

LONG TERM SITE WIND DATA ANNUAL REPORT

WBZ

July 1, 2012 – June 30, 2013

Prepared for

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NOTICE AND ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

All the work presented in this Wind Data Report including installation and decommissioning of the meteorological tower and instrumentation, and the data analysis and reporting was performed by the Wind Energy Center (WEC) at the University of Massachusetts, Amherst.

Wind monitoring equipment was first installed at WBZ AM radio tower in Hull, MA on August 28, 2006. On July 22, 2012 new wireless sensors and a data logger was installed at the site in hopes that the wireless equipment would be immune to the radio interference which has been a problem at the site. Sensors are located at 118m (387 ft), 87m (285 ft), and 61m (200 ft).

During the period covered by this annual report, July, 2012 – June, 2013, the mean recorded wind speed at 118 m was 7.60 m/s (17.00 mph*). The annual average wind speed for this year is similar to the estimated long term annual average wind speed of 7.61 m/s (17.02 mph) at the site. The estimated long term annual average wind speed is estimated by correlating the wind data at WBZ with the long term wind data at Thompson Island. Much of the wind direction data was lost due to sensor failures, but the prevailing wind direction during the first 4 months of the monitoring period was from the South-Southwest. The average turbulence intensity measured at wind speeds near 10 m/s at 118 m was 0.103. The gross data recovery percentage (the actual percentage of expected data received) was 99.2% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 35.3%. The majority of the missing data were due to the failure of 7 of the 10 sensors during the monitoring period.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, “Interpreting Your Wind Resource Data,” produced by the WEC and the Massachusetts Technology Collaborative (MTC). This document is found through the WEC website:

http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/ERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1 - Station Location

The WBZ radio tower is located near the salt marsh on the west coast of the Hull isthmus that is located on the southern portion of the Boston Harbor, as shown in Figure 1. The site coordinates are 42° 16' 44.11" N by 70° 52' 34.39" W. These coordinates correspond to the NAD83 datum.

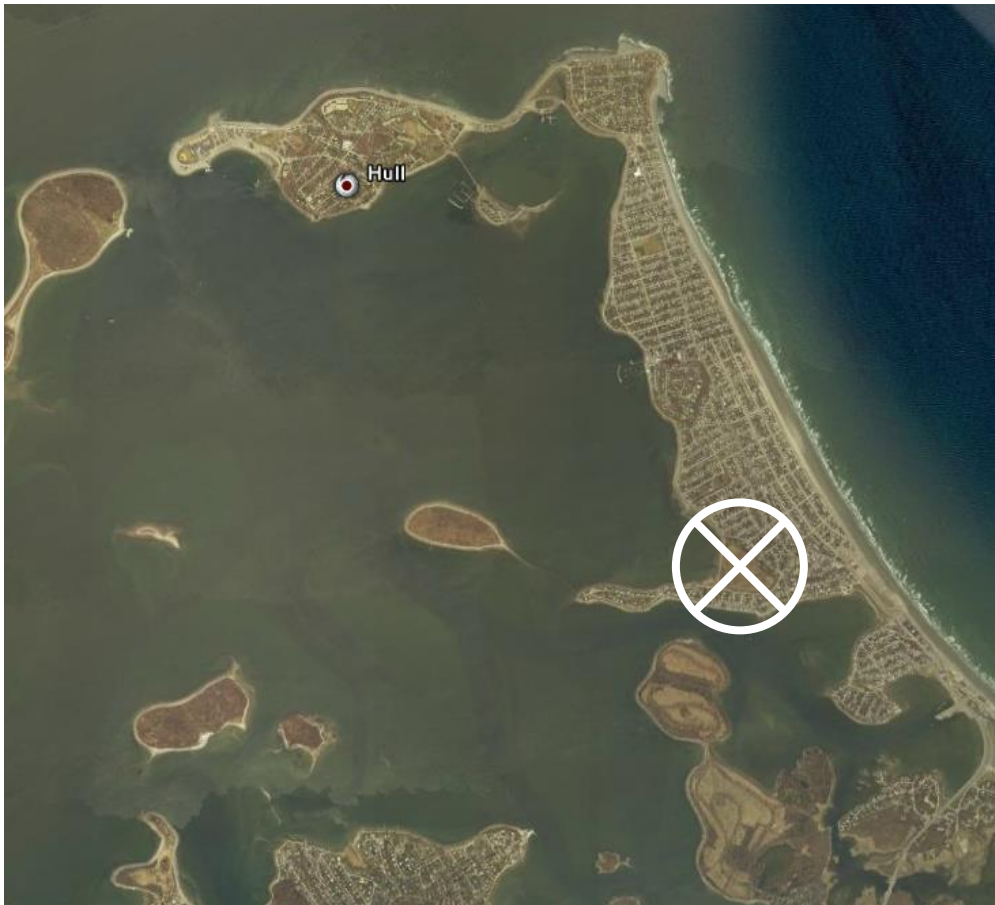


Figure 1 - WBZ Site Location in Hull, MA

Terrain

The site is located on an AM radio tower. The interference from the AM signal has been an ongoing problem at the site and it also makes maintenance at the site difficult because the AM signal needs to be shut down for maintenance. A bay is located to the west of the tower. A small section of land is located to the east of the tower and beyond the land is the ocean.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an existing radio tower, known as the WBZ AM broadcast tower. The following list of sensors and other equipment are mounted on the tower:

- 1 – Etesian 101 anemometer located at a height of 87 m (285 ft).
- 3 - Etesian 101-D combination anemometer/wind vane located at heights of 118m (387 ft), 87m (285 ft) and 61m (200 ft).
- 2 – Etesian 101-T combination anemometer/temperature sensors located at heights of 118m (387 ft) and 61m (200 ft) each.
- Etesian 201 data logger.

The data from the Etesian data logger is downloaded to the Wind Energy Center at the University of Massachusetts, Amherst on a daily basis. These text files are then imported into a database software program where they are subjected to quality assurance (QA) tests prior to using the data.

