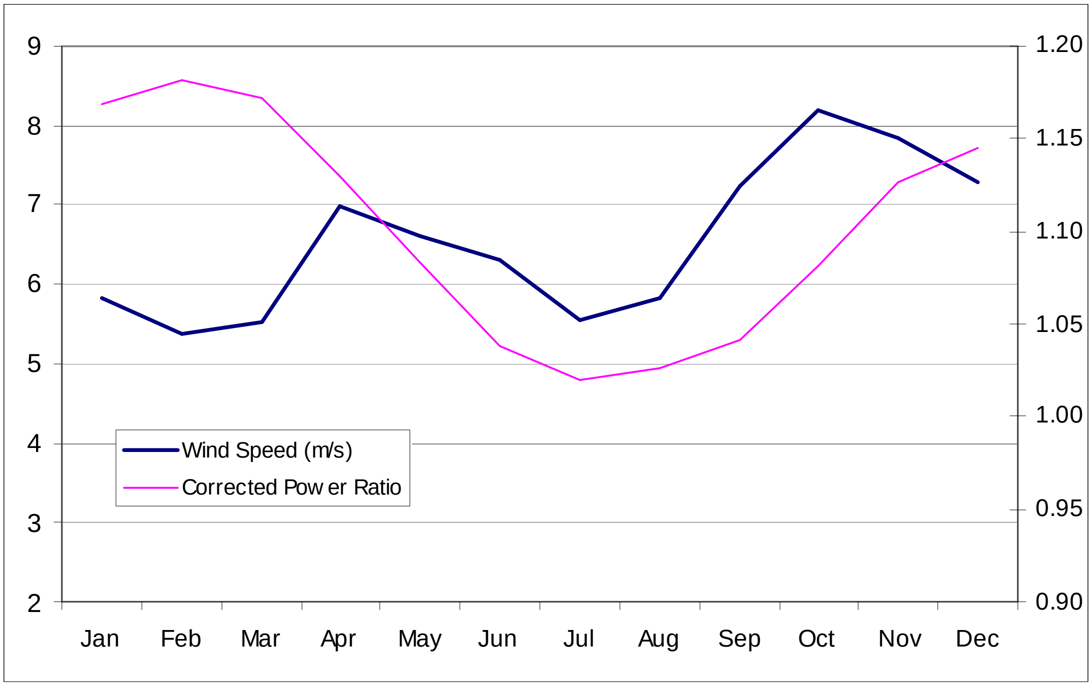

Figure 4: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the right side and the air density to the left.

Recommendations

This site is relatively difficult to access from the Hamlet. A road will be required unless all equipment can be moved by helicopter. Without a road however it will be difficult to maintain the equipment.

Another alternative is to place the tower on a small hill by the landfill, however this location is too close to the airport and may not pass NavCan approval. The peninsula just southwest of the Hamlet is also a possibility, it is road accessible and within one kilometre from the grid.

Further consultation with the hamlet and a development consultant is recommended. The wind monitoring should continue to a full year and could be moved to a more accessible site should the present one prove to be unfeasible. The wind monitoring tower should be left at the site to confirm the wind speed and to become a permanent wind monitoring station for a future wind farm.

Appendix F – Yellowknife

Progress Report for Wind Energy Monitoring in Yellowknife, NWT

Summary

The long term wind speed at the Yellowknife Jackfish telecommunications tower was projected to be 4.37 m/s and 4.98 m/s at 30 and 60 m above ground level (AGL) respectively using the 2001 to 2006 airport data as a baseline. The measurements were made from the Jackfish telecommunication tower north of downtown. The predominant wind directions there were estimated to be from the north-northwest and the south-southeast. The wind speeds at this site are considered less than marginal. Sites on hill tops in the greater Yellowknife region are recommended if further wind monitoring is desired.

Site Description

The wind monitoring station began collecting data on 11 July, 2006. The sensors were installed on a telecommunications tower just north of downtown Yellowknife (Figure 1). The site is 3.3 km east-northeast of the air strip centre and is near a power line that serves the community (Figure 2). The site is accessible by road.

