Potential Wind Farm Locations for the Yellowknife Area

Prepared for

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Executive Summary

This report provides an assessment of potential sites for further wind energy investigation in the Yellowknife area, particularly along the Snare Grid powerlines. The report addresses the question of what hills are above the temperature inversion effect (which reduce winter wind speeds at lower elevations), and what the expected long term mean wind speeds are on these hills.

Terrain elevation data was used to identify hills of interest near the Snare Grid. Upper air data from three NWT meteorological stations (Inuvik, Norman Wells, and Fort Smith) and other surface stations were analysed to assess the wind climate at different elevations in the Yellowknife area.

Wind speeds of at least 6 m/s should be found at elevations of 350 m above sea level (ASL) (or approximately 150 m above the general surrounding plain) in the Yellowknife area along the grid. The wind speeds at 350 m ASL increase during the winter, suggesting that this is above the inversion effect. At 400 m ASL, wind speeds are estimated to be 6.2 m/s.

Berry Hill and two hill complexes, one near Bluefish Dam area and the other near the Snare River Dams, have been identified as good candidates for their elevation and proximity to the grid. Berry Hill peaks at 275 m ASL, and with a proposed wind turbine tower of 75 m (bringing the hub height to 350 m ASL) could have wind speeds of 6.0 m/s. North of Berry Hill, there is a complex of hills that are 3 to 6 km west of Bluefish Dam that peak at 260 m ASL. With a 75 m wind turbine tower this would put the hub height to 335 m ASL and at this height the wind speed is expected to be about 5.8 m/s. Berry Hill would have room for one wind turbine while the hills to the north may have room for about one dozen turbines.

The Snare River hill complex has many hills peaking at over 360 m ASL and could have room for two dozen wind turbines. With wind turbine hub heights reaching to 435 m ASL, these hills will likely have wind speeds of 6.4 to 6.6 m/s. The Snare River hills are all within 6 km, with several of the hills within 1 km, of the powerline leading back to Yellowknife. There is a road and powerline leading to one of the hills which has a communication tower that could be instrumented for wind measurements.

The recommended next steps are to set up a wind monitoring station at Berry Hill or the hills west of Bluefish, and on the communication tower at the Snare River hills. Once the measurements have been made, an economic assessment should be done to further compare the sites.

Introduction

The city of Yellowknife has a population of about 19,200 (2011 census) people and is the capital of the Northwest Territories. The city is located on the north shore of Great Slave Lake and is accessible year round by highway and by air.

The total generation capacity of the Snare Grid is about 65 MW with a 38 MW portion from Hydro generators at Bluefish and Snare River. The generation facilities are owned and operated by Northwest Territories Power Corporation (NTPC) and provide about 220 GWh annually (based on 2008 figures) of electricity to its customers. Diesel normally provides about 5% of the annual electricity on the grid, but in 2014 that number was expected to rise to 30% due to water shortage[1].

NTPC is looking to expand the renewable energy capacity of the grid to include wind energy. For most wind projects in the north a long term annual mean wind speed of at least 6.0 m/s is desirable for considering their economics. Even more desirable is wind energy that is more plentiful during the winter months to meet the increased electricity demand. However, those stronger winter winds can be impacted by winter inversions at lower elevations.

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

A previous report (Pinard et al., 2008) has shown that the wind potential around the Yellowknife area was relatively low and would require subsidies to be competitive with diesel. The long term (1998-2007) average wind speed from NTPC's Jackfish tower measurements was estimated at 4.8 m/s at 37 m above ground level (AGL) and 5.5 m/s at 80 m AGL. NTPC's Jackfish tower is located on a hill at 197 m ASL. While report indicated that wind speeds were lower in the wintertime, it also suggested that from weather balloon measurements that above 100 m AGL the winter winds would be stronger.

The purpose of this report is to investigate whether Berry Hill or other sites near Yellowknife would be high enough to reach above the inversion layer to provide economically viable winter wind energy on the grid. This analysis will use existing upper air or weather balloon measurements, and terrain elevation data covering the Snare Grid connecting to Yellowknife to provide the assessment.

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

Area for Wind Energy Study

The Snare Grid connects two hydro projects to the City of Yellowknife (Figure 1). The Blue Fish hydro project is located about 25 km north of Yellowknife and the Snare River Dams are located about 145 km northeast of Yellowknife. The map shows terrain elevation data which was extracted from Natural Resources Canada's GeoGratis website (http://geogratis.gc.ca/site/eng/extraction). The map shows areas in green being below 200 m ASL, while the areas in brown are above 300 m ASL. The three areas of interest for this study include Berry Hill, hills just west of the Bluefish Dam, and the hill complex just south of the Snare River Dams. These hills will be discussed in further details.

