AURORA RESEARCH INSTITUTE
AURORA COLLEGE

Wind study for Thor Lake Area

by

Jean-Paul Pinard, P. Eng., Ph.D.
703 Wheeler St., Whitehorse, Yukon Y1A 2P6
Tel. (867) 393-2977; Email jpp@northwestel.net

July 2009

Summary

In April 2009, a wind prospecting visit was made to the Thor Lake exploration camp. Afterwards, a preliminary assessment of the wind energy potential for the area was carried out. Five weather stations and three publically available large-scale wind models were used to predict the average wind speed in the Thor Lake area. A small scale wind flow model was also used to predict the wind speed at a local level.

From the analysis and modeling, a long-term annual average wind speed of 6.6 m/s at 50 m above ground level are predicted to exist at a hill by the Hearne Channel. This site is located about 4 km from the mine site. At 80 m above ground level the winds are expected to be above 7 m/s. These wind speeds are considered quite good for producing wind energy. An economic analysis and a full year of wind measurements will be necessary to confirm this prediction and the viability of wind energy for the Thor Lake mine site.

Introduction

The Thor Lake Rare Metals Project is owned by Avalon Ventures Ltd. and is located in the Mackenzie Mining District of the Northwest Territories (NWT), a few kilometres north of the Hearne Channel of Great Slave Lake and approximately 100 km east-southeast of Yellowknife (see Figure 1). The property is accessible from Yellowknife by float- or ski-plane and summer barge.

The topography is typically Canadian Shield with gently rolling bedrock exposure interlaced with glacial till cover and numerous shallow lakes. Vegetation is dominated by spruce, poplar, and willow.

A mine is expected to be built on the Thor Lake site in the next few years and will employ 100 people. There will be a mine, a mill and a camp and the operation is expected to demand 5 to 10 megawatts (MW) of electric power which will likely come from diesel generators, with possibly hydro and wind energy supplementing this.

For wind energy to be viable, a mean annual wind speed of at least 6 m/s is typically required although much depends on several factors such as power line, turbine, and installation costs. Typically the more expensive it is to ship the diesel fuel to the site the more favourable the economics are for wind energy. From traditional knowledge the dominant easterly winds in the Hearne Channel near Thor Lake are strong and often problematic for boating in the summer, and so there may be a strong case for wind energy development in this area.

On April 17, 2009, an initial wind prospecting visit was made to the Thor Lake exploration camp to inspect the area for potential wind development. Hilltop sites with exposed bedrock by the Hearne Channel shoreline were identified as possible locations for placement of wind monitoring equipment. A local weather station was also identified and located at the north end of the project area.

This study provides an analysis of historical weather and wind climate models which are used to estimate the mean long-term wind speed in the area. Wind flow modelling was performed to identify locations that may have the best wind potential in the Thor Lake area. Recommendations are provided herein.

Figure 1: Great Slave Lake area showing Thor Lake in relation to Yellowknife.

Overview of the Thor Lake Area

The Hearne Channel (Great Slave Lake) is at 157 m above sea level (ASL) and its banks are somewhat steep: over a horizontal distance of 600 m north from the shoreline the land rises to a plateau of about 250 m ASL. From the west side of the Thor Lake area the land gently rises from 234 m ASL at Thor Lake proper to above 290 m ASL at a discontinuous ridge on which forms an arch around the north and eastern edge of the Thor Lake area (Figure 2).

Brochures by Avalon Ventures Ltd. indicate that the proposed locations for the mine site's operations such as the bunk house, the plant site, and the ramp site will be approximately located as identified in Figure 2. A wind farm development ideally should be located within a few kilometres of these facilities where the electrical load will be located.

Accompanied by Senior Geologist Chris Pedersen (Avalon) and Wade Carpenter (Environment and Natural Resources, Government of the NWT), the author visited the weather station at the north end of the Thor Lake area. The group also travelled onto the ice of the Hearne Channel to view the land along the shoreline, where it was proposed the best winds may be located. From the ice ("Viewpoint" in Figure 2) we were able to identify clearings to the east of the trail that leads along parallel to the shore. Due to collapsing deep snow conditions we were only able to travel as far east as the "farthest site visited" in Figure 2. The high ground of interest for wind development is Site #1 about 800 m east of this visited location.