SECTION 3- Data Summary

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

Table 1. Wind Speed and Direction Data Summary

	Month	Mean Wind Speed [m/s]	NDR [%]	Max Wind Speed [m/s]	NDR [%]	Prevailing Direction [deg]	NDR [%]
118 m	12-Jul*	6.298	29.10	19.5	29.10	**	3.786
	12-Aug	5.903	90.41	13.6	90.41	**	0
	12-Sep	6.583	92.34	18.4	92.34	**	0
	12-Oct	7.581	90.19	29.2	90.19	**	0
	12-Nov	8.024	96.06	23.3	96.06	**	0
	12-Dec	8.082	96.26	25.4	96.26	**	0
	13-Jan	8.844	92.47	24	92.47	**	0
	13-Feb	9.07	95.44	30.3	95.44	**	0
	13-Mar	8.401	97.13	21.5	97.13	**	0
	13-Apr	7.86	95.09	18.4	95.09	**	0
	13-May	6.592	94.02	16	94.02	**	0
	13-Jun	7.006	95.12	17.1	95.12	**	0
	FY 2013	7.596	93.9	30.3	93.9	**	0.315
87 m	12-Jul*	5.872	29.35	17.2	29.35	SSW	13.04
	12-Aug	5.372	91.51	13.2	91.51	SSW	80.22
	12-Sep	6.118	93.54	17.4	93.54	SSW	83.66
	12-Oct	7.278	88.69	27.9	88.69	W	56.9
	12-Nov	7.734	97.55	22.7	97.55	**	1.713
	12-Dec	7.645	96.21	25.1	96.21	**	3.45
	13-Jan	8.141	89.14	20.4	89.14	**	0
	13-Feb	**	0	**	0	**	0
	13-Mar	**	0	**	0	**	0
	13-Apr	**	0	**	0	**	0
	13-May	12.58	0.6944	16	0.6944	**	0.7841
	13-Jun	**	0	**	0	**	0
	FY 2013	7.000	52.3	27.9	52.3	SSW	52.3
61 m	12-Jul*	5.310	29.3	16.3	29.3	**	0
	12-Aug	4.847	90.12	11.8	90.12	**	0
	12-Sep	5.501	93.56	16.8	93.56	**	0
	12-Oct	6.779	87.25	27.1	87.25	**	0
	12-Nov	20.21	2.616	26.1	2.616	**	0
	12-Dec	15.49	2.531	25.4	2.531	**	0
	13-Jan	18.65	1.03	26.4	1.03	**	0
	13-Feb	20.88	3.075	25.9	3.075	**	0
	13-Mar	17.18	3.651	23.9	3.651	**	0
	13-Apr	11.35	0.9491	15.7	0.9491	**	0
	13-May	10.24	0.8065	16	0.8065	**	0
	13-Jun	5.283	0.6713	13.9	0.6713	**	0
	FY 2013	6.198	28.12	27.1	28.12	**	0

* Data recording began on July 22, 2012. Therefore there is no data from July 1st to July 21st.

** Invalid data due to a lack of data recovery

Wind data statistics in the table are reported when more than 90% of the data during the reporting period that are valid. In cases when a large amount of data is missing, the percent of the available data that are used to determine the data statistics is noted. No measurement of wind speed or direction can be perfectly accurate. Wind speed measurement errors occur due to anemometer manufacturing variability, anemometer calibration errors, the response of anemometers to turbulence and vertical air flow and due to air flows caused by the anemometer mounting system. Every effort is made to reduce the sources of these errors. Nevertheless, the values reported in this report have an expected uncertainty of about $\pm 2\%$ or ± 0.2 m/s, whichever is greater. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of ± 5 degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included in Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed at each measurement height is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α , have been determined. They can be used in the following formula to estimate the average wind speed, $U(z)$, at height z , when the average wind speed, $U(z_r)$, at height z_r is known:

$$U(z) = U(z_r) \left(\frac{z}{z_r} \right)^\alpha$$

The change in wind speed with height is a very complicated relationship related to atmospheric conditions, wind speed, wind direction, time of day and time of year. This formula will not always provide the correct answer at any given site. Nevertheless the calculated shear coefficient, based on measurements at two heights, can be used to characterize the degree of increase in wind speed with height at a site.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{low} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log \left(\frac{U(z_{high})}{U(z_{low})} \right) / \log \left(\frac{z_{high}}{z_{low}} \right)$$

Table 2. Shear and Turbulence Intensity Data Summary

	Month	TI at 10 m/s [-]	NDR [%]		Month	Mean Wind Shear Coefficient [-]	NDR [%]
118 m	12-Jul*	0.07651	29.10	Mean Wind Shear Coefficient Between 118 and 87 meters	12-Jul	0.2299	29.1
	12-Aug	0.1026	90.41		12-Aug	0.3092	90.41
	12-Sep	0.1028	92.34		12-Sep	0.2403	92.34
	12-Oct	0.1103	90.19		12-Oct	0.1336	88.69
	12-Nov	0.09998	96.06		12-Nov	0.1207	96.06
	12-Dec	0.09536	96.26		12-Dec	0.1824	96.21
	13-Jan	0.1009	92.47		13-Jan	0.2718	89.14
	13-Feb	0.09495	95.44		13-Feb	**	0
	Mar-13	0.1076	97.13		Mar-13	**	0
	Apr-13	0.1067	95.09		Apr-13	**	0
	13-May	0.1125	94.02		13-May	**	0.6944
	13-Jun	0.1061	95.12		13-Jun	**	0
	FY 2013	0.103	93.9		FY 2013	0.2684	52.3
87 m	12-Jul*	0.08347	29.35	Mean Wind Shear Coefficient Between 118 and 61 meters	12-Jul	0.2585	29.1
	12-Aug	0.1207	91.51		12-Aug	0.2989	90.12
	12-Sep	0.1246	93.54		12-Sep	0.2721	92.34
	12-Oct	0.1265	88.69		12-Oct	0.1693	87.25
	12-Nov	0.1094	97.55		12-Nov	**	2.616
	12-Dec	0.1093	96.21		12-Dec	**	2.531
	13-Jan	0.117	89.14		13-Jan	**	1.03
	13-Feb	**	0		13-Feb	**	3.073
	Mar-13	**	0		Mar-13	**	3.651
	Apr-13	**	0		Apr-13	**	0.9491
	13-May	0.05586	0.6944		13-May	**	0.8065
	13-Jun	**	0		13-Jun	**	0.6702
	FY 2013	0.117	52.3		FY 2013	0.3084	28.12%
61 m	12-Jul*	0.08692	29.3	Mean Wind Shear Coefficient Between 87 and 61 meters	12-Jul	0.283	29.3
	12-Aug	0.1448	90.12		12-Aug	0.29	90.12
	12-Sep	0.1436	93.56		12-Sep	0.2995	93.54
	12-Oct	0.1237	87.25		12-Oct	0.2	87.25
	12-Nov	0.08824	2.616		12-Nov	**	2.616
	12-Dec	0.08139	2.531		12-Dec	**	2.531
	13-Jan	**	1.03		13-Jan	**	1.03
	13-Feb	**	3.075		13-Feb	**	0
	Mar-13	**	3.651		Mar-13	**	0
	Apr-13	0.08097	0.9491		Apr-13	**	0
	13-May	0.1083	0.8065		13-May	**	0.8065
	13-Jun	**	0.6713		13-Jun	**	0
	FY 2013	0.1286	28.12		FY 2013	0.3427	28.12%

* Data recording began on July 22, 2012. Therefore there is no data from July 1st to July 21st.