The wind sensors are located at elevations of 10, 20 and 38 m, the wind vane is at 38 m, and a temperature sensor is at approximately two metres. The site elevation is approximately 200 m above sea level (ASL).

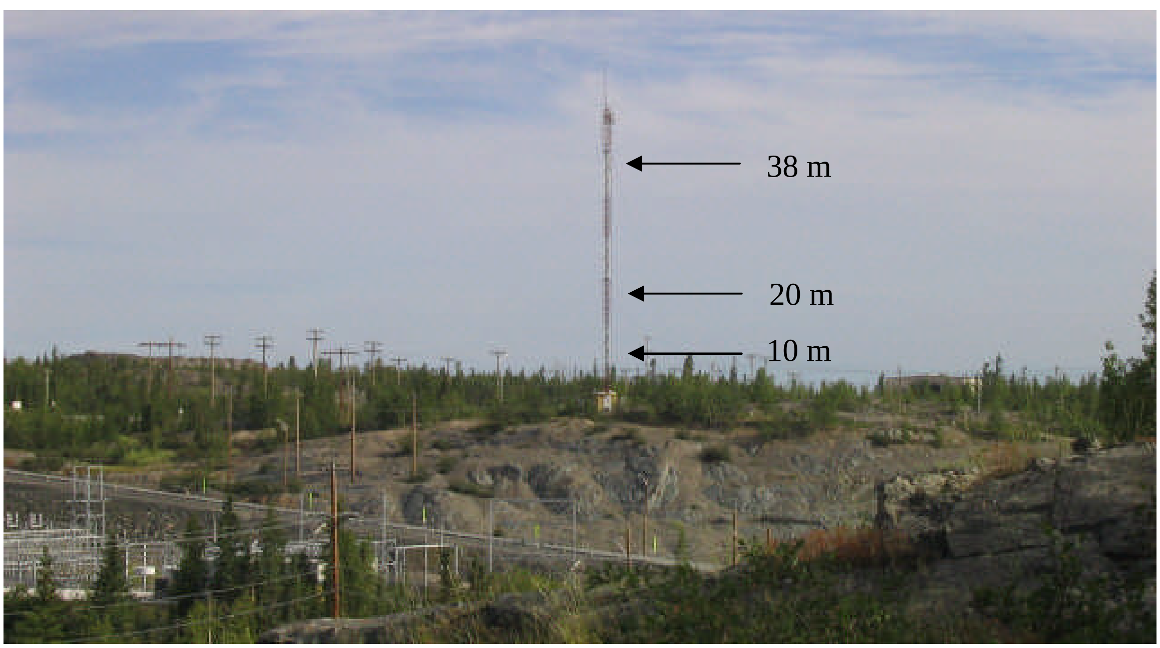

Figure 1: View of the wind monitoring station facing towards the north. Electric facilities for NTPC are located to the left of the tower.