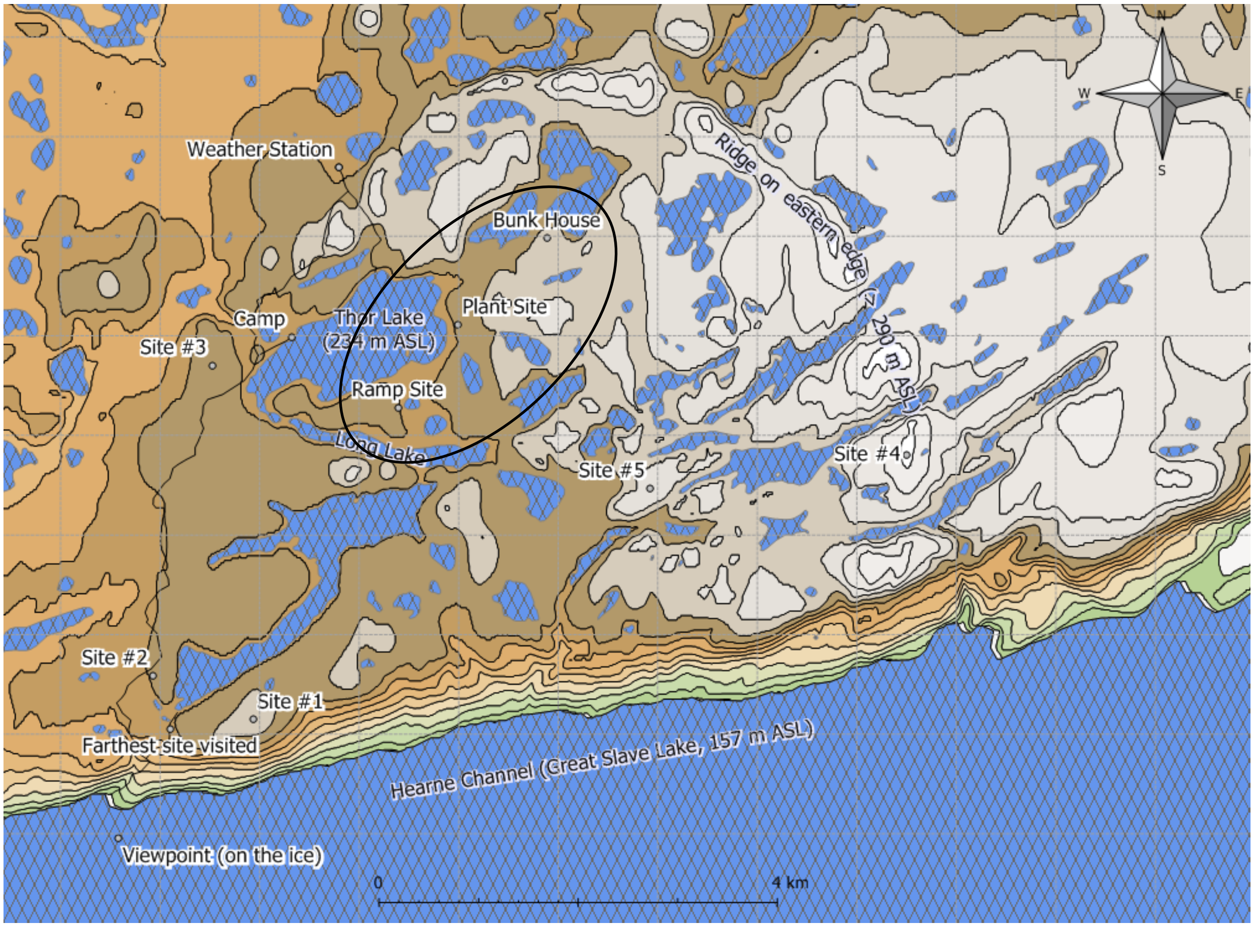

Figure 2: Topography of the Thor Lake area showing locations of potential mine (oval). The contours are at 10-metre intervals starting at 160 m above sea level (ASL) at the Hearne Channel shoreline, the channel is at 157 m ASL. The contours reach a maximum height of 290 m ASL.

Description of the Regional Weather Stations

Wind data from five weather stations are used for this study. The weather stations at Inner Whalebacks, Lutselk'e, Yellowknife, and Fort Resolution are known to measure wind speed and direction at the standard height of 10 m above the ground. The locations of these stations are shown in Figure 3. Inner Whalebacks is on a small island about 12 km west of shoreline, out on the open waters of the main body of the Great Slave Lake. The station is directly west of the mouth of the Hearne Channel.

According to Environment Canada (EC), the station at Lutselk'e is about 200 m north of the local airstrip. On Google Earth this ends up in the forest north of the airstrip (not likely the case). The station is probably in an open field near the airport terminal buildings. Interestingly, the land just east of the Lutselk'e station consist of a ridge that rises to at least 60 m above the station's ground surface. This would effectively reduce wind speeds (from dominant easterly winds as shown later) experienced at the station. At Yellowknife there are two stations: one is located at the airport in an open field and the other is at the Jackfish Lake communications tower owned by NTPC. The data from these two stations were analysed in Pinard and Maissan (2008). At Fort Resolution the weather station is likely near the airport buildings that are at the southeast end of the northwest oriented airport in the community. The area surrounding the community is generally flat rising to a maximum of about 10 m above the lake level.

The wind data from these Environment Canada weather stations are hourly data that are downloadable in monthly files from their website. For most weather stations, the hourly wind data is available to at least 10 years back from present. The possible errors in the measurements are considered to be within 2 % or about 0.1 m/s. Based on previous studies (Pinard 2007) these EC weather stations (the automated and climate stations in particular) are reasonably accurate and representative of their surrounding region if it is relatively flat (relief < 10 m). Where the terrain becomes hilly the surrounding area that the station's wind measurements accurately represent becomes considerably small. In this case, measurements and small scale wind flow modelling become important tools in projecting mean wind speed to nearby locations of interest.