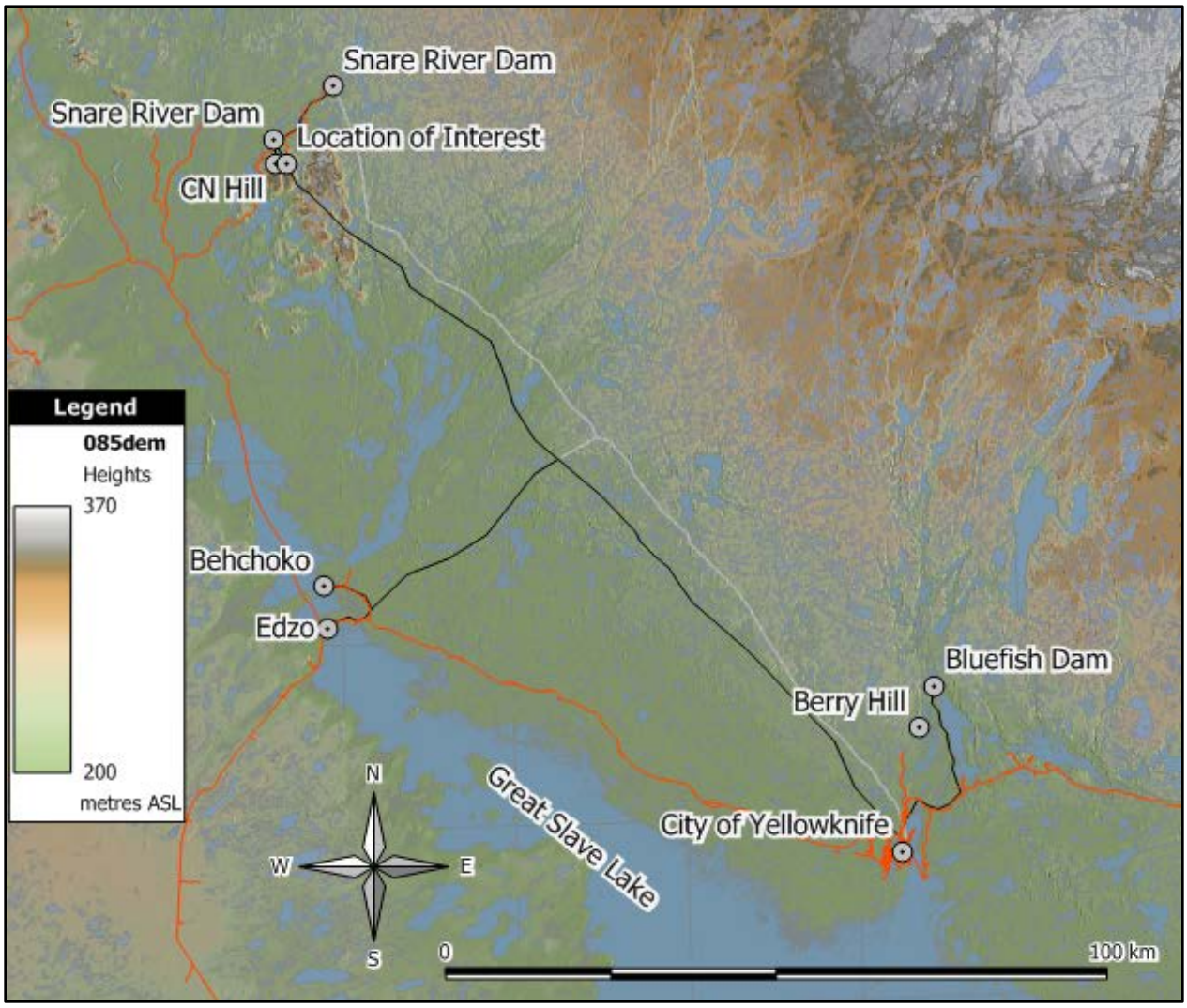

Figure 1: Map of Yellowknife area showing the extent of the Snare Grid (black line), which extends from the Bluefish Dam to the Snare River Dams. The gray line shows a previously used powerline, and roads are in red. Powerlines currently in use are in black.

Analysis of Upper Air Measurements

Upper air measurements are a useful way of understanding the atmosphere in term of wind climate, and temperature profiles. The weather balloons used to collect upper air data are typically released every 12 hours, and most stations have been running since the 1950s and 1960s. There are no upper air stations in Yellowknife but there three in the NWT: Fort Smith, Norman Wells and Inuvik. From these upper air measurements, an analysis was done to explore the relationship between wind speed and height, wind energy and direction, and the seasonal variations of wind speeds at key elevations in the Yellowknife area.

Wind Direction Analysis

Figure 2 shows the land elevations as well as the wind roses at the three upper air stations and one surface weather station in Gameti (included because it is in the same valley as the Snare hill complex, about 105 km to the northwest).