** Invalid data due to a lack of data recovery

The seasonal Average wind shear is given in Table 3. Table 4 gives the average night and day time wind shear values. Day time is defined as 6 AM to 6 PM with night time being all other

times. The average directional wind shear is given in Table 5. The average directional wind shear is calculated by placing the wind shears in bins and calculating the average for each bin. The bin centers are the directional sectors listed in Table 5. For instance, the directional sector of 0 is the average of all wind shear values when the wind direction is between 347.75° and 12.25° .

Table 3. Seasonal Average Wind Shear

	Mean Wind Shear Coefficient Between 118 and 87 meters [-]	NDR [%]	Mean Wind Shear Coefficient Between 118 and 61 meters [-]	NDR [%]	Mean Wind Shear Coefficient Between 87 and 61 meters [-]	NDR [%]
Jul - Sep 2012	0.260	70.62	0.277	70.52	0.291	70.99
Oct - Dec 2012	0.146	93.65	**	30.80	**	30.80
Jan - Mar 2013	**	29.71	**	2.58	**	0.34
Apr - Jun 2013	**	0.23	**	0.81	**	0.27

Table 4. Day and Night Time Wind Shear Averages

	Mean Wind Shear Coefficient Between 118 and 87 meters [-]	Mean Wind Shear Coefficient Between 118 and 61 meters [-]	Mean Wind Shear Coefficient Between 87 and 61 meters [-]
Day	0.747	0.372	0.079
Night	0.829	0.443	0.156

Table 5. Average Directional Wind Shear

Direction Sector [deg]	Mean Wind Shear Coefficient Between 118 and 87 meters [-]	Mean Wind Shear Coefficient Between 118 and 61 meters [-]	Mean Wind Shear Coefficient Between 87 and 61 meters [-]
0	0.199	0.341	0.455
22.5	-0.067	0.177	0.388
45	-0.467	-0.052	0.294
67.5	-0.585	-0.137	0.226
90	-0.278	-0.024	0.149
112.5	0.189	0.324	0.424
135	0.648	0.470	0.305
157.5	0.462	0.465	0.451
180	0.356	0.394	0.424
202.5	0.393	0.457	0.508
225	0.393	0.445	0.483
247.5	0.348	0.369	0.380
270	0.266	0.284	0.296
292.5	0.162	0.195	0.223
315	0.274	0.265	0.253
337.5	0.313	0.351	0.371

SECTION 4- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). Each quarterly graph corresponds to a quarter of fiscal year 2013: Quarter 1 (July 2012-September 2012), Quarter 2 (October 2012 to December 2012), Quarter 3 (January 2013 – March 2013), or Quarter 4 (April 2013 – June 2013). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed.
- Monthly Average – A plot of the monthly average wind speed over the three-month period. This graph shows the trends in the wind speed over the year.
- Diurnal – A plot of the average wind speed for each hour of the day.
- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed. Turbulence Intensity is calculated as the standard deviation of the wind speed

divided by the wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine.

- Wind Rose – A plot, by compass direction showing the percentage of time that the wind comes from a given direction and the average wind speed in that direction.
- Annual Average Wind Speed – A plot of the annual average wind speed at the site for each fiscal year.

With regard to the WBZ site, the following observations are noted.

- Time Series – Very high wind conditions were recorded on October 30th and February 9th.
- Wind Speed Distribution – The high wind conditions can be seen in the wind speed distributions for quarter 2 and quarter 3. The anemometer used are self powered wireless anemometers which do not record wind speeds less than approximately 2 m/s.
- Monthly Average – The winter months show higher average wind speeds than the summer months.
- Diurnal – A plot of the average wind speed for each hour of the day.
- Turbulence Intensity – In each quarter turbulence intensities for high wind speeds generally stay below 0.2
- Wind Rose – The wind direction data was invalid for much of the recording period. 76.03% of the data was valid for Q1 and 20.89% of the data was valid for Q2. The predominant wind directions were from the west and the south-west during these two quarters. No valid data was recovered for Q3 and Q4. Wind data from 87 meters were used to make these figures since the 118 meter wind vane did not report valid data for most of this period.
- Annual Average Wind Speed – The annual average wind speed at the site of 7.6 m/s is very similar to the estimated long term wind speed at the site of 7.61 m/s which is calculated using by correlating the WBZ wind data to the long term Thompson Island wind data.

Data for the wind speed histograms, quarterly and diurnal average plots, and wind roses are included in APPENDIX B.

