Final
Report of Wind Measurements at 50-meter Tower at Big Bay State Park, Madeline Island, WI
Nov. 1, 2008-Oct. 31, 2009

Feb. 4, 2010

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Introduction

This is a report of wind measurements at Big Bay State Park ("BBSP"), Madeline Island, Wisconsin, for the period from November 1, 2008, through October 31, 2009.

These measurements were undertaken to assist the Town of La Pointe Alternative Energy Committee ("AEC") in evaluating the economic and meteorological feasibility of undertaking a community wind farm using commercial-scale wind technology on Madeline Island. They were designed to evaluate the wind resource at BBSP, which is key to the feasibility of a commercial wind installation there. This report accomplishes that objective.

Measurement Site

The BBSP meteorological tower was a 50-meter NRG tilt-up tower leased from the Bad River Tribe. Seventh Generation Energy Systems ("SGES") selected the site in consultation with the AEC.

The tower was (and continues as of February 2010 to be) located at coordinates 46◦ 47.325' N, 90◦ 40.219' W, at an elevation of approximately 640' MSL (above mean sea level). This is a grassy area of BBSP with a mowed lawn situated about halfway between the historic Hagen House (to the S of the tower) and a large garage (to the N) used to store BBSP park equipment. The tower is E of a gravel service road. The site is marked by an "X" on Appendix A, an excerpt from the Madeline Island 7.5-minute quadrangle map.

The mowed area surrounding the met tower is less than an acre in size. It lies within a larger area of about eight acres which is predominantly grass covered, but is also broken up into smaller pieces by trees, mostly spruce or fir of less than 40 feet height, by some smaller fruit trees to the SE of the tower, and by the Hagen House and garage. Grass within this larger area is mostly uncut and ranges up to heights of about five feet E and SE of the tower. It probably averages two to three feet in height over the eight acres and has 10-to-20 percent coverage by trees. Compared to a more typical meteorological tower site on cultivated crop land or pasture or CRP grassland, this "cleared" eight acres is quite aerodynamically rough.

Surrounding the comparatively rough grassy area are large trees in all directions except SE-S. To the SE at a range of about 100 meters across an old orchard with tall grass and some old fruit trees ranging up to about 15 feet in height lies Lake Superior. The lake is about 40 feet below the tower. For wind flow from the SE, the met tower receives wind flow relatively to completely undisturbed by the larger trees surrounding the site in most directions. This is true to a progressively lesser degree for S-SSW winds (and mainly only above 40 m for SSW winds)..

For wind flow from the NW-N-NE-ENE, the met tower is downwind of fir and spruce trees predominantly. These average about 60 feet in height. For winds from the

E-ESE, the met tower is downwind of deciduous trees ranging up to about 80 feet. For S winds, the met tower is about 120 meters from the lake and downwind of deciduous trees ranging up in height to about 40-60 feet. For SW-W winds, the tower is downwind of predominantly deciduous trees ranging up to about 80 feet in height. To the SW (220 degrees), the lake is about 200 m away. For winds from a more westerly direction (even 230 degrees), the lake is much more distant.

While this site generally exhibits a comparatively high surface roughness, it is nonetheless typical of heavily wooded Madeline Island in that regard. The island is more than 95 percent wooded, and most clearings are quite small. Some of the larger clearings which do exist are too close to homes to be desirable wind development sites.

Meteorological Sensors

SGES instrumented the met tower with six NRG #40C calibrated anemometers. Unfortunately, these anemometers were manufactured prior to the early 2009 re-design of the NRG #40s to eliminate "dry friction whip ("DFW")," a slowing of some anemometers during field exposure which can cause significant understatement of the measured wind resource. DFW has presented meteorologists some difficulties in recent years because it can cause intermittent under-reading of wind speed, but it does not affect all anemometers of the subject vintage; it can take from a few weeks to a number of months to develop; it can be fairly subtle initially; and it does not manifest itself at all wind speeds, but does so preferentially, some of the time, at wind speeds of 5-9 m/s (which are themselves fairly uncommon at the BBSP site as compared to a windier site). When DFW does occur, it can cause under-reading by up to 0.6 m/s, but typically it is less than this, with some tendency to increase with time. DFW is a factor tending to increase the uncertainty as to the wind resource at BBSP. (This uncertainty can be reduced or mitigated by post-exposure re-calibration of the anemometers, however.)

SGES also instrumented the met tower with two NRG #200P wind vanes. These were on 60-inch-long side-mount booms oriented due S at 48 m and at 39 m. The wind vane booms were approximately one meter below S-oriented anemometer booms.

SGES placed S and W-oriented anemometer booms (90 degrees apart) at 49, 40, and 30 meter heights on the met tower. The anemometer booms were 43 inches long according to the SGES site commissioning form.

SGES placed an NRG #100S radiation-shielded thermometer on the N side of the tower at about 2 meters.

Except for DFW, all sensors performed well during the first year of measurements. I will address DFW further later.