The wind roses depict annual mean wind energy by direction at 200 m AGL, except for Gameti which records wind speeds on a 10 m tower. The wind energy roses show that the dominant winds are mainly from the northwest with a smaller portion from the south in Fort Smith and Inuvik, and southeast for Norman Wells and Gameti. In Norman Wells there are the localised effects of the Norman Range and the Mackenzie River Valley directing the winds parallel to the ridge and the river. Not shown here is that the northwest winds dominant become more dominant at higher elevations (e.g. 500 m ASL and higher). Judging by the wind roses at Gameti, as well as at the upper air stations, it likely that the winds at the Snare hill complex experiences the same dominant northwesterly winds.

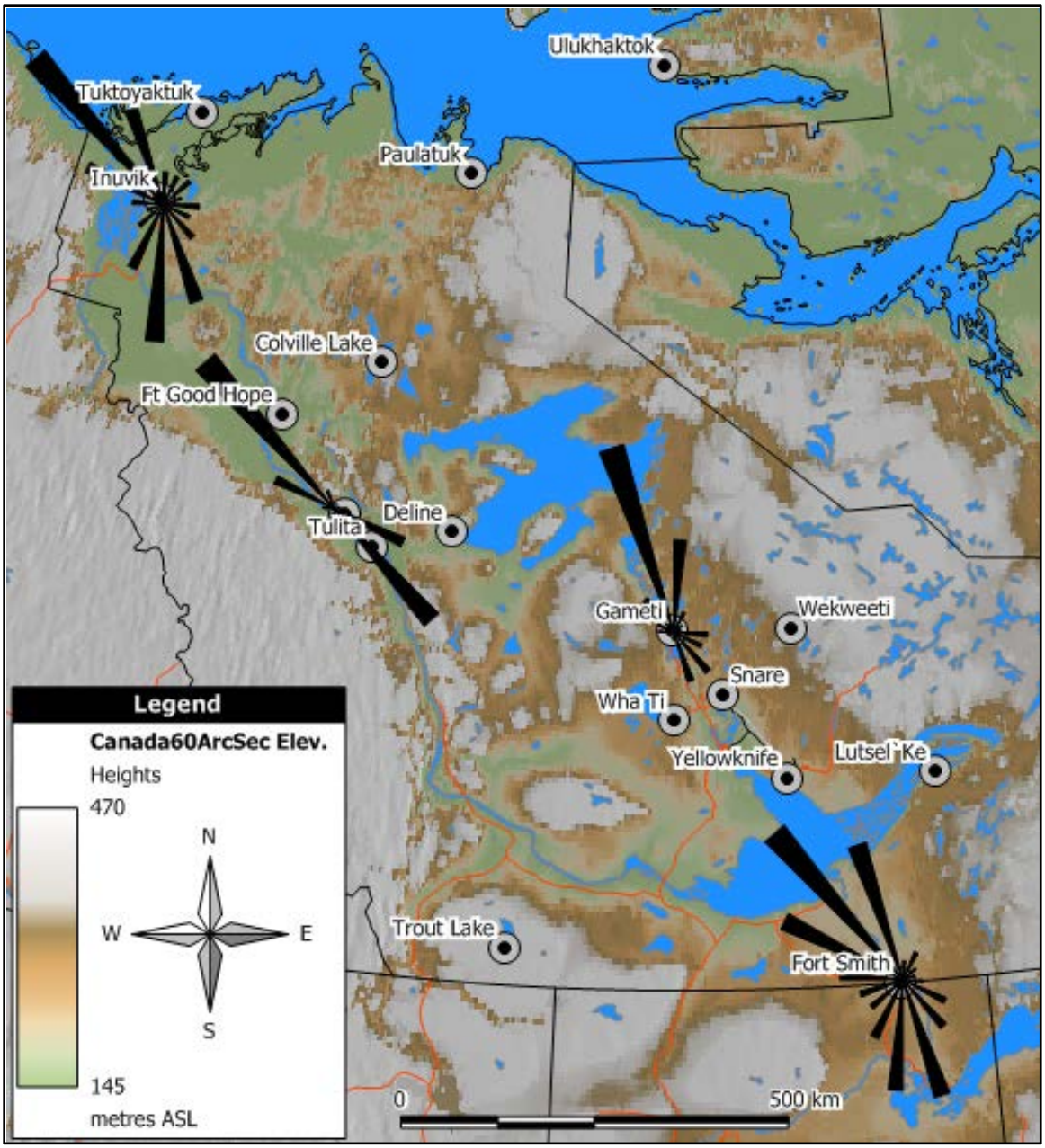

Figure 2: Wind roses indicating wind speeds and direction at 200 m AGL at each station. The map also includes a wind rose for the airport station measurements in Gameti (10 m AGL).