Wind Speed Time Series

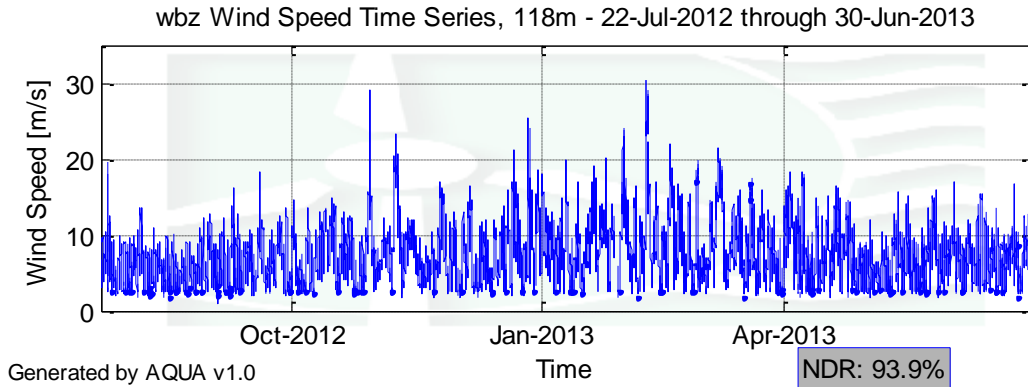


Figure 2 – Wind Speed Time Series

Wind Speed Distributions

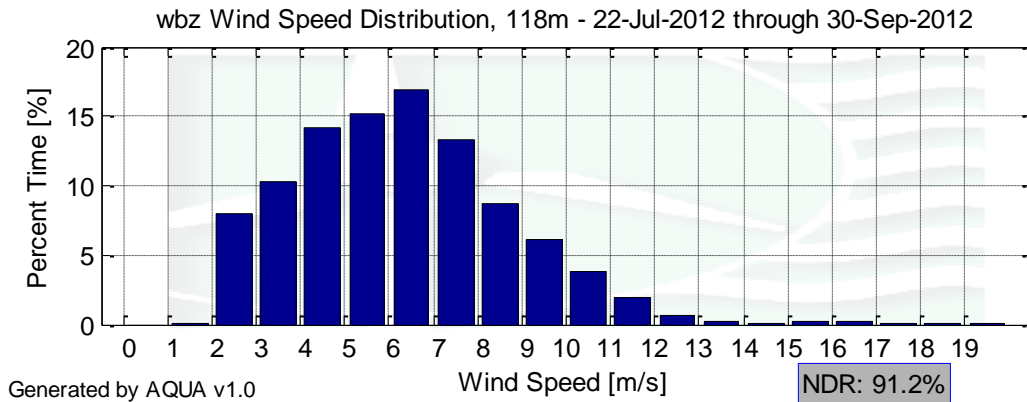


Figure 3a – Wind Speed Distribution Jul 2012 – Sep 2012

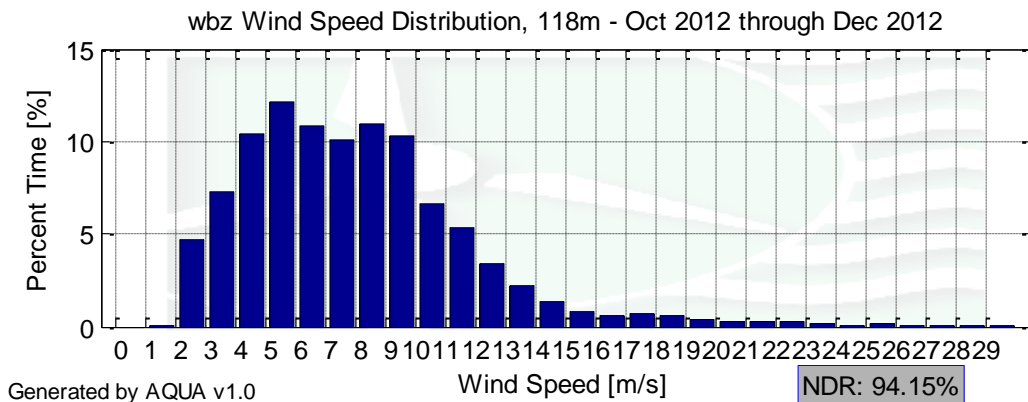


Figure 3b – Wind Speed Distribution Oct 2012 – Dec 2012

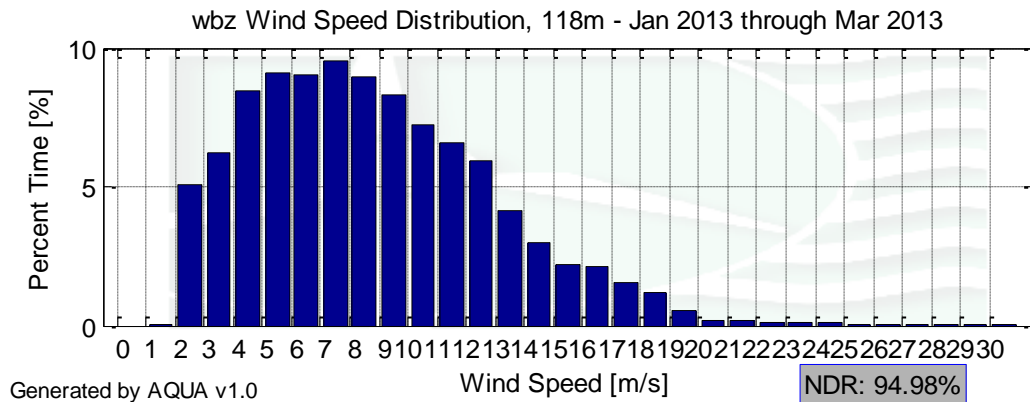


Figure 3c – Wind Speed Distribution Jan 2013 – Mar 2013