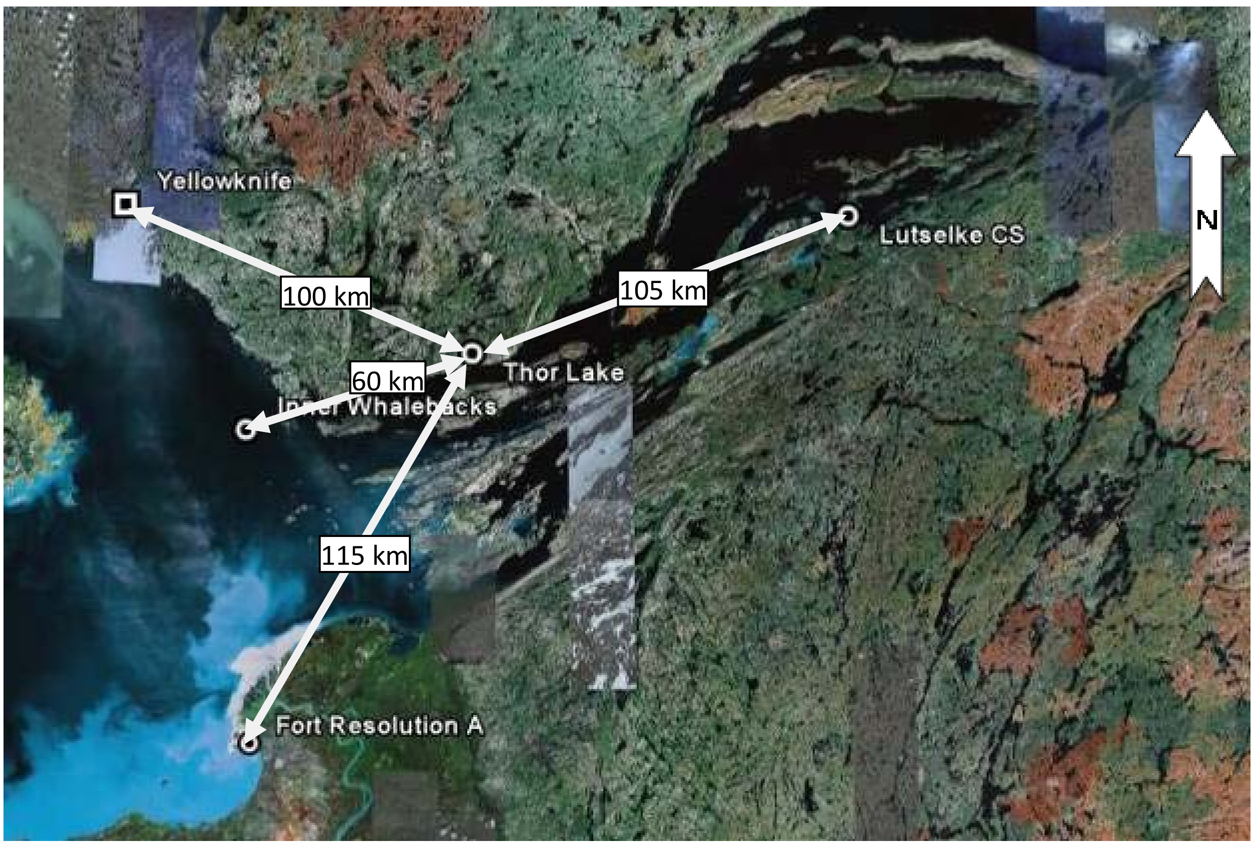

Figure 3: Satellite image (Google Earth) of the eastern Great Slave Lake showing Thor Lake in relation to Yellowknife and three other locations (Inner Whalebacks, Lutselk'e, and Fort Resolution) where weather stations exist.

The fifth weather station is at Thor Lake (see Figure 4) and is equipped with a wind sensor on a tower that is approximately 5.1 m tall. This station is located in a lightly forested depression that is overshadowed by a hill to the east. The wind measurements from this station will not be weighted upon very heavily as the status of calibration of the wind instruments were unknown to the author at the time of writing and the data that was made available from this station only covered about nine months, which is less than the one-year limit required to properly assess this data set.

Figure 4: Weather station at the north of the Thor Lake area. The view is looking towards the east-southeast.

Wind Climate of the Hearne Channel Region

The hourly data for the four community airport weather stations were downloaded from the Environment Canada website for the period of 2004-2008. From that data the 5-year (2004-08) average wind speed at 10 m above ground level (AGL) was 3.24 m/s at Lutselk'e, 6.71 m/s at Inner Whalebacks, and 3.55 m/s at Fort Resolution. In Yellowknife the airport's long-term (1998-2007) mean was 3.28 m/s and at the Jackfish Lake tower it was 3.62 m/s (both at 10 m AGL).

The prevailing wind direction at Inner Whalebacks was easterly (from the east) whereas at Lutselk'e it was east-northeast to easterly (Figure 5). At Fort Resolution the winds were from the northwest and the southeast (Figure 6), parallel to the main shoreline of Resolution Bay. At Yellowknife the dominant winds were from the east, however lesser components came from the northwest and the south-southeast.

The weather monitoring station at Thor Lake revealed a prevalent wind from the east-northeast (Figure 6) and an average wind speed of 1.55 m/s (9 months of wind data) at 5.1 m AGL. This is an unexpectedly low wind speed average (3 m/s more likely) even compared to other weather stations across the north. As noted earlier the status of calibration of the Thor Lake wind data is unknown and the period of available data is too short (typically need one or two years of data) so it is not possible to draw any conclusion on the wind speed of the area based on this data. We must now look to existing models to provide more clues about the wind climate in this area.