SGES sensor deployments were as follows (correcting an error in the site commissioning form as to the directional orientation of Sensors 5 and 6*):

Sensor 1	#40C	SN 84895	49 m	Oriented S (180 degrees)
Sensor 2	#40C	SN 94233	49	" W
Sensor 3	#40C	SN 94894	40	" S
Sensor 4	#40C	SN 84292	40	" W
Sensor 5	#40C	SN 84234	30	" W*
Sensor 6	#40C	SN 84232	30	" S*
Sensor 7	#200P		48	" S
Sensor 10	#200P		39	" S
Sensor 11	#110S		2	" N

BBSP Park Superintendent Mark Eggleson provided digital photos of the met tower which were quite helpful in my understanding of the sensor booms and orientations.

The SGES site commissioning form for the BBSP met tower is attached as Appendix B.

Data Recovery

WI DNR (BBSP) personnel recovered the data by data card exchange on approximately a weekly basis and then e-mailed the raw data. There were no data losses or significant glitches in this process.

There were extremely modest data losses due to sensor icing in the first year. Data recovery from all sensors was outstanding, greatly exceeding 99 percent in all cases.

The data averaging period used was ten minutes.

Anemometer Correction for Dry Friction Whip

When dry friction whip (DFW) occurs, the affected anemometer converts some wind energy to vibration instead of rotation. DFW can be a rather subtle and insidious phenomenon. I consulted with NRG Systems, the seller of the anemometers, and conducted some extra analyses to attempt to determine which, if any, of the BBSP anemometers were suffering from this phenomenon. As a result of the consultation and analyses, I identified Sensor 5 as probably suffering from DFW beginning in late August 2009. This was the 30 meter anemometer oriented to the W of the tower. Other sensors were not so obviously affected.

I corrected wind speeds from Sensor 5 in the 5-to-9 m/s range by adding .25 m/s to such speeds on and after August 23.

I did not correct reported wind speeds for any other anemometers because I did not see unambiguous evidence of DFW in the data from other anemometers on the BBSP met tower. There was some ambiguity in the scatter plots, however, so it is possible that Sensor 5 was not the only one affected by DFW.

A way to check this would be to subject any current anemometer suspected of DFW to post-exposure calibration testing when and if the tower is lowered in Spring 2010. A substantial increase in anemometer offset as compared to the pre-exposure value measured by Otech Engineering (see Appendix B2) would be a red flag warranting another look at whether a particular anemometer was being affected by DFW. Even if an anemometer is later determined to be suffering from DFW, its mean wind speed will probably not be dramatically increased as a result. An upper limit for an increase in annual average wind speed, if the DFW existed for virtually the entire period of measurements, is probably about 0.2 m/s.

While this measurement campaign did not include funding for post-exposure anemometer calibration testing, such testing would be a useful addition to the effort this spring. It could reduce the uncertainty in the 49-m mean wind speed at BBSP if at least the two 49-m anemometers would be re-calibrated post exposure.

In the absence of such testing, I conclude that the 49-m wind measurements were not subject to DFW and did not systematically understate the winds experienced for the first year at BBSP.[1]

Measurement Results

Year 1 (Nov. '08-Oct. '09) Wind Speeds

Measured wind speeds for the six different anemometers for the first year at BBSP were as shown in Table 1 below. Since icing data losses for the first year were insignificant, I have not bothered to attempt to replace the values lost due to icing on one or a few occasions (half of the anemometers lost no data at all to icing). I have simply averaged the valid values.

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[1] This is not to say that the anemometers were unaffected by tower shadow. At this site, though, with its low frequency of winds from due N, tower shadow had little net depressing effect on S-oriented sensors.

Table 1

Measured BBSP Mean Annual Wind Speeds and Other Statistics
11/1/08-10/31/09

Sensor	Mean W/S m/s	Mean W/S (mph)	Mean Std Dev. m/s	Turbulence Intensity (TI)[2]	Number Valid Values[3]	% Data Recovery
49 m S	4.96	(11.1)	.85	.17	52,495	99.88
49 m W	4.93	(11.0)	.83	.17	52,495	99.88
40 m S	4.51	(10.1)	.88	.20	52,560	100.00
40 m W	4.44	(9.9)	.88	.20	52,560	100.00
30 m S	3.81	(8.5)	.93	.24	52,539	99.96
30 m W	3.79	(8.5)	.92	.24	52,560	100.00

Measured wind speeds at each tower level are very close to each other. Wind speeds on S-facing booms are slightly higher than those on W-facing booms. Wind speed increases rapidly with height, and turbulence intensity decreases fairly rapidly with height. All of these features make sense at this site and are consistent with measurement accuracy and repeatability.

Unfortunately, they are not consistent with a highly promising wind resource. The 49 m S annual mean of 4.96 m/s (11.1 mph) is too modest to support commercial-scale wind generation at the 49-m elevation. Furthermore, the turbulence intensity of .17 at 49 m, although considerably lower than that at 30 m (.24) or even 40 m (.20), is too high to support commercial-scale wind generation at the 49-m level. The modest wind speeds and comparatively high turbulence intensity at BBSP would counsel use of a taller tower to increase the former and decrease the latter.

Turbulence intensity does vary with wind direction at BBSP. It is notably lower for SE-S-SSW winds, which are off the lake and less affected by trees before reaching the top of the met tower than are winds from other directions. While the mean turbulence intensity at the 49-m S anemometer is .17, the TI averages only .09 for wind from 140 to 220 degrees. What this means is that winds from 140 to 220 degrees are off the lake and are often reaching the 49-meter anemometer without being affected by trees between the lake and the met tower.