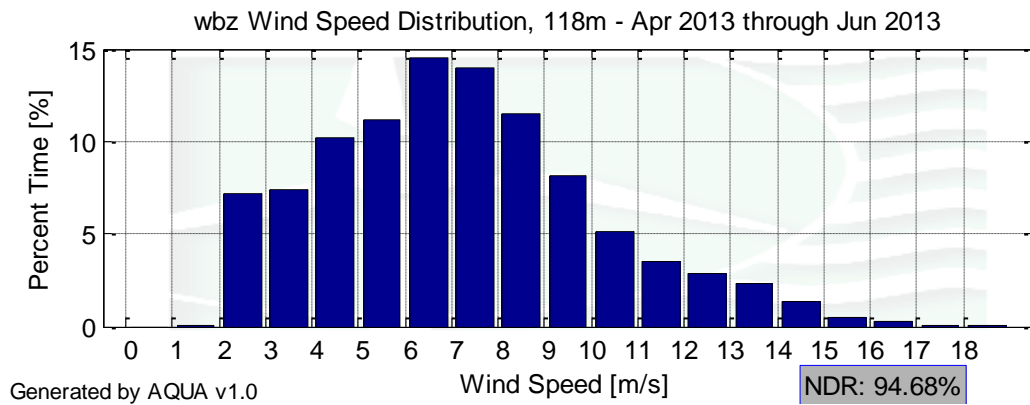


Figure 3d – Wind Speed Distribution Apr 2013 – Jun 2013

Monthly Average Wind Speeds

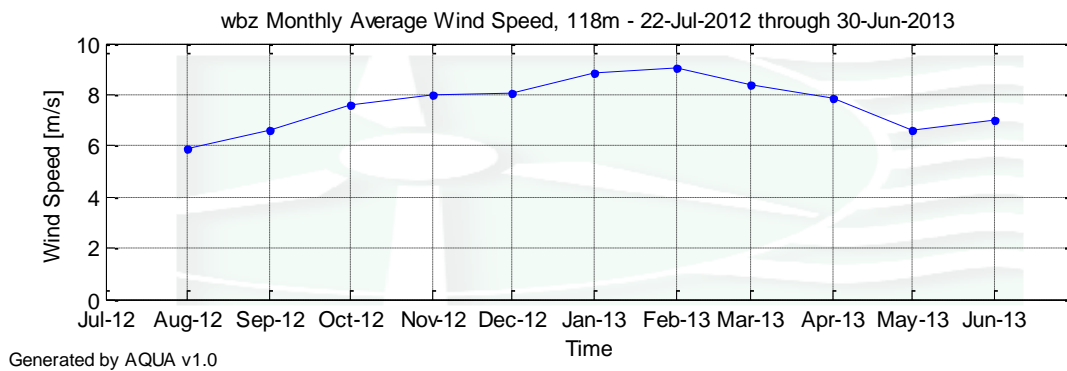


Figure 4 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

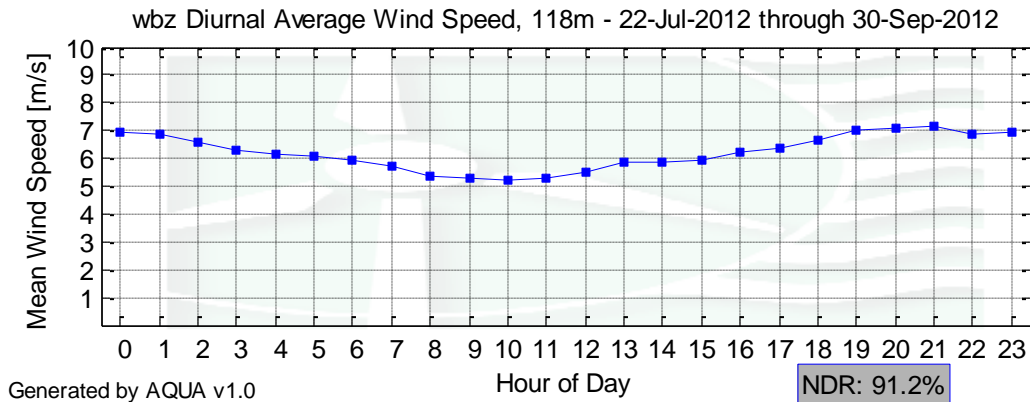


Figure 5a – Diurnal Average Wind Speeds Jul 2012 – Sep 2012

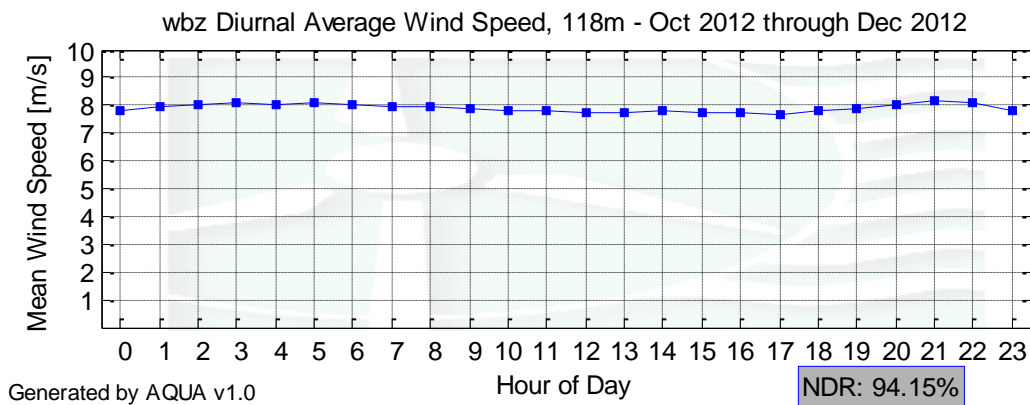


Figure 5b – Diurnal Average Wind Speeds Oct 2012 – Dec 2012