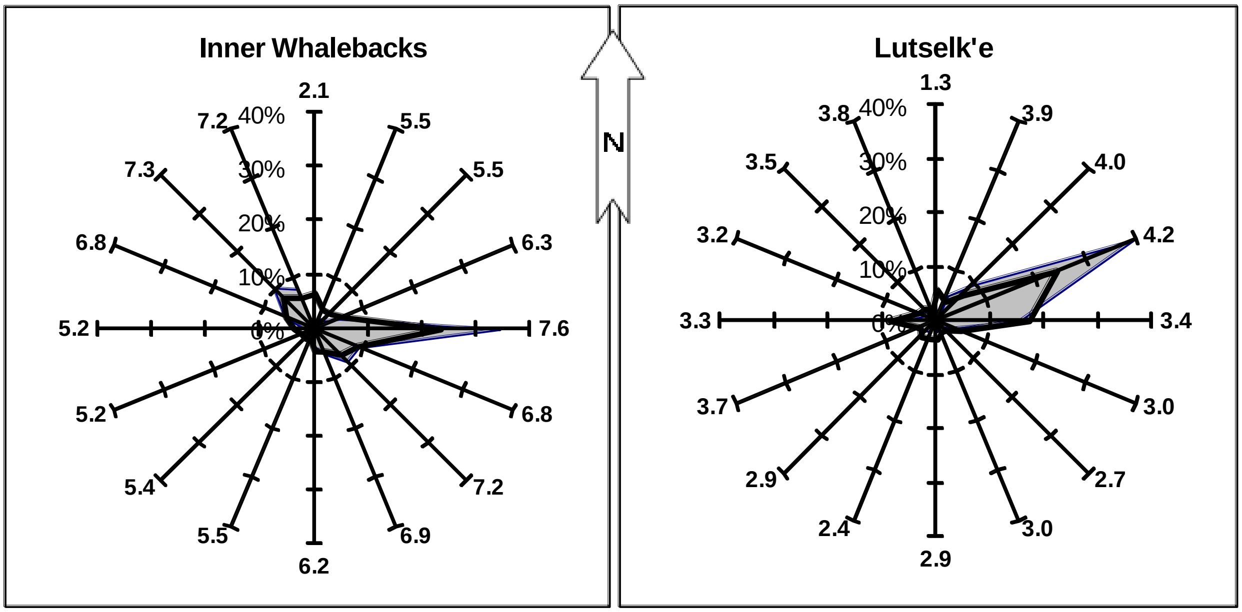

Figure 5: Wind energy roses for the Environment Canada weather stations at Inner Whalebacks and Lutselk'e. The shaded rose is the relative wind energy by direction, and the outlined rose is the wind frequency of occurrence by direction. The mean wind speed by direction sector is indicated at the end of each axis. North is up and west is to the right.

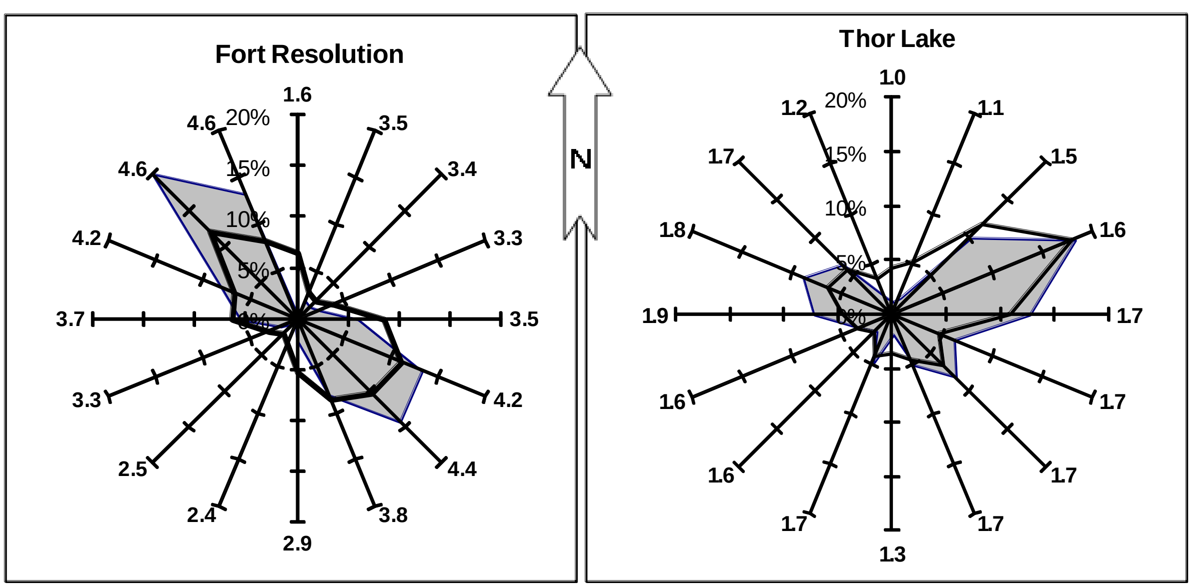

Figure 6: Wind energy roses for Environment Canada's Fort Resolution station and for the Thor Lake weather station. See Figure 5 for rose explanation.

Large Scale Wind Mapping Models of the Thor Lake Area

There are three publicly available wind climate models (known to the author) that provide wind data for Canada. FirstLook (http://firstlook.3tiergroup.com/) is operated by 3TIER, a global consultant in weather-driven renewable energy assessment and forecasting for wind, solar and hydro power projects. WindNavigator is owned and maintained by AWS Truewind (http://navigator.awstruewind.com/) whose core service areas include energy assessment, mapping, and forecasting for both wind and solar energy projects. WindAtlas.ca (http://www.windatlas.ca) is maintained by an Environment Canada research group named RPN (Rechèrche en Prévision Numérique).

The three atlases use standard statistical weather analysis and large scale wind flow models to provide mean wind speed and direction data over geography. The wind input data typically comes from a database of wind data from all available measurements that have been reanalysed and repackaged for use in these wind climate models. These models are made up of a three-dimensional orthogonal grid of inter-related points each of which uses a set of formulae to calculate wind speed and direction (among other variables). Both the FirstLook and the RPN atlases use a horizontal grid spacing of 5 km in the north-south and east-west direction. The grid spacing for windNavigator is 2.5 km in the two horizontal directions. In the vertical direction these models will typically start with a grid spacing that are a few tens of metres apart near the surface and increase their grid point spacing towards the top of the model's limits, which will typically be 5 to 10 km above the surface depending on the model.

It should be note here that all three wind maps are at a fairly primitive stage of development in terms of accuracy. Wind measurements, particularly in the north, are very sparse. These three models as a result are using wind statistics derived from sparsely (locally) available wind data as input. To compound the problem, a course 5-km resolution also diminishes the accuracy of the model output. For windNavigator the higher resolution ought to improve the modelling accuracy, however, the input wind data can still be the limiting factor. As a result, it is prudent to compare these models to existing measurements.