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[2] TI is the standard deviation (m/s) divided by the wind speed (m/s). It is non-dimensional.

[3] % Data Recovery = (No. Valid Values/52560)100.00%.

Wind Shear

Wind shear (increase of wind speed with height) was very high, but did decrease significantly with tower height, during the first year of measurements. Shear exponent at BBSP varied as follows:

	S-oriented sensors	W-oriented sensors
40-49 m	.47	.52
30-40	.59	.55

Wind shear exponents at or above .4 are typically associated with forest land cover. While high in absolute terms, wind shear does appear to drop off with height. This is also consistent with the forest surroundings.

For winds from the SE-S-SSW, wind shear is lower at BBSP. This reflects the fact that wind flow off the lake is less disturbed by trees in winds from these directions. For winds from 140 to 220 degrees, the S-oriented sensors had a mean wind shear of .35 from 40-to-49 meters. The relatively high shear value even for less turbulent flows off the lake suggests that such air was often highly stable (temperature increasing with height) or that SW winds tend to have high shear. Both factors were probably at work here.

The high level of mean wind shear for most wind directions means that the improved wind resource would easily justify the increased cost to use taller towers on the island.

First Year Seasonal Variations

Monthly mean wind speeds varied significantly in the first year. In general, the summer season was less windy than the rest of the year. Monthly means are shown in Table 2 below. While this figure just shows 49-meter data from the S-facing boom, the other anemometers display a similar seasonal pattern.

Table 2

Month	49-m S Mean Wind Speed (m/s)
Nov. 2008	5.34
Dec.	6.18
Jan. 2009	5.33
Feb.	4.90
Mar.	5.15
Apr.	4.90
May	5.53
June	4.08
July	4.33
Aug.	4.51
Sept.	3.76
Oct.	5.46

Diurnal Variation

Even at the 49-meter level, the BBSP met tower displayed a variation between day and nighttime mean wind speeds, with winds reaching their highest hourly averages in mid afternoon and lowest around sunrise. Morning winds were in general slightly less than afternoon winds. The hourly figures are shown in Appendix C. It would be dangerous to infer from Appendix C, however, that the same pattern would apply at a greater tower height better suited for wind power production on Madeline Island. Probably, the pattern at 75 or 80 or 100 meters would be somewhat different.

Wind Roses

The prevailing winds at BBSP at 49 meters are from the SSW-SW. SW winds generate significantly more wind energy than any other direction. They are both relatively frequent and relatively strong in mean wind speed. This is commonly true at Wisconsin wind sites.

The wind rose showing 49-meter wind direction frequencies is in Appendix D.

The wind rose showing 49-meter wind energy by direction is in Appendix E.

Wind roses at 75 meters would probably look similar to Appendices D and E.

High-Wind Events

BBSP experienced a number of winter storms, thunderstorms, an episode of extremely sudden warming, and other events with elevated winds in the first year of wind measurements.

The island also experienced a period of about four weeks of extremely light winds in a September warm spell prior to a windy period just before the end of that month.

One of the more extraordinary events occurred on May 20, 2009, when the temperature at the BBSP met tower climbed from 2.3 C (36 F) to 24.9 C (77 F) between about 5:20 a.m. and 3:20 p.m. This event was accompanied by strong winds and was quite similar in its temperature impact to a Chinook wind event E of the Rocky Mountains. Actually, Lake Superior tempered the thermal impact of this event at BBSP. At the Bayfield State Fish Hatchery, Darren Miller reported that the temperature range this day was from 30 F to 93 F! At Ashland Kennedy Airport, it was from 33 F to 90 F. At some locations in Minnesota, the temperature reached or slightly exceeded 100 F.

While the day started out calm, the high temperatures at BBSP on May 20 were accompanied by strong winds. The highest 10-minute mean wind speed that day was 19.2 m/s (43 mph) at the 49-meter S anemometer at 4:20 p.m. The highest gust wind speed that day, at the same anemometer, was 22.4 m/s (50 mph). The strong winds on May 20 were from the SW.

The highest 10-minute mean wind speed for the year was 19.2 m/s on May 20. The highest gust of 23.1 m/s (52 mph) occurred on the 49-m S anemometer on September 28 at 10:30 a.m. from the N during a cold rain event.

BBSP Temperatures

The mean temperature at BBSP for the first year of wind monitoring was 5.62 C (42.1 F).[4] The highest was 32.8 C (91 F) on August 13. The lowest was -27.4 C (-17 F) on February 28. (Ashland on the mainland reported hourly highs of 90 on May 20 and lows of -20 on January 15 and February 28.) July was unusually cool, with a mean temperature of 17.9 C (64 F). The warmest month was August, with a mean of 18.6 C (65.5 F). September was extraordinarily warm, with a mean temperature of 17.7 C (64 F). These last are means from the met tower sensor, which may be upward biased by 0.6 C or more.