Wind Speed in Relation to Height

Figure 3 shows long-term annual wind speed in relation to height above sea level at Inuvik, Norman Wells and Fort Smith. Note that the majority of balloon measurements were made at the standard heights of 300 and 600 m ASL, which shows up as relatively straight lines between those heights in the graph for Inuvik and Norman Wells.

Wind speeds of at least 6 m/s should be found at elevations of 350 m above sea level in the Yellowknife area. The Fort Smith station is at roughly the same elevation (ASL) as Yellowknife and most areas along

the Snare Grid. Data from the Fort Smith station indicate a long term average wind speed of 6.2 m/s at 400 m ASL; at the other stations, which are about 100 m lower than Fort Smith, a similar wind speed was attained at 300 m ASL.

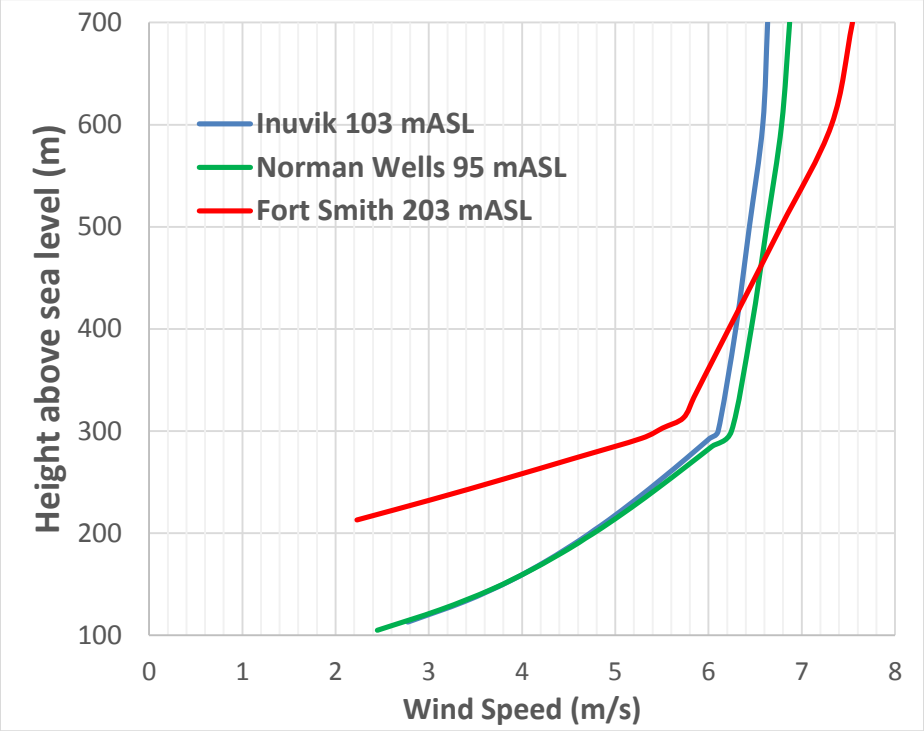

Figure 3: Vertical profile of horizontal wind speed versus height above sea level (ASL) at three upper air stations in the NWT.

Figure 4 shows the same profiles as Figure 3, but at elevations relative to the height of each surface station. The graph includes log wind profile curves fitted to the Jackfish tower and the Fort Smith measurements. The log wind profile is generally accurate to 100 m above the surface in neutral atmospheric conditions.

From Figure 4, and using the Fort Smith and the Jackfish tower measurements, one can draw a few conclusions of expected wind speeds at key heights above an elevation of 200 m ASL:

- At about 100 m AGL long term mean wind speeds of 5.6 (Fort Smith) to 5.75 (Jackfish tower) m/s could be attained.
- At 150 m AGL about 6 m/s would be expected based on the Fort Smith measurements.
- At 200 m AGL for the three surface stations a long term mean wind speed of 6.2 to 6.4 m/s could be attained.
- At 250 m AGL using the Fort Smith measurements and its accompanying fitted log wind profile, long term mean wind speeds of 6.5 to 6.75 m/s are possible.

At the NTPC Jackfish tower site, wind speeds projected to 100 m AGL were calculated to be 5.75 m/s (Pinard et al. 2008).