Comparing Models to Measurements

As a matter of increasing our confidence in the three models used for this study, they are compared to the measurements of four weather stations that are within 100 km of Thor Lake. None of the models provide wind speed estimates at 10 m AGL so the wind speed must be projected down from the other three levels noted in Table 1 below. To compare these wind speed predictions to a standard height above surface level at the weather stations we need to vertically project the wind speed and for this we need a formula.

Table 1: Height of the three levels at which the wind mapping models provide their estimates of mean long-term annual wind speed.

	Height in metres AGL		
Level:	1	2	3
FirstLook	20	50	80
windNavigator	60	80	100
WindAtlas	30	50	80

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 (see 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 categorised by type and size of vegetation as well as the hilliness of the ground itself. If we know the wind speeds at two heights of, for example, 10 and 30 m, then we can also find the value of z_o, look the value up on a roughness charts, and compare the land description to the actual ground surrounding the station. With the known z_o we can use the log equation to predict the wind speed at other elevations.

The three wind climate models use interactive geographic maps of the country, and by clicking on a specific location on the map we can extract a mean wind speed for any area of interest. Where the weather stations exist we can extract the estimated mean wind speeds from the models and compare them to those measurements. The modelled wind speeds are projected down to 10 m AGL from the two lowest levels available by the models (see table 1) by using the formulations above. The measured long-term mean wind speeds at the four weather stations are listed in Table 2 along with the projected wind speeds of each wind climate model.

Table 2: Comparison of the three public wind climate models against measurements at four weather stations within 100 km of Thor Lake. The comparisons are all at 10 m AGL, the height of the measurements. The difference between the model prediction and the measurement (and divided by the measurement value) made at each site is shown as a percentage error in the columns titled %E. The second to last column gives the average of the errors at the four sites, which is used only to show each model's bias or tendency in its prediction. The last column is the mean or average of the absolute values of the errors for each models, this is a better measure of each model's accuracy.

	Inner Whalebacks		**Lutselk'e**		**Yellowknife**		**Ft Resolution**		**Mean**	**|Mean|**
@ 10 m AGL	Speed (m/s)	%E	m/s	%E	m/s	%E	m/s	%E	%E	|%E|
Measurements	6.71		3.24		3.62		3.55		(bias)	(absolute)
FirstLook	4.35	-35%	3.44	6%	2.86	-21%	2.84	-20%	-18%	**21%**
windNavigator	6.30	-6%	3.25	0%	2.81	-22%	2.93	-17%	-11%	**12%**
WindAtlas	6.10	-9%	4.10	26%	4.60	27%	3.19	-10%	9%	**18%**

In Table 2 the most important information is in the last column (|Mean|) which gives the mean of the absolute values of the percentage difference between model and measurements. It shows that windNavigator is on average 12% off of the measurements and so tends to be more accurate than the other models which are closer to 20%. The second to last column which gives the mean percentage error is an indicator of bias where, for example, the WindAtlas model tends to over-predict (by about 9%) whereas windNavigator tends to under-predict (by 11%).

The Models' Wind Speed Predictions at Thor Lake

As note earlier the three wind climate models use maps to help the user identify their location of interest and by clicking on a specific spot on the interactive map we can extract a mean wind speed at three heights above the ground for that location. For FirstLook and WindAtlas.ca the wind speeds for a given grid point location represent a larger 5 by 5 km area whereas for windNavigator it is 2.5 by 2.5 km. In this study the location of interest is Site #1 and it is shown on the windNavigator map of Figure 7. Site #1 is on a hill by the shoreline of the Hearne Channel.