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[4] I am not correcting the BBSP temperature, but it is possible that that sensor is reading slightly too high. In an April 19, 2009, icing event, both 49-m anemometers and the 49 and 39-meter wind vanes apparently iced up and stopped turning while the 40 and 30-meter anemometers continued to spin. This event started with the reported 2-meter temperature at 1.0 C or 33.8 F. The temperature cannot have been that high. It was at least .6 C or 1.0 F colder than this. In a precipitation event, the temperature at 49 m cannot be more than about 0.5 C or 0.8 F lower than the 2-meter temperature. In this case, it appeared that the temperature was slightly below freezing at 49 meters and just about right at freezing at 39 meters. When the reported 2-meter temperature rose to 1.3 C, the top sensors thawed and resumed spinning. I conclude that the reported BBSP temperatures are upward biased by at least .6 C or 1.0 F. This would tend to explain part of the difference between the mean temperatures at BBSP and Ashland for the first year of BBPS measurements (42.1 vs. 39.6). The higher elevation of the Ashland Airport may explain part of the difference also.

Inter-annual Wind Variability

The 49-m S wind speed mean at BBSP for the first year was 4.96 m/s (11.1 mph). Was this typical or above or below the long-term mean for this location? To try to answer this question, I looked at hourly 10-meter wind speed data from Ashland Kennedy Airport, about 19 miles SSW of BBSP. I also looked at some monthly wind speed data from Duluth, MN, approximately 74 miles W of BBSP. I considered but decided not to use comparison data from the Devils Island C-MAN Station in the Apostles because this station experienced substantial data loss during the first year of monitoring at BBSP. Due to its virtually complete data record and proximity, I used Ashland Airport as my primary comparison station for BBSP. At the end of my analysis, I concluded that the mean wind speed measured at BBSP for the first 12 months was probably close to the current annual normal.

Ashland Wind Data 11/1/04-10/31/09

In considering which station to use as a primary comparison for the BBSP site, I looked at recent anemometer changes. National Weather Service Duluth Meteorologist Steve Gohde reported that the anemometer at Ashland was changed to a sonic anemometer in November 2004. An NWS Duluth electronics technician maintains the wind sensor at Ashland. Typically, the change to a sonic anemometer has slightly reduced reported mean wind speeds, so I resolved to look only at Ashland data subsequent to October, 2004.

I obtained five years of Ashland hourly data from the Midwest Regional Climate Center covering the period from November 1, 2004, through October 31, 2009, and put it into database format for analysis. This data includes sonic anemometer wind speeds from the Ashland 10-meter anemometer.

The Ashland anemometer is located near the S end of the airport and did not move during the five-year reference period. There is a good-sized woodlot about 200 meters S of the anemometer mast. This appears to span an arc from about 120-to-180 degrees relative to the anemometer tower. A portion of the woodlot about 150 meters S of the tower and to its SE was apparently cut either in Fall 2008 or Spring 2009, according to Steve Gohde. In looking at wind data subsequent to Spring 2009, I could not discern a very significant effect on mean wind speeds from this cut. SE wind frequencies at Ashland are modest. I decided to assume any increase in wind speeds from this reduction in size of the nearby woodlot to the SE was *de minimus* in effect on Ashland mean wind speed. Any resulting increase would probably be less than 0.2%.

The reporting format for wind at Ashland in the MWRCC data changed half way through the five year period. Prior to the format change, hourly data reported wind speed rounded to whole knots. Thereafter, decimal knots were reported, and the lowest non-zero value reported was 2.6 rather than 3 knots. In both cases, values of less than the threshold were reported as 0 (even though the sonic anemometer can resolve a wind speed as low as 0.4 knot). This procedure treats very low non-zero wind speeds as if they are zero and slightly understates mean wind speed. Unfortunately, the change in non-zero reporting threshold from 3 to 2.6 probably has the result of reducing the understatement of actual wind speed, and means that there must be some adjustment to compare pre- and post-reporting-change mean wind speeds. In the 3-knot case, winds of 2.6 to 2.99 knots are reported as 0. In the 2.6-knot case, they are reported as 2.6 knots.

To correct for the effects of this reporting change, I am assuming that there is a uniform distribution of wind speeds below 3 knots and that there are no actual zero wind speeds. Thus, I asume that the wind speed range from 2.6 to 2.99 accounts for 13 % of wind speeds below the 3-knot level, and I assume that the mean wind speed of this range is 2.8 knots. I am correcting the pre-change reported wind speeds upward accordingly so they are comparable to the post-change reported wind speeds.[5]

Data recovery for wind data for the five years at Ashland was very high. Missing data never exceeded 59 hours in any of the five years. Temperature data recovery was also high. Table 4 below shows the means of wind speed and temperature for the five years examined at Ashland.