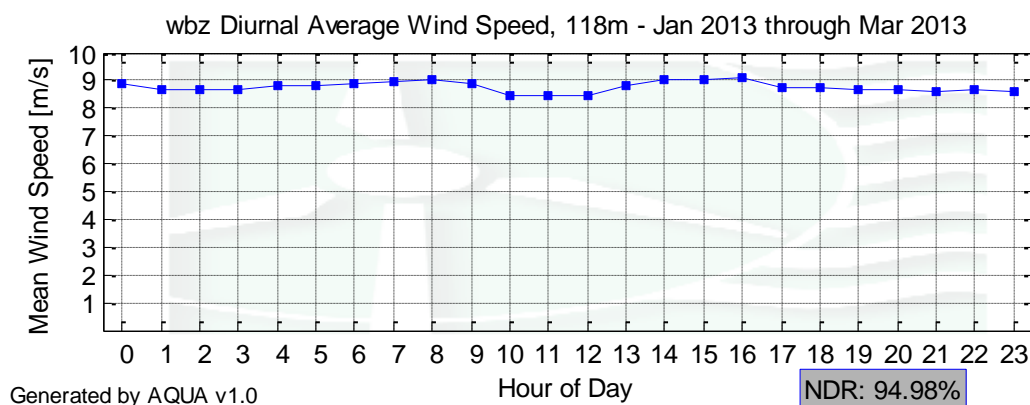


Figure 5c – Diurnal Average Wind Speeds Jan 2013 – Mar 2013

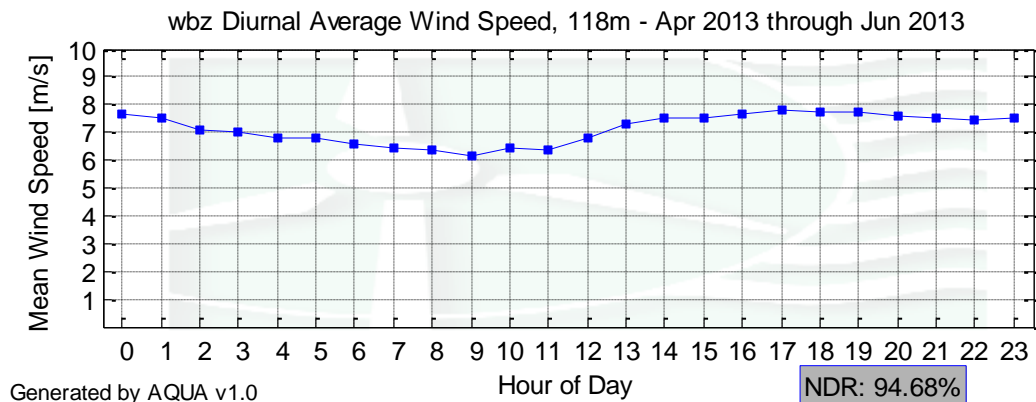


Figure 5d – Diurnal Average Wind Speeds Apr 2013 – Jun 2013

Turbulence Intensities

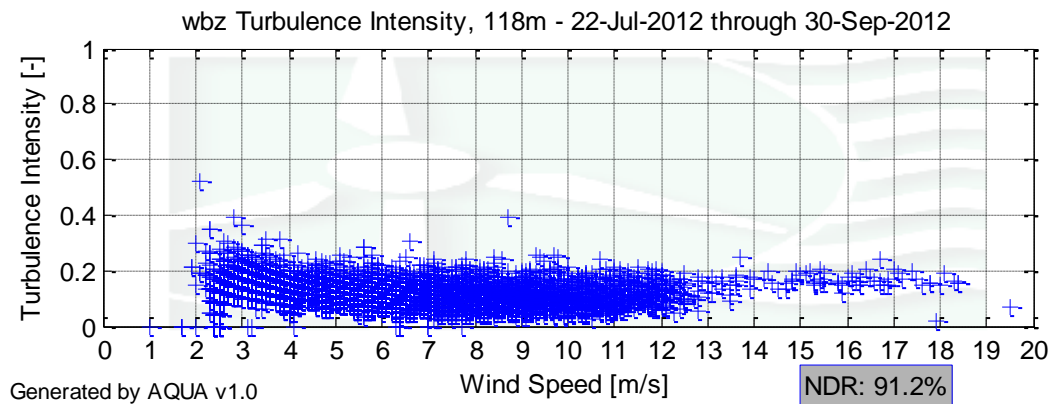


Figure 6a – Turbulence Intensity Jul 2012 – Sep 2012

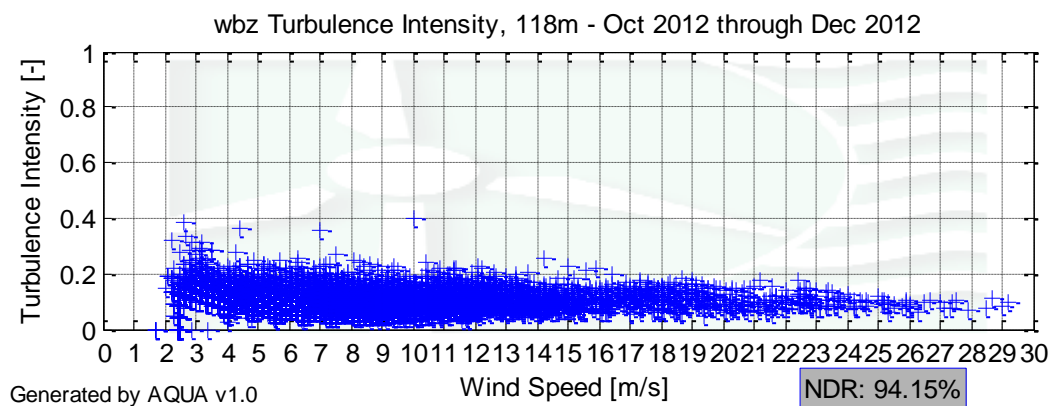


Figure 6b – Turbulence Intensity Oct 2012 – Dec 2012