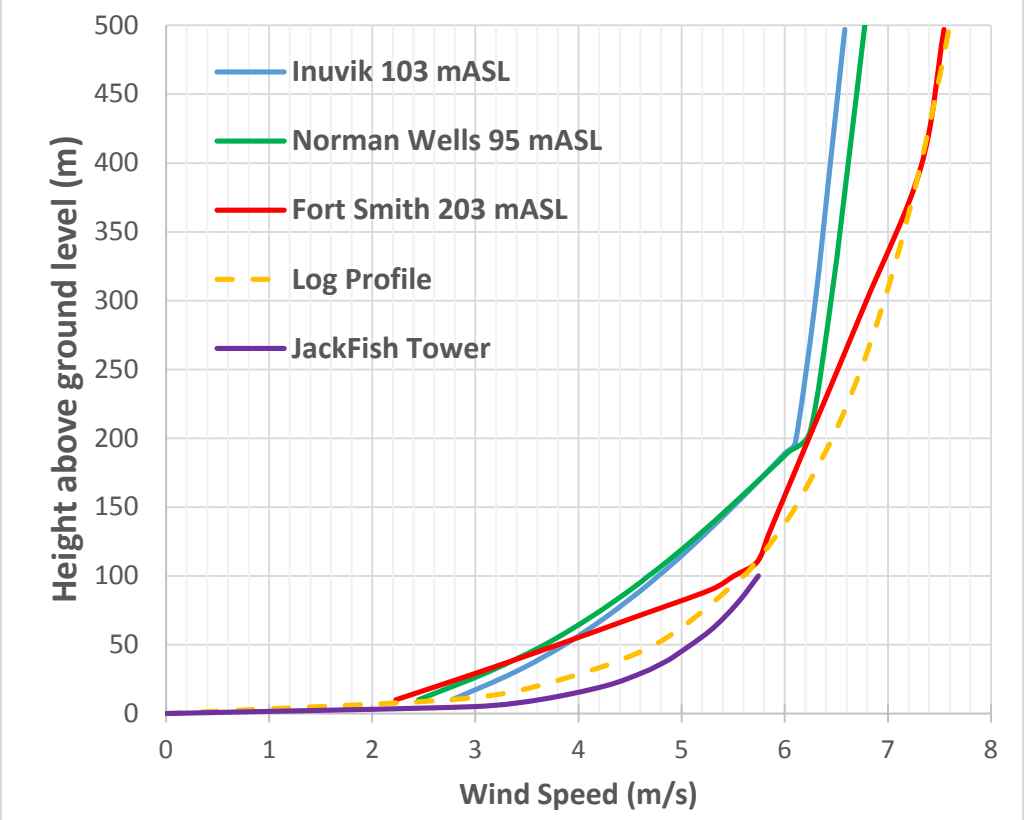

Figure 4: Vertical profile of horizontal wind speed versus height above ground level (AGL) at three upper air stations in the NWT.

Monthly Mean Wind Speed

Figure 5 shows the monthly mean wind speed measured near the surface (10 m AGL), and at roughly 200 m AGL for each upper air station. Also included for reference are the monthly mean wind speeds at about 100 m AGL at the Fort Smith station. The average wind speeds at 200 m AGL for Fort Smith, Norman Wells, and Inuvik are 6.2, 6.2, and 6.1 m/s, respectively. At 100 m AGL for Fort Smith the mean wind speed is 5.6 m/s. At the surface (on the 10 m towers) the mean wind speed for Fort Smith, Norman Wells, and Inuvik are 2.2, 2.4, 2.8 m/s, respectively.

The upper air wind speed measurements demonstrate a marked difference in seasonal wind patterns. The wind speeds at the surface increase during the summer and decrease during the winter. At 100 and 200 m AGL (or 300 and 400 m ASL) the winter wind speeds are increased compared to the summer. This suggest that 200 m AGL and even 100 m AGL is high enough to be above the most influential part of the winter inversion layer.