Table 3

Period	Mean Wind Speed	Mean Corrected W/S	Mean Temp.
11/1/2004-10/31/2005	7.18 mph	7.24 mph	42.2 F
11/1/2005-10/31/2006	6.77	6.84	43.7
11/1/2006-10/31/2007	7.81	7.83	43.9
11/1/2007-10/31/2008	7.72	7.72	40.3
11/1/2008-10/31/2009	7.38	7.38	39.6
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Five-year mean		7.40 mph	41.9 F

For the first year of monitoring at BBSP, Ashland Airport experienced a mean wind speed of 7.38 mph, 99.7% of the five-year normal annual mean of 7.40 mph at airport. It is unlikely that the mean for this 12-month period would have been less than 7.37 mph, which is more than 99.5% of the normal, even if the trees SE of the airport anemometer had not been cut. I conclude that the measured 49-m S value of 4.96 m/s (11.1 mph) is probably equal to the long-term mean wind speed at 49 meters at Big Bay State Park and that the corresponding value at 50 meters is 5.00 m/s (11.2 mph). How-

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[5] My correction procedure is to determine the number of hours of zero reported wind, multiply that by 0.13 times 2.8 times 1.15, add the product to the total original wind speed-hours, and divide the sum by the total number of hours of valid data for the period in question. The corrected wind speed result is comparable to the wind speeds reported after the non-zero threshold was dropped to 2.6 knots.

ever, there is a slightly larger chance that the actual values are larger than smaller than these estimates. The last year may have been very slightly below the long term mean.

Duluth Wind Data

The National Weather Service Station at Duluth International Airport also has a long-term wind speed data record. The mean wind speed at Duluth , the closest first order climate data station to Madeline Island, for the period Nov. 1, 2004, through Oct. 31, 2009, was 9.76 mph. But for the last year corresponding to the first year of measurements at BBSP, the mean was 9.42 mph, 96.5% of the five-year normal.

While the Duluth wind measurement location and height did not change during this period and the anemometer exposure remained the same according to Meteorologist Steve Gohde, the anemometer type did change. The NWS replaced the old Belfort cup anemometer at Duluth with a sonic anemometer on July 25, 2007. For the two (Nov.-Oct.) years since this anemometer change, the Duluth mean wind speed was 9.736 mph. By comparison, the most recent Nov.-Oct. mean was 9.419 mph, 96.7% of the two-year "normal."

While it is likely that Nov. 2008 through Oct. 2009 mean wind speeds were significantly below normal at Duluth, it is less likely that they were significantly below normal at BBSP. I believe it is appropriate to give greater weight to the Ashland than to the Duluth comparison wind speeds in view of the much closer proximity of Ashland Airport to Madeline Island.

Further BBSP Measurements

Measurements are continuing at BBSP. Longer-duration measurements tend to reduce the uncertainty band around the BBSP wind resource. Measurements longer than a year are particularly useful at sites remote from comparison stations or differing significantly (offshore versus onshore, mostly wooded versus mostly grass-covered) from those stations. After I have an additional six or more months of data from BBSP, I may have a somewhat increased level of confidence about its long-term wind resource, and my estimate of the long-term mean may also change.

Is Global Warming Raising/Lowering the Mean Wind Speed at BBSP?

While the last two years of cooling at Ashland do not disprove global warming, it is nonetheless true that the recent trend in mean annual temperatures has not been up at Ashland.

Recently, some researchers have indicated that there appears to be an upward trend in wind speeds in the Lake Superior Region which they attribute to climate change and greater warming of the lake than the atmosphere in the region.[6] This is

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[6] Ankur R. Desai, *et al.*, "Stronger winds over a large lake in response to weakening air-to-lake temperature gradient," Nature Geoscience 2, 855-858 (2009).

an interesting theory based on pre-2008 data which warrants further research. In the absence of corroboration, though, I am not inclined to predict a 5% per decade increase in mean wind speeds at BBSP or Madeline Island in general.

If the theory is correct and the region is now in a cooling phase driven by a recent change in the Pacific Decadal Oscillation or the Arctic Oscillation or a solar minimum, the same theory would suggest that winds at Madeline Island should decline during the cooling phase.

If, on the other hand, the lake is not differentially warming/cooling relative to the local atmosphere, the theory would suggest that mean wind speeds should stay about the same.

In other regions of North America, there appears to be a negative correlation between mean temperature and mean wind speed. In these areas, warming begets a longer summer and lower mean annual wind speeds. The exceptionally low mean wind speed of September 2009 on the island occurred during an exceptionally warm month (although wind speeds increased and temperatures dropped sharply at the end of that month). This pattern is common in the Midwest. Very warm months often have very low mean wind speeds. Meteorologically, this makes sense because very warm months tend to involve long-duration high pressure ridges which displace the polar jet stream far to the N of its normal seasonal position. In the Midwest, we tend to experience light winds under such ridges.

If we would experience longer, warmer, summers in the Lake Superior Region, we would also normally spend more time under the influence of warm high-pressure ridges with light winds. Summer winds, at least, would probably tend to decline.

I cannot predict the future course of warming or cooling in the region and cannot confidently speculate on future changes in mean wind speed. It could increase, decrease or stay the same. If it would increase by 5% per decade, that would be a tremendous boon for turbine owners. Under that scenario, wind energy production would likely increase by more than 10% per decade. I am just skeptical as to the likelihood of such a scenario and would consider it imprudent to do financial planning for a wind turbine or turbines on the basis of such a rosy, optimistic, scenario.

We cannot be certain that the Lake Superior Region is currently warming or that it will be warming for the useful life of 20-30 years of a new wind turbine installation. Even if global warming is proceeding, a regionally significant cyclical phenomenon like a cold phase of the PDO or the AO could completely, if temporarily, mask the warming signal on Lake Superior, leaving the island unable to benefit for decades from the phenomenon recently identified. The prudent course is not to bank on it.