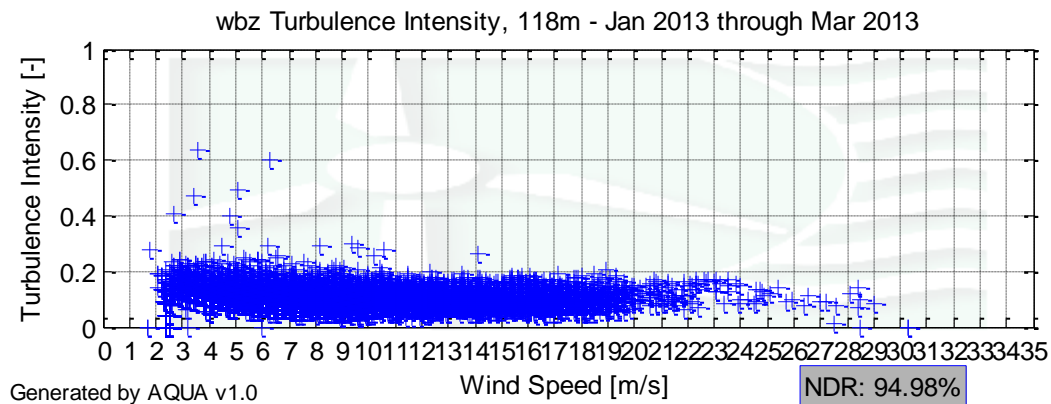


Figure 6c – Turbulence Intensity Jan 2013 – Mar 2013

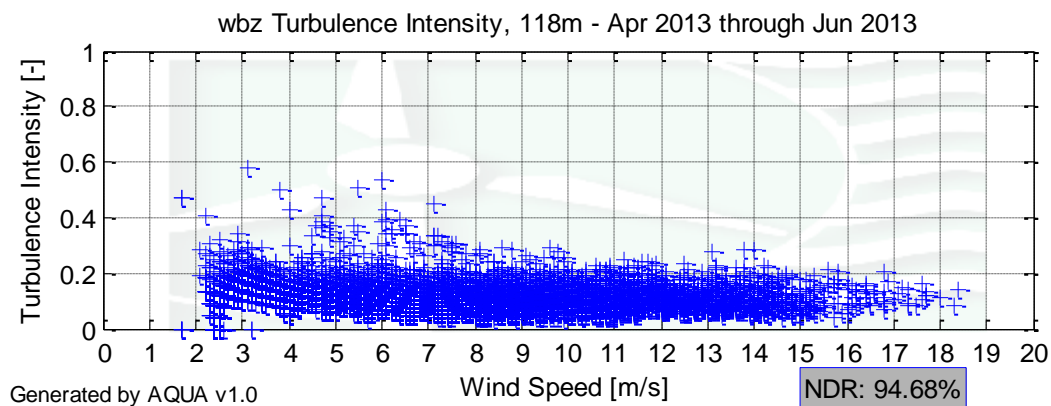
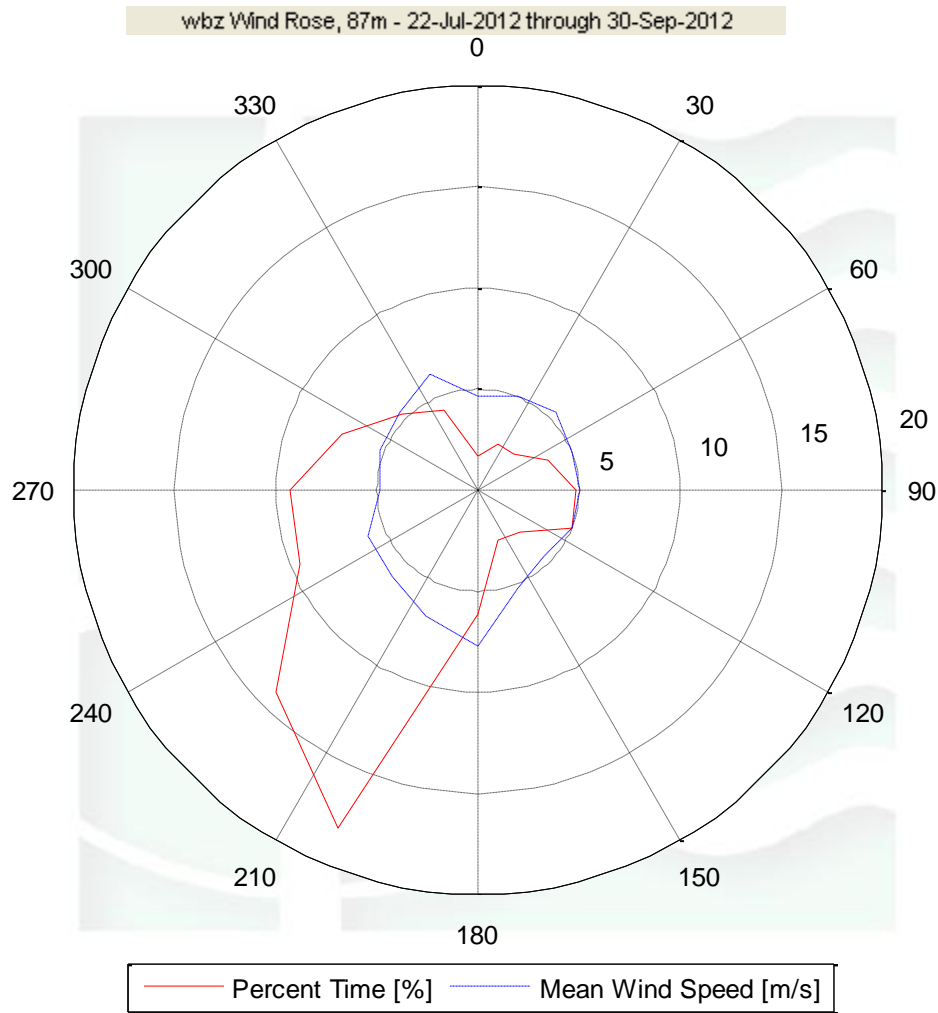


Figure 6d – Turbulence Intensity Apr 2013 – Jun 2013

Wind Roses



Generated by AQUA v1.0

NDR: 76.03%

Figure 7a – Wind Rose Jul 2012 – Sep 2012

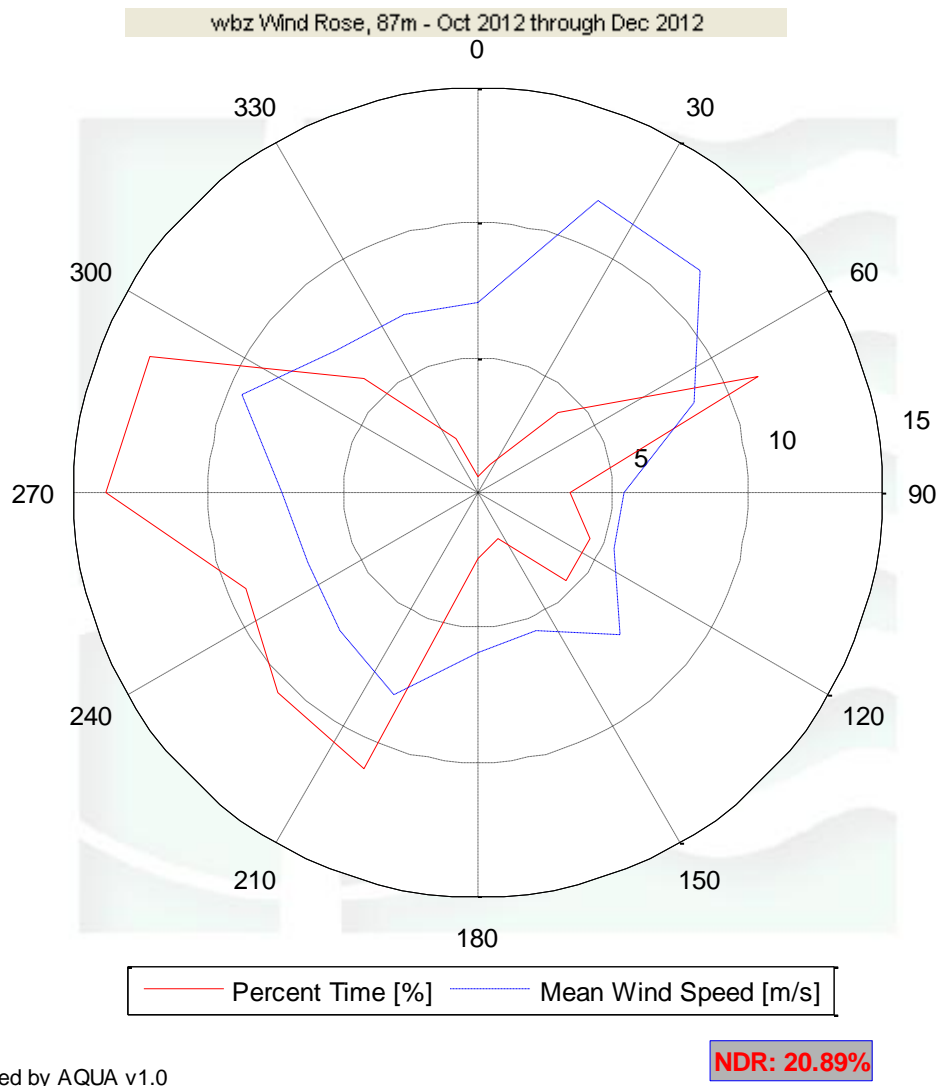
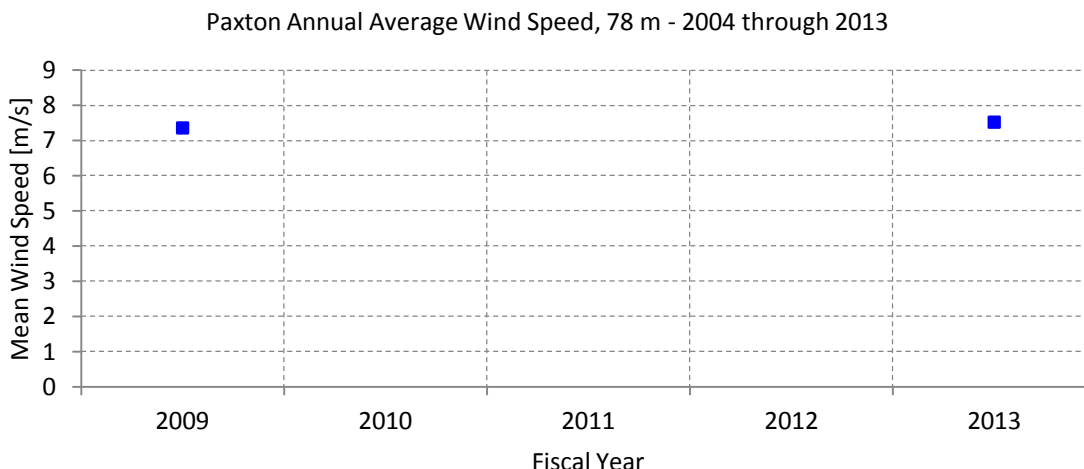