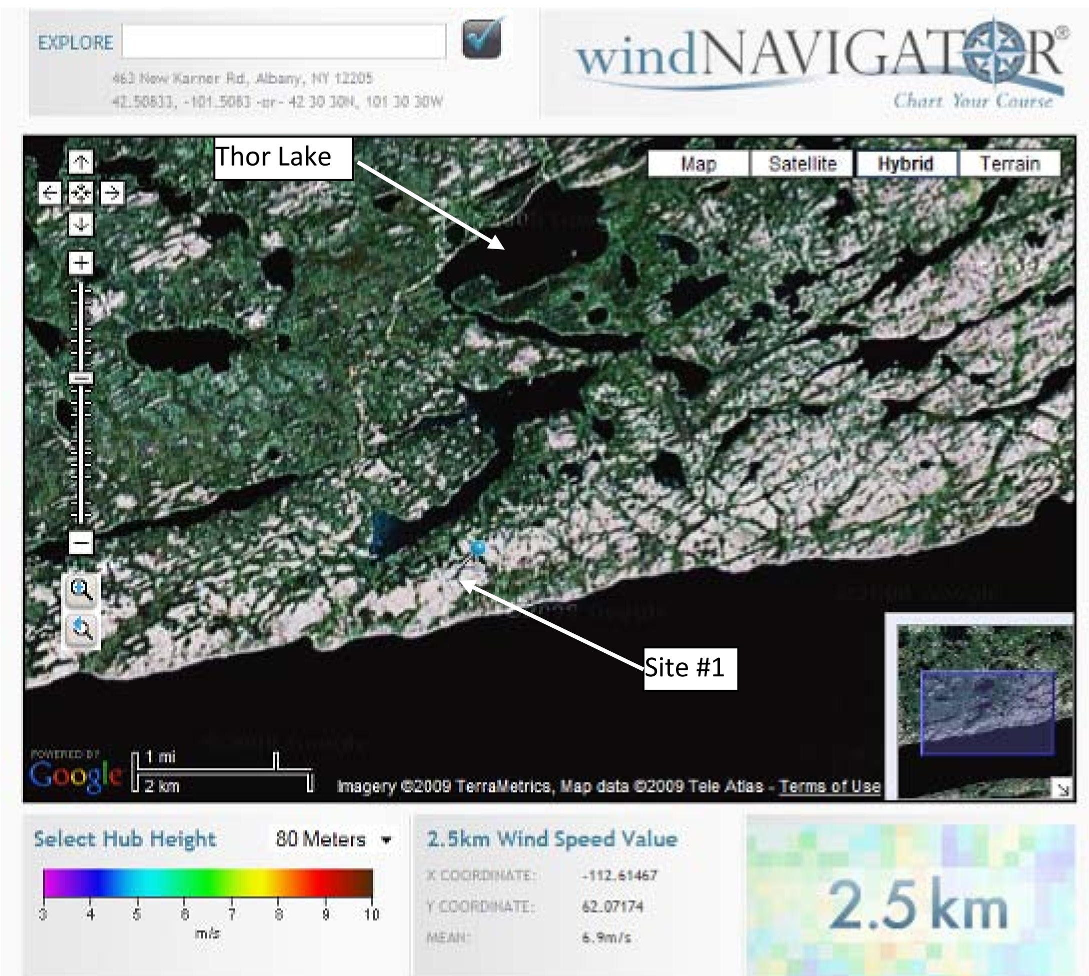

Figure 7: A view of windNavigator over the Thor Lake area. The arrow indicates the location from which the wind speed information was extracted. In this case the windNavigator model predicts that in the area that Site #1 is located the average wind at 80 m AGL is 6.9 m/s.

The estimates of the long-term (typically over 40 years of the Reanalysis data is used for these models) mean wind speed at three levels above ground at that site are shown in Table 3 below. Using 50 m AGL as the reference level we note that wind speed estimates range from 5.2 to 6.7 m/s, with FirstLook providing the lowest estimate and WindAtlas the highest. The model windFarmer provides a more middle-of-the-road estimate of 6.20 m/s (projected from 60 and 80 m AGL). We must bear in mind that although these wind speeds are given for Site #1, the actual grid point where the wind speed was calculated is somewhere within a 5 km square (2.5 km for windFarmer) area with the grid in the center of the area. Therefore these modelled wind speeds represent a larger area and not the specific site.

Table 3: Wind Climate model estimates of the long-term mean wind speed at Site #1. The table also contains columns of the natural log profile fitted to estimated wind speed values of each model.

Elevation	FirstLook		windNavigator		WindAtlas	
above ground	From model	Fitted log profile	From model	Fitted log profile	From model	Fitted log profile
10 m		3.27		3.78		5.23
20 m	**4.10**	4.10		4.82		5.87
30 m		4.59		5.43	**6.25**	6.25
40 m		4.93		5.86		6.52
50 m	**5.20**	5.20		6.20	**6.72**	6.72
60 m		5.42	**6.47**	6.47		6.89
70 m		5.60		6.70		7.03
80 m	**5.70**	5.76	**6.90**	6.90	**7.60**	7.16
90 m		5.90		7.08		7.27
100 m		6.03	**7.21**	7.24		7.36
110 m		6.14		7.38		7.45
120 m		6.25		7.51		7.53
130 m		6.34		7.63		7.61
140 m		6.43		7.74		7.68
150 m		6.52		7.84		7.74
Zo =		0.65 m		0.8 m		0.035 m

All three models show a tendency for the winds to increase over the Hearne Channel and to decrease towards the northern portions of the Thor Lake area. For example, the WindAtlas wind speed map for the 50 m level above ground is shown in Figure 8 where the Thor Lake area is at the north end of an area of maximum wind speed. The WindAtlas provides locations of its grid points and they are also shown in the figure. Grid point A is located over water and has a wind speed of 7.26 m/s at 50 m AGL whereas grid point B has a wind speed of 6.72 m/s (which is also given in Table 3).

In this short exercise let us extract some wind speeds at 50 m AGL from the three wind climate models over the Hearne Channel and over the Thor Lake area. Let us use the mean bias found in Table 2 to adjust those wind speeds over both areas. For example, we multiply the FirstLook bias of 18% by 5.2 m/s and add to the same wind speed to obtain 6.11 m/s (see Table 4). Applying this to all the models and taking an average of the adjusted values, we can then attain an estimated mean wind speed over the area that ranges from 6.4 to 6.8 m/s at 50 m AGL over the Thor Lake area and the Hearne Channel, respectively.

At Site #1 by the shoreline we might then expect the wind speed to be in the range 6.4 – 6.8 m/s at 50 m AGL. This site is on a relatively bare rock outcrop whose surface is fairly clear of trees. Its surface roughness is estimated to be z_o = 0.1 m, using the natural log formulation above we can project these last wind speed estimates vertical and those are shown in Table 5. To evaluate the estimated winds of Site #1 relative to the surrounding area we can also use a micro-scale model, which is discussed in the follow section.