Conclusions

I have a 95% level of confidence that the long-term mean wind speed at 50 m at BBSP lies between 4.8 and 5.5 m/s. My current estimate is 5.0 m/s (11.2 mph). The upper range is as high as it is because I am uncertain about the DFW status of the 49-m anemometers.

With post-exposure calibration testing by Otech Engineering of the 49-m anemometers and at least six months more of wind data likely to be available by spring, I would expect to be able to refine the above wind-speed range to a narrower range by June.

Even if my mean wind speed estimate remains at 5.0 m/s, wind shear at BBSP is so substantial that I am 90% confident that a wind resource of 5.6 m/s (12.5 mph) or higher exists at BBSP at and above 75 m. I am 50% confident that this BBSP resource meets or exceeds 6.0 m/s (13.4 mph).

This means that the island appears to have a modest tall-tower wind resource. However, such resources have been developed for community wind projects elsewhere. An example is Fox Island, ME. Some of the public school and college campus community wind projects in MN and IA are also probably in this wind speed range.

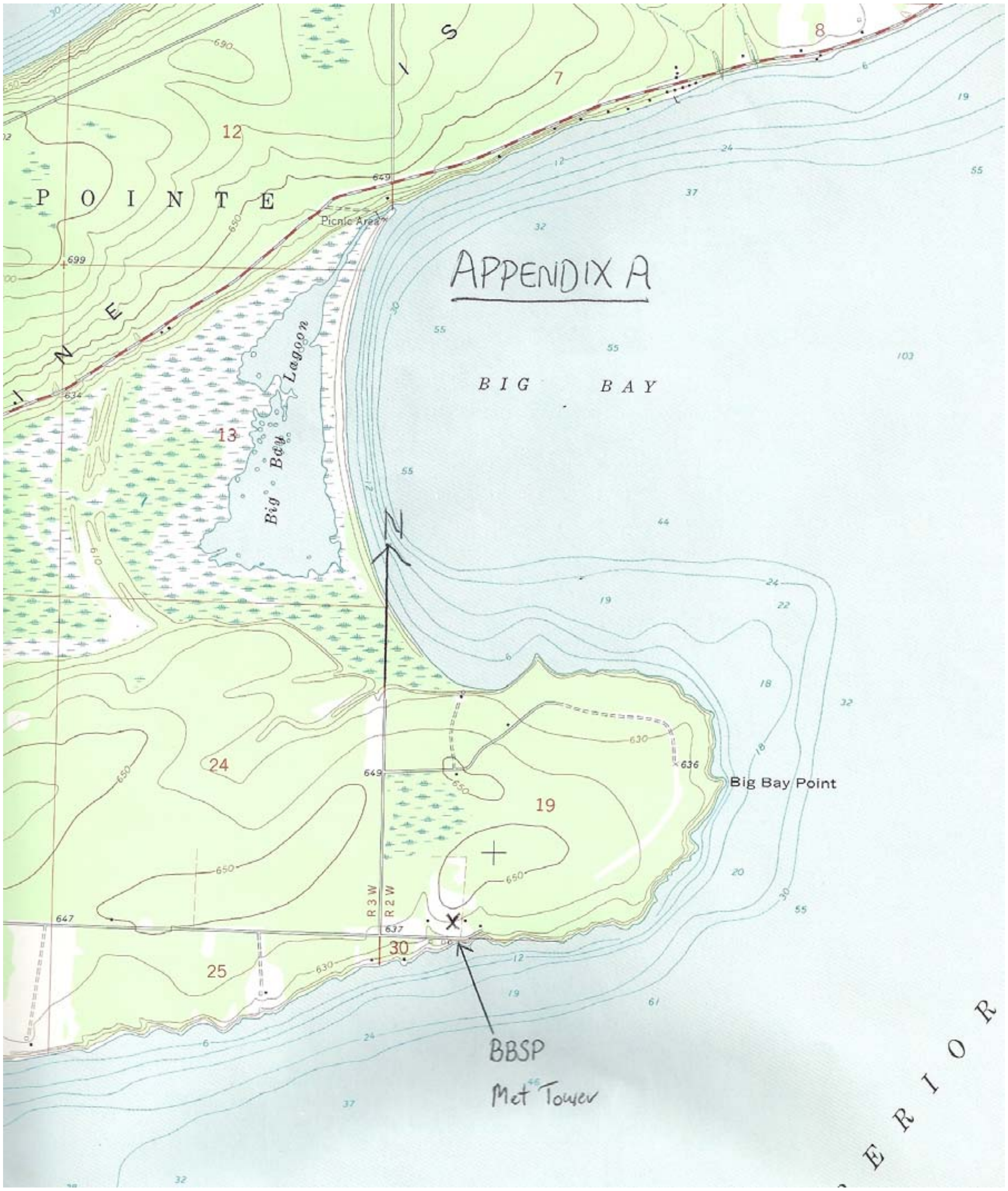
A subsequent report on sodar measurements at BBSP funded by Xcel Energy will shed further light on the wind-shear situation above 50 meters at that site.