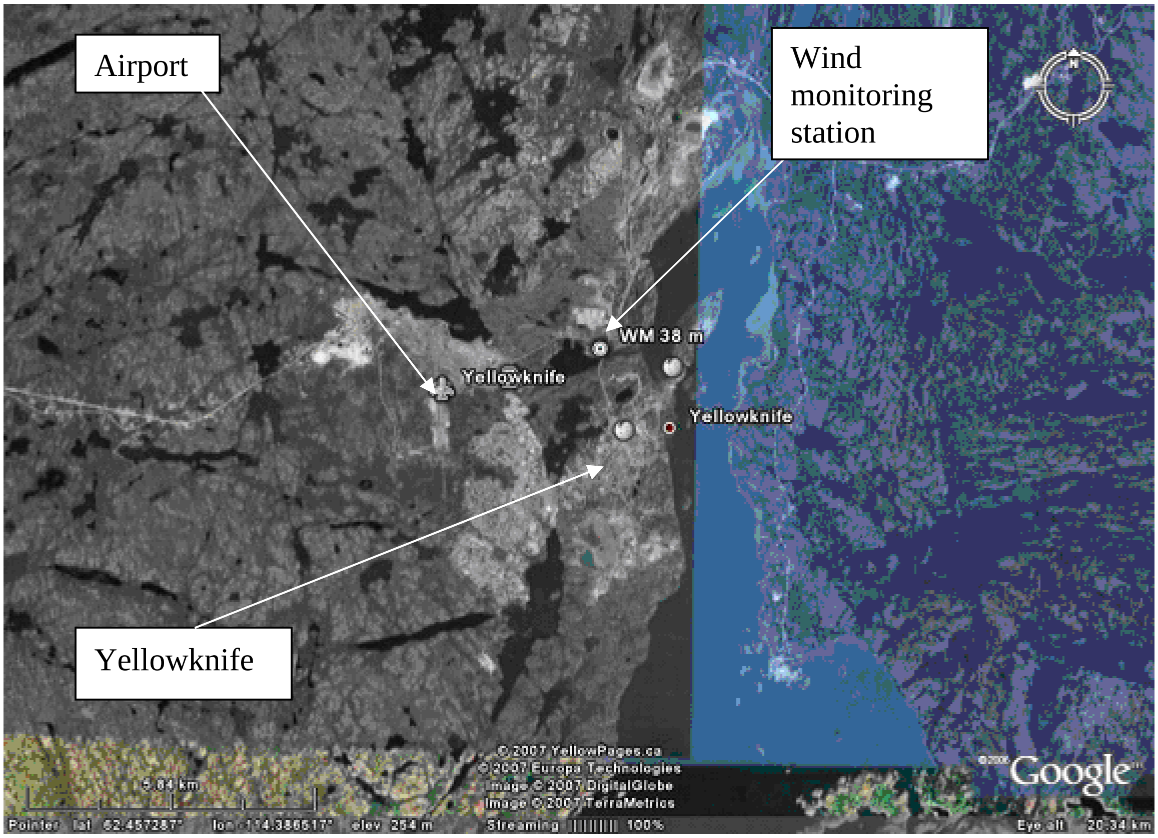

Figure 2: Satellite image of the area around Yellowknife.

Data Analysis

Wind Direction

The airport station shows dominant wind energy modes from the east, from south-southeast, and from the northwest (Figure 3) . The wind monitoring station shows predominant winds from the north-northwest and the south-southeast.

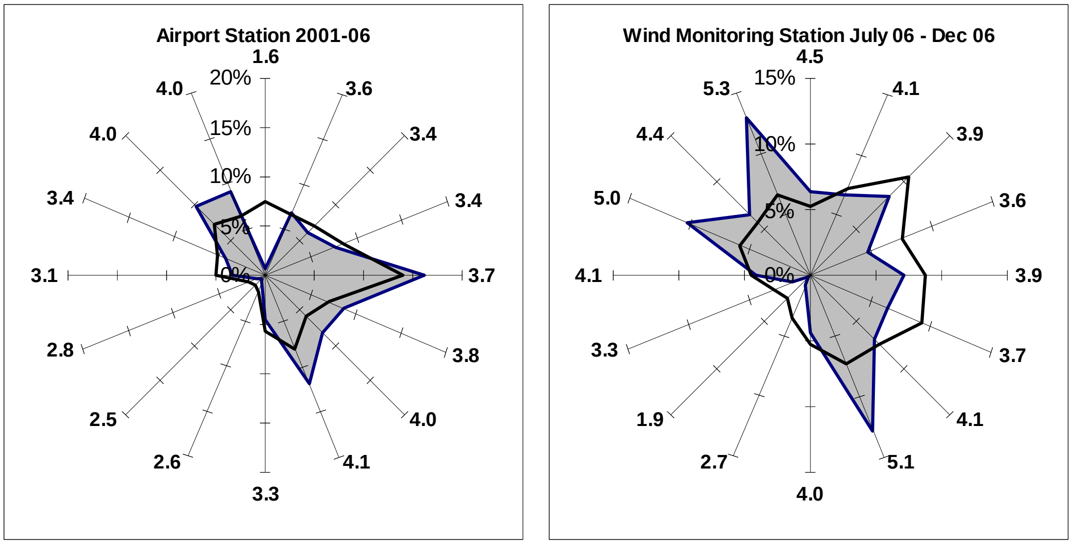

Figure 3: Wind roses for the airport and the Jackfish 38 m wind monitoring station. The shaded area represents the relative wind energy and the transparent outline represents the wind frequency of occurrence. The outer numbers are the average wind speeds in each direction sector.