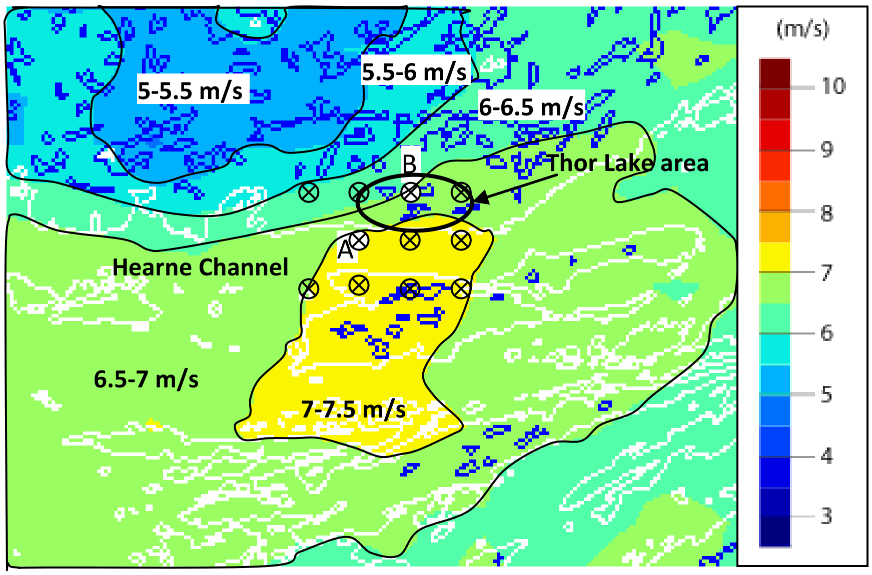

Figure 8: Wind Atlas estimate of wind speed at 50 m AGL. The circle-crosses are some of the grid points from the model of the Canadian Wind Atlas. Locations A and B refer to grid points that are used to extract the modelled wind speeds in this study. The white lines represent the shorelines. The area of highest estimated wind speed (7-7.5 m/s at 50 m AGL) is south of the Thor Lake area.

Table 4: Adjusting the modelled wind speeds using the mean bias from Table 2.

	Modelled Wind Speed at 50 m AGL		Bias Adjustment	Wind Speed Adjusted by Bias	
	Thor Lake	Hearne	multiplier	Thor Lake	Hearne
FirstLook	5.20	5.35	1.18	6.11	6.29
windNavigator	6.20	6.76	1.11	6.90	7.54
WindAtlas	6.72	7.26	0.91	6.15	6.64
Mean:	6.04	6.46		**6.39**	**6.82**

Table 5: Projecting the wind speeds calculated in Table 4 to other levels above ground.

Height (m)	Minimum (m/s)	Maximum (m/s)
0	0	0
5.1	4.0	4.3
10	4.7	5.1
20	5.4	5.8
30	5.9	6.3
40	6.2	6.6
50	**6.4**	**6.8**
60	6.6	7.0
70	6.7	7.2
80	**6.9**	**7.3**
90	7.0	7.5
100	**7.1**	**7.6**

A Small Scale Model Evaluation of the Thor Lake Area

To estimate the relative mean wind speed at a more local level in the Thor Lake area we use a small-scale numerical wind modelling tool called MS-Micro. Originally based on boundary-layer wind field theories of Jackson and Hunt (1975), it was modified and made into a user-friendly computer wind modelling tool by Walmsley et al. (1986).

MS-Micro was run for the Thor Lake area using data elevation model from the Geobase.ca centre. The surface roughness were estimated with lakes being z_o = 0.00001 m (ice surface), the forest being z_o = 0.2 m, and the rocky outcrops being z_o = 0.1 m. The model domain has an area that is 18 km square with an inner area of interest that is 9 km square which covers the Thor Lake area. The model's surface (elevation) resolution is about 140 m horizontally (128 by 128 grid points), whereas the model grid for wind calculations is about 70 m (grid of 256 by 256).

The winds that were applied in the model simulation are normalised, arbitrary wind speeds. Two main wind directions were also applied to the model: those being 68 and 90 (westerly) degrees to represent the two main wind directions identified by the weather stations. The model was run twice, once for each direction, and the resulting wind speed outputs were blended into a single output using a scaling based on the wind energy rose of the weather stations at Inner Whalebacks and Lutselk'e.

The output of the micro-scale wind flow is recalibrated using five grid points from WindAtlas that cover the Thor Lake area. The micro-scale wind map is also adjusted using the mean wind estimates given in Table 4. The resulting wind map is shown in Figure 9.

In Figure 9 the white areas to the south along the shoreline of the Hearne Channel represent the fastest winds. From the model output, the suggested sites have the following predicted wind speeds (at 50 m ASL):

- Site #1 – 6.6 m/s
- Site #2 – 6.5 m/s
- Site #3 – 6.1 m/s
- Site #4 – 6.6 m/s
- Site #5 – 6.2 m/s
- Weather Station – 5.3 m/s

The predicted wind speed of 5.3 m/s (50 m AGL) at the Thor Lake weather station would mean that the station would have measured a long-term mean wind speed of 3.1 m/s at 5.1 m AGL (assuming surface roughness z_o = 0.2 m) which is possible and should be verified. It is the author's opinion that these predicted wind speeds are reasonable.