Acknowledgments

Many people and groups have contributed to this wind measurement effort. A big thank you is due to the dedicated volunteers of the Town of La Pointe AEC, who have worked hard to make it happen, Burke Henry, Larry Bean, Carl Frederickson, Mark Eggleson, and Alan Fischlowitz. The Bad River Band made the meteorological tower available. Mark Eggleson and Greg Behling of the DNR BBSP Staff worked diligently to keep the data flowing (and are continuing that effort). Mark also provided helpful digital photos of the site and sensors/sensor booms. SGES put up the tower and Dave Drapac of SGES provided me with the SGES site commissioning form. Julia Austin and John Goglia of NRG Systems helped with the DFW analysis. National Weather Service Meteorologist Steve Gohde of the NWS Duluth Forecast Office provided important information on the anemometers and exposure conditions at Ashland Kennedy Airport and Duluth International Airport. Burke Henry caught a data processing error which I have corrected in this final report. Alan Black of the Midwest Regional Climate Center provided hourly weather data for Ashland Kennedy Airport for the previous five years. My son Michael helped with the data. Wisconsin Focus on Energy supported the effort financially, as did a number of other organizations involved through the hard work of the AEC. While I appreciate all of the help of the above groups and individuals, the conclusions and any underlying errors in this report are my responsibility.

February 4, 2010 Robert H. Owen, Jr., P.E.

APPENDIX A



POINTE
Picnic Area
Big Bay Lagoon
BIG BAY
Big Bay Point
N
R3W
R2W
12
13
24
25
7
8
19
30
649
699
634
647
637
636
650
630
BBSP
Met Tower
ERIOR

APPENDIX B

BBSP Met Tower
Site Commissioning Form

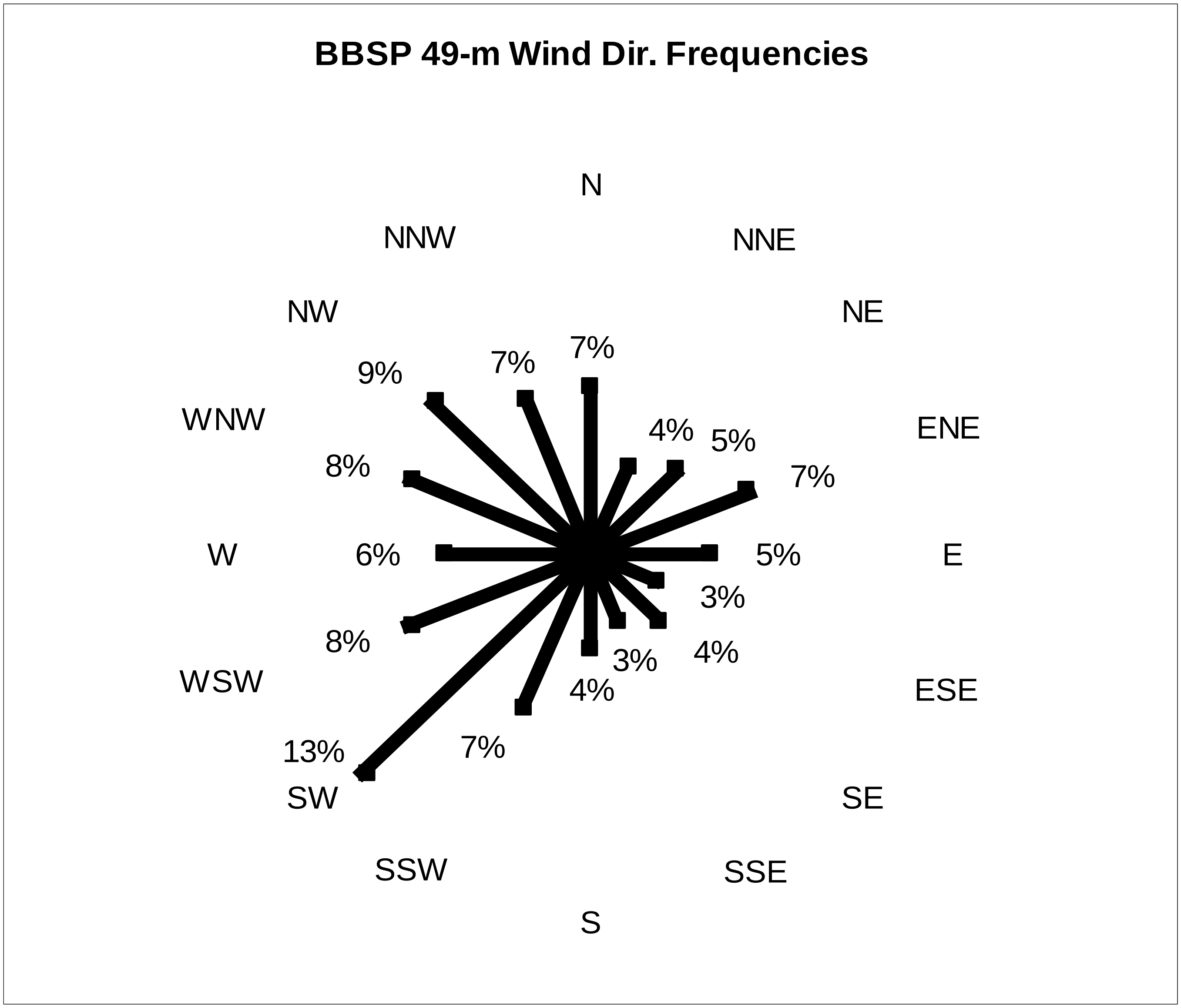
(4-page .pdf document BBSPAPPENDIXB2
entitled: “SGES Tall Tower
Site Commissioning Form
0001 Madeline Island”)