Wind Speed

Both the airport and the wind energy monitoring stations are analyzed and compared. The wind monitoring (WM) sensors have a correlation with the airport measurements with an r value of 0.80. Icing may occur occasionally at this site. For the period of measurement about 7 % of the wind conditions were reported to be calm, a minority of this period may be attributed to icing. By eliminating the calm period accounts for a increase of 3 % in the wind monitoring station mean wind speed. This correction will be ignored and not applied to the following calculations.

The mean wind speed at the wind monitoring site is 4 % higher (projected down to 10 m height for comparison) than the airport (Table 1). The six-year average at the airport is 112 % of the July-Dec 2006 average so the wind speeds measured at the wind monitoring site should be proportionally higher when projected to a long term mean. The long term annual mean wind speed at the wind monitoring site is estimated to be 4.37 m/s at 38 m AGL and 4.98 m/s at 60 m AGL using the 2001 to 2006 airport data as a basis. A surface roughness of 0.2 m (sparse short forest.) was applied in the vertical projection.

Table 1: Wind speed calculations for the airport and the wind monitoring sites.

Location and measurement period	Height	Wind speed	
Yellowknife Airport 11 July to 31 Dec 06	10 m AGL	2.93	m/s
Jackfish WM 11 July to 31 Dec 06	10 m AGL	3.06	m/s
	20 m AGL	3.51	
(Ch 2)	38 m AGL	4.02	
(Ch 1)	38 m AGL	4.08	m/s
Yellowknife A 2001-06 average	10 m AGL	3.29	m/s
Ratio of 6-year to July-Dec 06 means		1.12	
WM wind projected to 2001-06 at	10 m AGL	**3.41**	m/s
	20 m AGL	**4.02**	m/s
	30 m AGL	**4.37**	m/s
	38 m AGL	**4.58**	m/s
	50 m AGL	**4.82**	m/s
	60 m AGL	**4.98**	m/s

Monthly and annual means of wind speed, temperature, pressure, air density, and power correction ratio based on the 2001 to 2006 airport data are listed (Table 2). A graphical representation of the wind monitoring station wind speed and the corrected power ratio is shown (Figure 4). The wind speed for the monitoring station (the unheated 30-m tower at the west end) is projected to 30-m AGL using a multiplier of 1.33 times the monthly mean of the airport. This multiplier is the ratio between the simultaneous measurements of the airport and the 30-m wind speed. The temperature and pressure are measured and the density is calculated from the two values. The corrected power ratio is a ratio of the calculated density and the standard density of 1.225 kg/m^3 used in turbine power curve generation. The equations are given and discussed in the executive report.

Table 2: Monthly mean values based on airport station for the period 2001- 2006. The wind monitoring station monthly mean wind speed are projected from the airport values times 1.33.

	Wind Speed (m/s)		Temperature	Pressure	Density	Corrected
	Airport(10m)	WindStn(30m)	(°C)	(kPa)	(kg/m^3)	Power Ratio
January	2.45	3.25	-24.3	99.1	1.39	1.13
February	2.80	3.72	-22.4	99.3	1.38	1.13
March	3.46	4.59	-16.7	99.3	1.35	1.10
April	3.67	4.88	-5.0	99.1	1.29	1.05
May	3.82	5.07	3.3	99.1	1.25	1.02
June	3.38	4.49	13.5	98.9	1.20	0.98
July	3.29	4.37	16.9	98.6	1.18	0.97
August	3.43	4.55	13.4	98.7	1.20	0.98
September	3.52	4.67	7.8	98.6	1.22	1.00
October	3.54	4.70	-1.1	98.7	1.26	1.03
November	3.37	4.48	-12.5	98.7	1.32	1.08
December	2.76	3.67	-17.8	98.6	1.34	1.10
Annual	3.29	4.37	-3.7	98.9	1.28	1.04