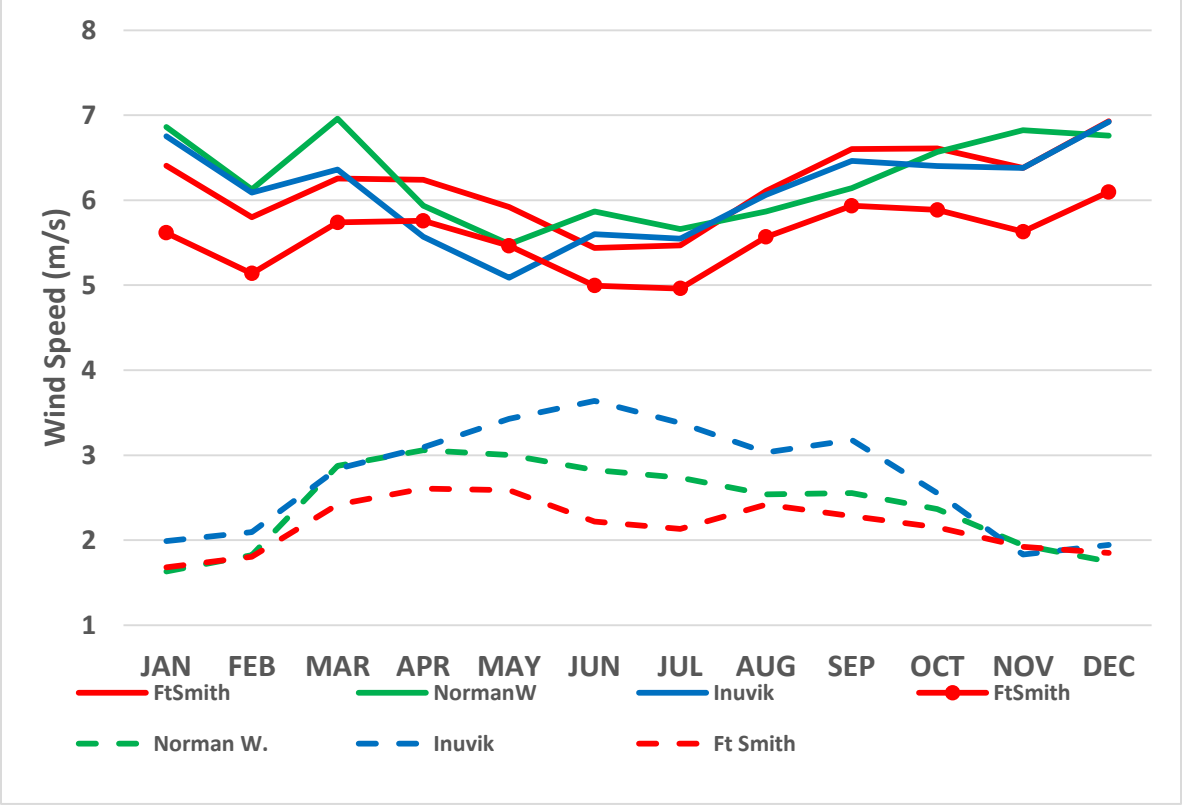

Figure 5: Monthly mean wind speeds at 10 m AGL (dashed lines) and at ~200 m AGL (solid lines) at each upper air station in the NWT. The monthly mean wind speeds at 100 m AGL at the Fort Smith station have also been included for reference (red studded line).

Berry Hill

Berry Hill has been of particular interest as a potential site for a wind project. It is a singular hill located about 16 km north of Yellowknife, it stands out and has a peak elevation of 275 m ASL (Figure 6). It is located about 3.5 km west of the powerline leading to the Bluefish Dam. Berry Hill is, however, a relatively narrow hill with an area above 270 m ASL that is about 100 by 200 m. There would be room for only one wind turbine. If a wind turbine were installed here, the hub height of the wind turbine would be approximately 350 m ASL and roughly 150 m above the surrounding area (closest lake to the east is 183 m ASL). From the analysis made earlier it would be expected that at 350 m ASL the long term mean wind speed would be 6 m/s. It's also possible, based on the evidence presented earlier, that these hills would be above the inversion layer and experience higher winter wind speeds.

Bluefish Dam Area

There is a complex of hills located 3 to 6 km directly west of the Bluefish Dam and the powerline (Figure 6). Those hills are 260 m ASL and could accommodate up to a dozen large scale wind turbines. If 75 m wind turbine towers were chosen, then the hub height of interest is 335 m ASL (260 m ASL plus 75 m AGL). The long term mean wind speed is estimated to be 5.8 m/s at this hub height.