Appendix C

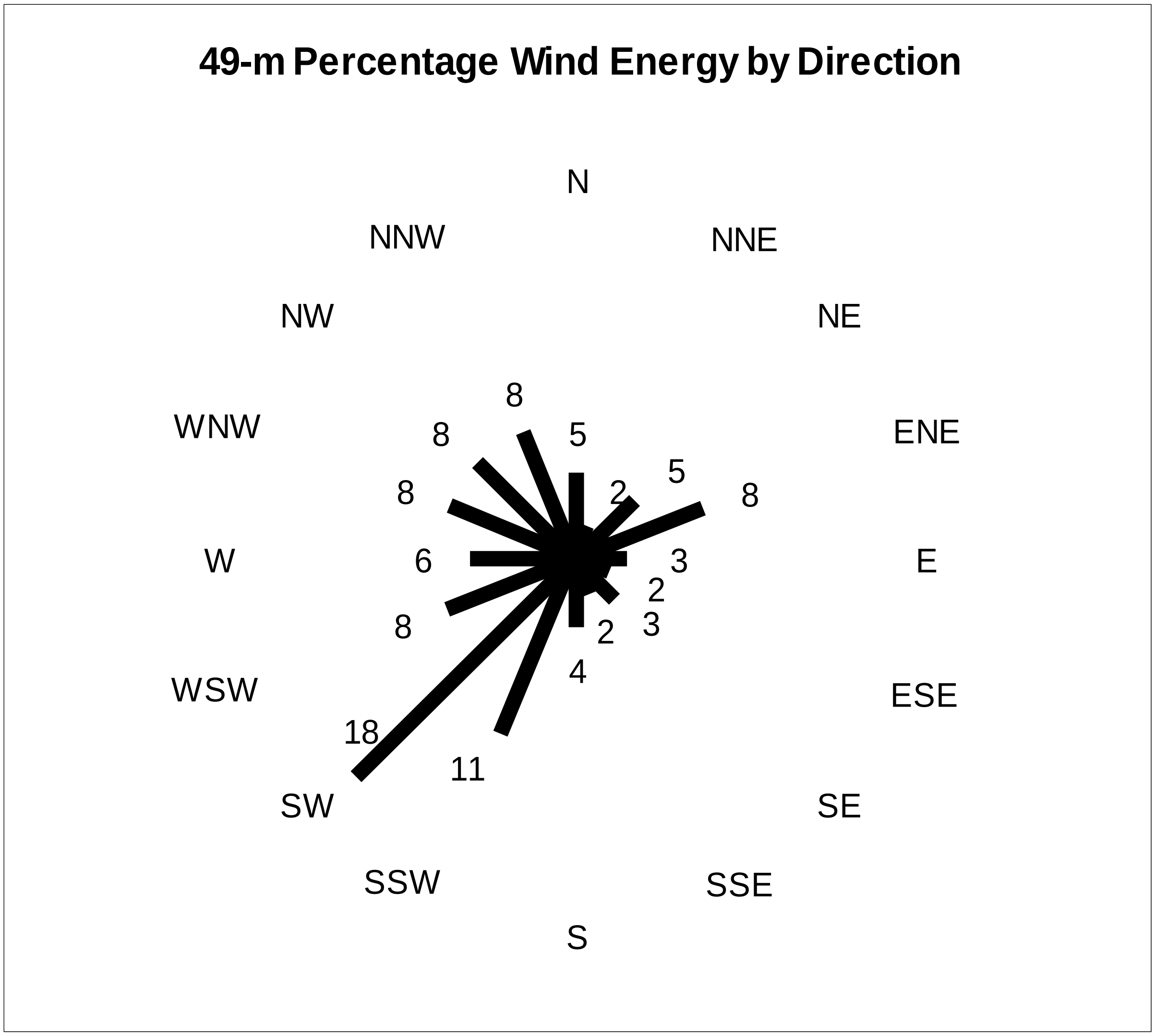
Variation of Mean Wind Speeds With Time of Day
BBSP 49-m S Mean Wind Speeds (m/s)

Hour	Mean Wind Speed (m/s)
Midnight-1 a.m.	4.93
1-2 “	4.96
2-3 “	4.95
3-4 “	4.84
4-5 “	4.84
5-6 “	4.91
6-7 “	4.78
7-8 “	4.31
8-9 “	4.85
9-10 “	4.74
10-11 “	4.85
11-Noon	4.86
Noon-1 p.m.	4.92
1-2 ”	5.08
2-3 “	5.17
3-4 “	5.32
4-5 “	5.15
5-6 “	5.10
6-7 “	5.05
7-8 “	4.97
8-9 “	4.99
9-10 “	5.07
10-11 “	5.09
11-Midnight	5.02

APPENDIX D


BBSP 49-m Wind Dir. Frequencies
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
7%
4%
5%
7%
5%
3%
4%
3%
4%
7%
13%
8%
6%
8%
9%
7%

APPENDIX E



49-m Percentage Wind Energy by Direction