The highest monthly mean wind speed is 5.07 m/s (at 30 m AGL) in May with a sustained average of above 4 m/s from March to November (Figure 4). The drop in the wind speed in December to February can be attributed to the high atmospheric stability, since these are the months with the lowest temperatures. The corrected power ratio increases to a maximum of 1.13 in January-February and diminishes to 0.97 in July. Mean annual corrected power ratio is 1.04.

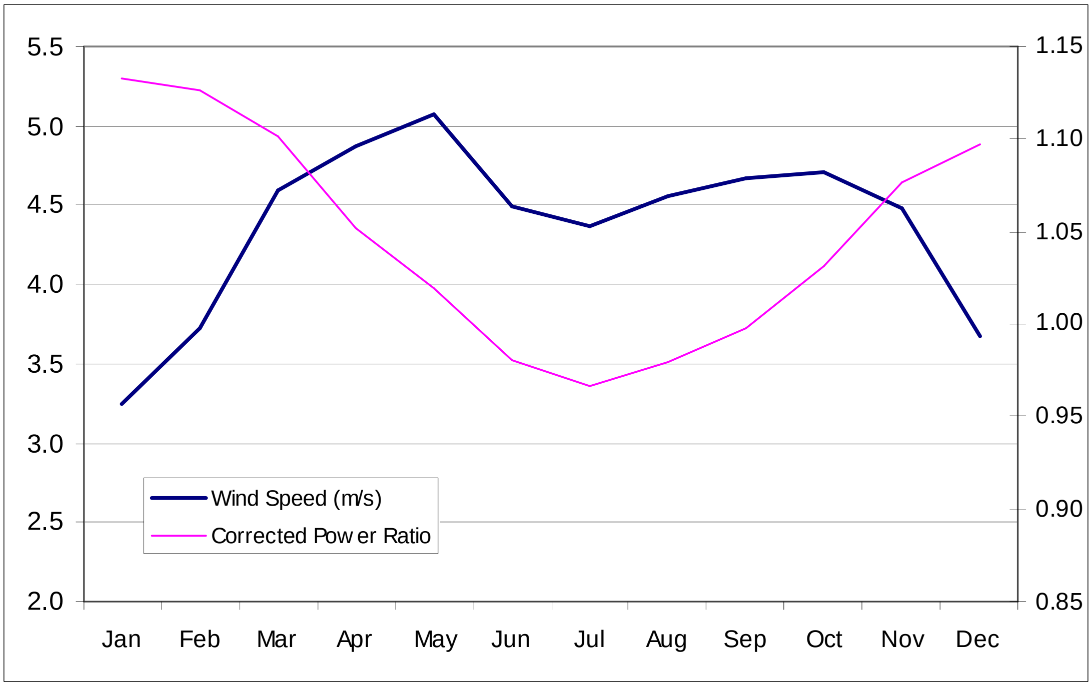

Figure 4: Monthly means of air density and wind speed based on the six-year airport data projected to 30-m AGL. The wind speed is referenced to the right side and the air density to the left.

Recommendations

The measurements to date indicate that the wind climate in this area is less than adequate for develop of wind energy with the present technology.

If further wind exploration is desired, the new locations should be selected for good exposure to the predominant winds. Those would be sites that are on hills that are perpendicular to the southeast and northwest where the predominant winds occur, and relatively near the grid. These hills should be more than 100 m above the surrounding height of land.

According to Canada Wind Atlas (www. windatlas.ca) the predicted wind speed in the Yellowknife area is 6.0 m/s at 30 m AGL and 6.4 m/s at 50 m AGL, which is about 1.5

m/s higher than the actual measurements in this project. The wind atlas map is shown below (Figure 5).