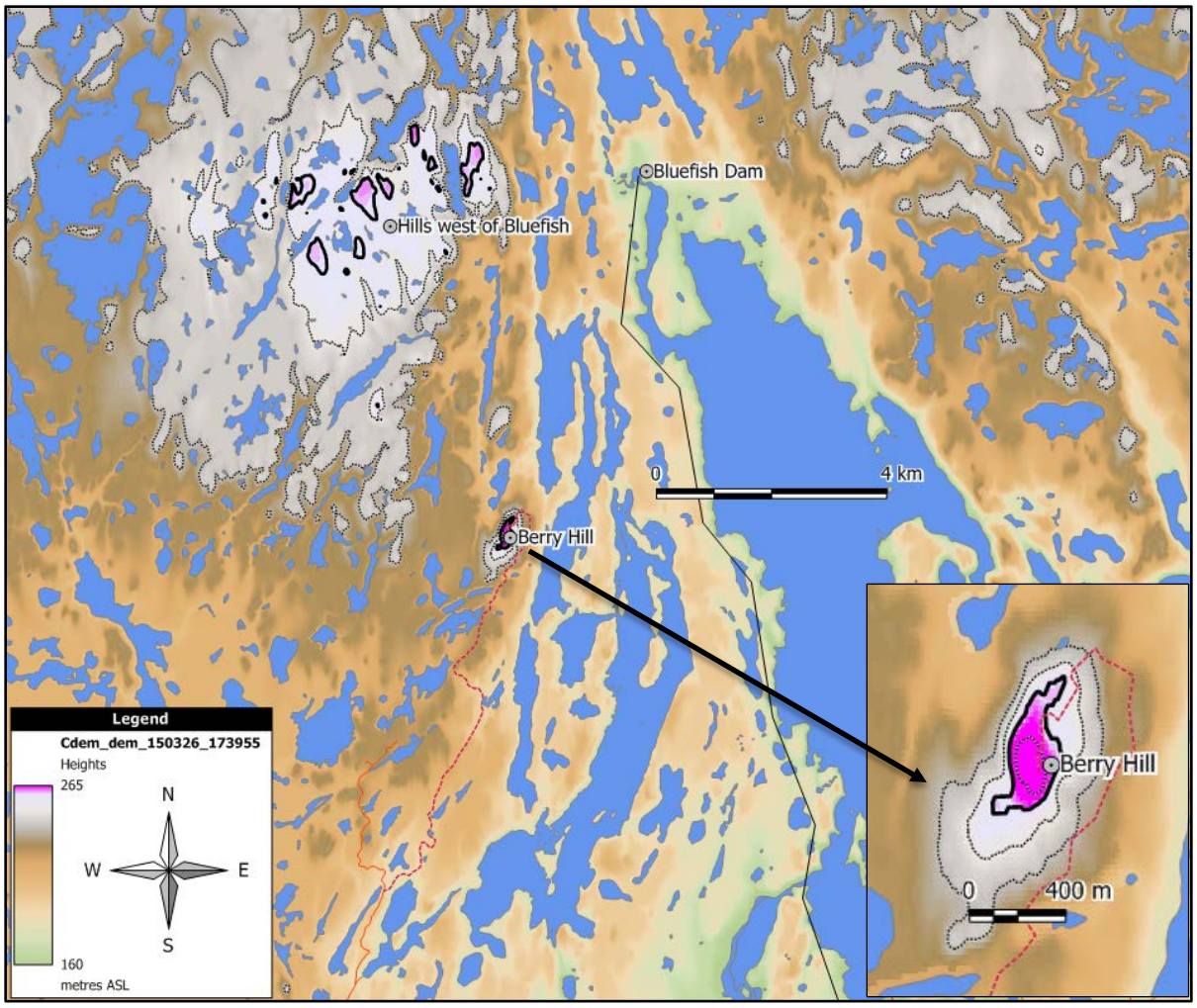

Figure 6: Map of the Bluefish area showing hills of interest, including a scale-up of Berry Hill. The dotted contour lines are at 240 and 250 m ASL, respectively. The bold contour line is at 260 m ASL. The dashed red line is the Berry Hill Trail.

Snare River Dam Hill Complex

The Snare River Dam hill complex is located about 130 km from Yellowknife and just south of the Snare River Dams. The hills start just 3.5 km from the southern dam, and many of them rise above 360 m ASL. All of these hills are within 6 km of the powerline, and a few of them are even intersected by the powerline, as can be seen in Figure 7. There are four or five hills in this area that are within 1 km of the powerline. Subject to the powerline capacity, there could be room for up to about two dozen large scale wind turbines on this hill complex.

CN Hill is the site of a Northwestel communication tower, which has a powerline and a road leading to the site. While the exact location is not known to the author, it is likely sitting at the top of the hill at an elevation of 367 m ASL.

This tower could be a candidate for instrumenting with (heated[2]) wind sensors to begin a site assessment. The nearby location of interest indicated on the map has three peaks at 366 m ASL which could accommodate three or four large scale wind turbines. These hills are about 300 to 700 m from the powerline. If wind turbines with hub heights of 75 m were placed there, the total height would be (360 m ASL + 75 m) 435 m ASL. Considering that the surrounding terrain is about 200 m ASL, this hill (with a turbine) rises about 235 m above that. From Figures 3 and 4, one could surmise the long term mean wind speed at this height to be about 6.4 to 6.6 m/s.