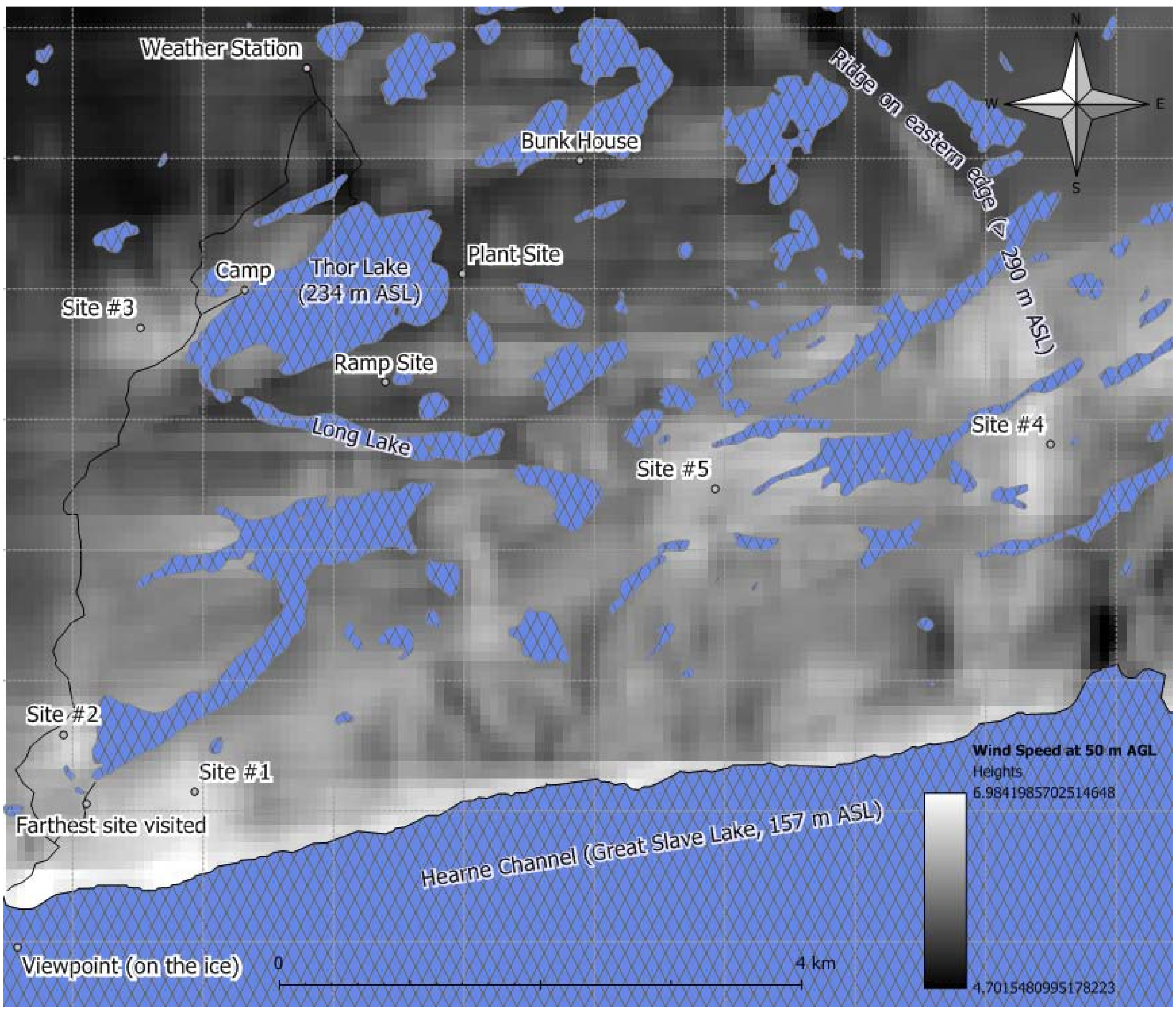

Figure 9: Relative wind speed output from the micro-scale wind flow model MS-Micro. According to this model the areas of stronger winds are on hill east of the larger bodies of water and along the shoreline of the Hearne Channel towards the southeast. Five sites with predicted high wind speed are identified here that are on a hill and that may be of interest for wind development.

From this modelling exercise the best locations are towards the south following the trends of the three large-scale wind climate models. The location identified as Site #1 is on a hill shown in the aerial photo in Figure 10 and Figure 11. At higher elevations (using the natural log formulation and z_o=0.1 m) the wind speeds at site #2 are predicted to be 7.1 and 7.3 m/s at 80 and 100 m AGL respectively.

However, as noted earlier, Site #1 is about 4 km away from the main loads of the proposed mine site and this will raise a cost issue with regard to transmission costs. Site #3 might be a better site despite its lower predicted wind speed of 6.1 m/s because it is only about 2 km from the load. Problems may arise at Site #3 concerning flight paths, since Thor Lake is the landing and takeoff site for small aircrafts. Site #4 is on the highest hill (290 m ASL) in the area and although it has significantly high wind speed, it is far (5 km) from the main mine site. Sites #2 and #5 are also interesting because they are on high ground as well.

Figure 10: Looking towards the east-northeast in an aerial photo of the hill by the shoreline of the Hearne Channel. The proposed Thor Lake mine site is to the left of the image, north of this location. The site of interest for a possible wind project is shown here as Site #1.

Figure 11: View from the ice on the Hearne Channel of hill where Site #1 is located.

Recommendations

The next steps are to confirm the wind speeds in the Thor Lake area that have been predicted in this study. A 50 m tall tower instrumented with calibrated anemometers is recommended at Site #1 and measurements should be made for at least one year. Wind data from the Inner Whalebacks station should be extracted for at least a ten-year period ending with the conclusion of the wind monitoring period at Site #1. The wind data from the local weather station at the north end of Thor Lake should be verified and also used to correlate with the other measurements.

An economic analysis should be made to provide the mining company the information necessary to base their decisions to implement wind energy into their portfolio.

Conclusions

Three weather stations and two public large-scale wind models were used to predict the mean wind speed in the Thor Lake area. A small-scale wind flow model was also used to prediction the wind speed at a local level in the Thor Lake area. From the analysis and modeling a long-term annual mean wind speeds of 6.6 m/s at 50 m AGL are predicted to exist at a hill site by the Hearne Channel. At elevations of 80 m and up the wind speed are expected to be in excess of 7 m/s. A full year of wind measurements will be necessary to confirm this prediction.

References

Jackson, P. S. and J. C. R. Hunt, 1975. **Turbulent wind flow over a low hill**. Quart. J. R. Meteor. Soc., 101:929–955.

Pinard, J.P., 2007. **Executive Progress Report for Wind Energy monitoring in Six Communities in the NWT**. Prepared for Aurora Research Institute, Inuvik, NWT.

Pinard, J.P. and J. F. Maissan, 2008. **Yellowknife Wind Energy Pre-feasibility Report**. Prepared for Aurora Research Institute, Inuvik, NWT.

Stull, R.B., 2000. **Meteorology for Scientists and Engineers**. Second Edition. Published by Brooks/Cole.

Walmsley, J., P. Taylor, and T. Keith, 1986. **A simple model of neutrally stratified boundary-layer flow over complex terrain with surface roughness modulations (MS3DJH/3R)**. Boundary-Layer Meteorology, 36:157–186.