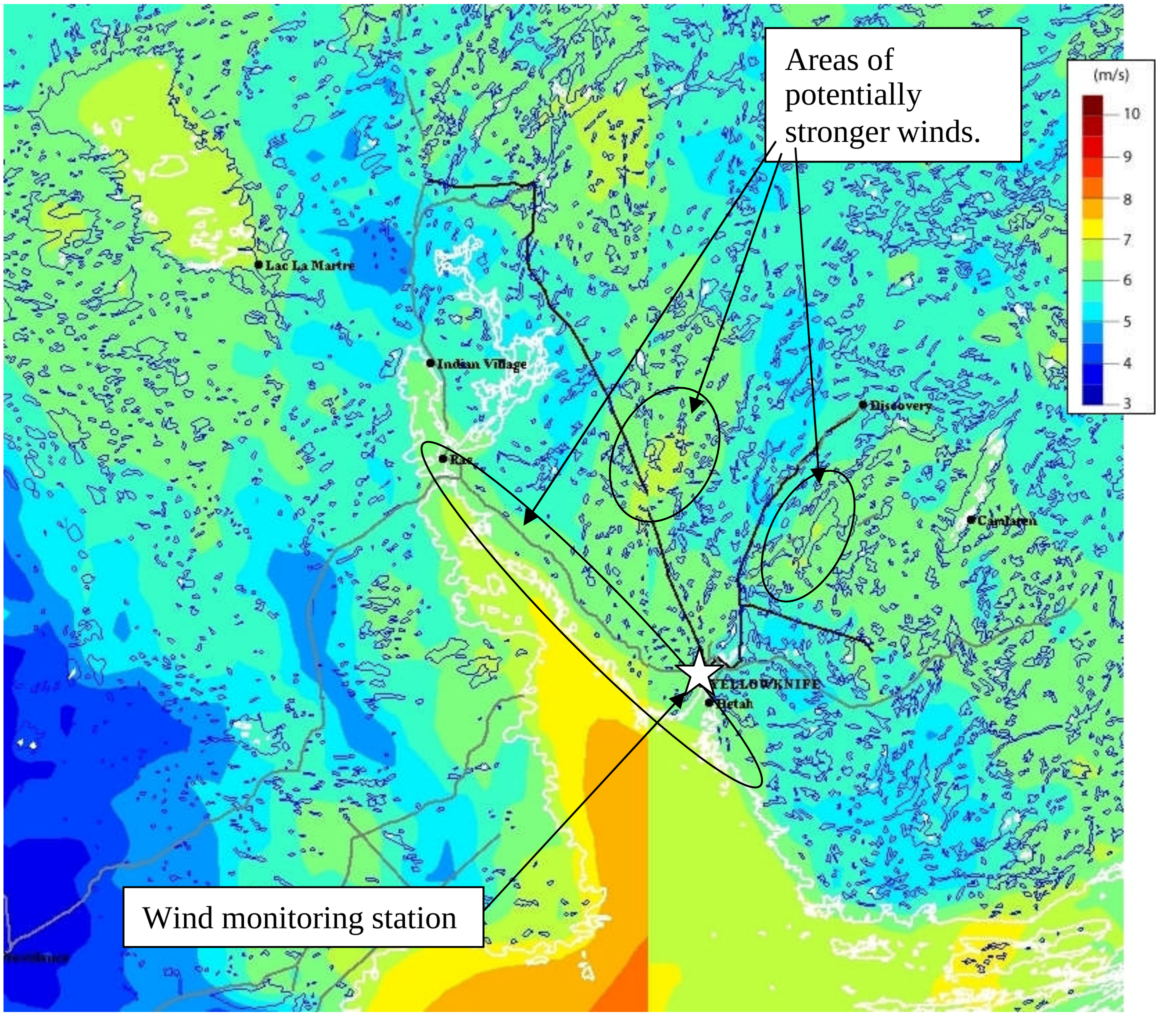

Figure 5: Map from www.windatlas.ca shows modelled mean annual wind speed at 50 m AGL. The map is from two separate simulated regions (with different climate input) that have been stitched together.