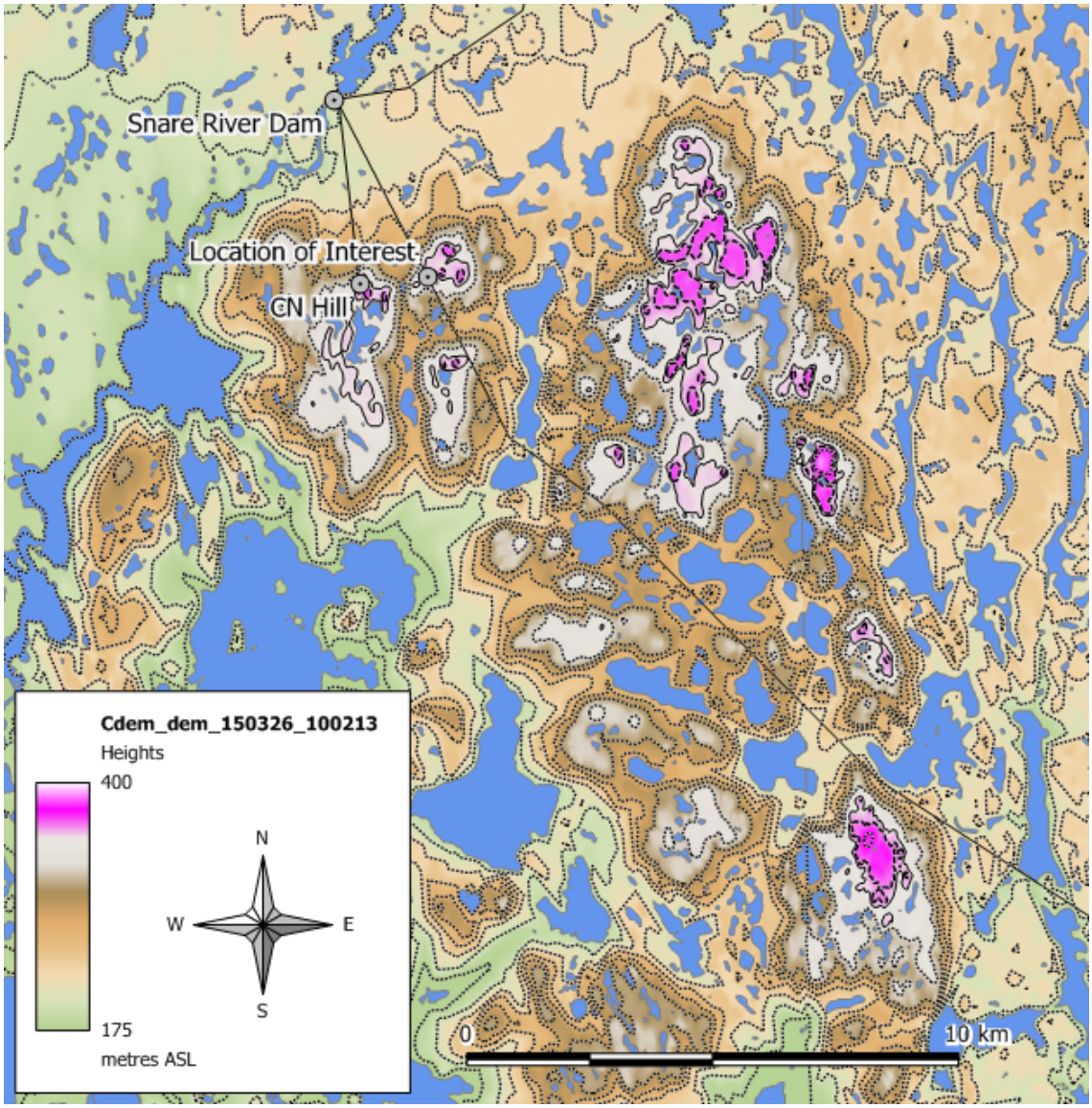

Figure 7: Map of the hill complex south of the Snare River Dams. The contour interval for all of dotted lines are 25 m starting at 200 m ASL. The solid line is at 350 m ASL, and an intermediate dashed contour line is at 360 m ASL, also indicated by the pink area.

[2] There is likely to be icing at this elevation. Heated wind sensors require grid power.

Conclusions

1. Wind speeds of at least 6 m/s should be found at elevations of 350 m above sea level or at heights of 150 m above the local terrain in the Yellowknife area along the grid. Wind speeds of 6.2 m/s are estimated at 400 m ASL.
2. At 350 m ASL or higher in the Yellowknife area, the winds are expected to be above the winter inversion layer, and so should exhibit stronger winter winds.
3. Berry Hill, with a turbine at a hub height (75 m tower) of 350 m ASL, will likely have wind speeds of 6.0 m/s. The site is 3.5 km from powerline access, but the site would likely only accommodate one large scale wind turbine.
4. The hills west of Bluefish Dam are 3 to 6 km away from the dam and powerline and could accommodate about one dozen wind turbines. Those hills collectively peak at 260 m ASL, and at a hub height total of (260 m ASL + 75 m tower) 335 m ASL the wind speeds are estimated at about 5.8 m/s.
5. The Snare River hill complex, with wind turbine hub heights of 435 m ASL, will likely have wind speeds of 6.4 to 6.6 m/s. While there is room for about two dozen wind turbines, one location of interest near the Snare Rapids Dam has three peaks within 300 to 700 m of the powerline and could accommodate three or four large scale wind turbines.
6. The Snare River hill complex is accessible by winter road from Yellowknife and one of the hills (CN Hill) has a Northwestel tower with road and powerline access, which could be used for measuring wind speeds in the area.

Next Steps

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

1. If possible, meteorological instruments with heated sensors should be installed at the Northwestel tower at CN Hill in the hill complex at Snare River.
2. A meteorological mast of 50 m or more should be installed on one of the Snare hills, one located direct east of the CN hill and along the power line.
3. A meteorological mast of 50 m or more should be installed at Berry Hill or at the hills east of Bluefish dam.
4. Following the measurement campaign an economic assessment to further compare the sites should be made.

References:

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

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