Figure 7b – Wind Rose Oct 2012 – Dec 2012

Note: There was no valid wind direction data for the last 2 quarters of the fiscal year.

Annual Average Wind Speed



The previous plot shows the annual average wind speed at the site compared to previous annual average wind speeds. It should be noted that there are also partial data sets available for 2007 and 2008 but since a whole year of data is not available the annual average wind speed for these years cannot be stated. Since the data at the site is so sparse, the long term average wind speed at the site will be estimated using the measure correlate predict (MCP) method. This way, the current annual wind speed can be compared to the estimated long term average wind speed.

SECTION 5 - Long Term Estimate and Capacity Factor

Wind speed varies year by year and the mean obtained over the measurement period may be less or more compared to what is seen over a longer time period. Therefore, the use of the long term mean at the site is preferred when projecting the performance of a wind turbine. The long term mean at a site may be estimated by using the Measure-Correlate-Predict (MCP) method.

The MCP method correlates wind speed measurements at the target site to a reference site which collects data over the same period of time and has been collecting data for a much longer period. Based on this correlation, the reference wind speed data is used to predict long term mean at the site.

Long term data from Thompson Island between May 1st, 1998 and July 30th, 2013 is used as reference in the case of the WBZ site. Correlation between the two sites is obtained from concurrent data between July 22nd, 2012 and June 31st, 2013. The long term mean at WBZ at 118 m is estimated to be 7.61 m/s with an uncertainty of 6.7% for the MCP process. This estimate may also be used to calculate the long term mean at different

heights by using the mean wind shear at site and the equation described in the previous section. The long term mean wind speed at 70 m height is estimated at 6.48 m/s.

The capacity factor of a wind turbine at a given site depends on the hub height, wind speed distribution at the hub height, the wind turbine power curve and any assumptions about down time and losses due to wake effects from upwind wind turbines, etc. If the hub height wind speed is estimated from data at lower heights, then the capacity factor will also depend on the estimated wind shear and the wind speeds measured at lower heights. No simple estimate of capacity factor at a site could take all of these effects and choices into account. Nevertheless, an estimate of the capacity factor of a wind turbine at this site is provided here to help the reader understand the order of magnitude of the wind resource at this site.

The estimates assume a GE 1.5 sl turbine with a hub height of 80 m and the long term mean wind speed estimate at the highest measurement height and the mean wind shear at the site, in order to determine the mean hub height wind speed, in this case 6.75 m/s. The wind speed probability distribution is assumed to be given by a Rayleigh distribution. The average wind turbine power is then estimated from:

$$\overline{P_w} = \int_0^{\infty} P_w(U) p(U) dU$$

where $P_w(U)$ is the wind turbine power curve and $p(U)$ is the wind speed probability distribution. The capacity factor is then calculated from:

$$CF = \frac{\overline{P_w}}{P_{rated}}$$

where P_{rated} is the rated capacity of the turbine, i.e., 1500 kW. Based on this equation, the estimated capacity factor of a wind turbine at this site would be about 0.338.

Significant Meteorological Events

There were very high wind events on October 30th (Hurricane Sandy) and on February 9th. Several of the sensors stopped working after the October 30th event and later the sensors were found to have been damaged in the storm.

SECTION 6 - Data Collection and Maintenance

The sensors at WBZ were installed on July 22, 2012. One anemometer and wind vane failed on August 7th 2012. Many of the sensors failed on October 30th 2012 following a high wind event. This included 3 of the 6 anemometers, 1 temperature sensor and 1 wind vane. This left 3 anemometers, 1 temperature sensor and 1 wind vane operational. There was also sporadic data transmission from some of the sensors which may be caused by interference from the AM tower.

SECTION 7 - Data Recovery and Validation

All raw wind data are subjected to a series of tests and filters to weed out data that are faulty or corrupted. Definitions of these quality assurance (QA) controls are given below under Test Definitions and Sensor Statistics. These control filters were designed to automate the quality control process and used many of the previous hand-worked data sets made at UMass to affect a suitable emulation. The gross percentage of data recovered (ratio of the number of raw data points received to data points expected) and net percentage (ratio of raw data points which passed all QA control tests to data points expected) are shown below.

Gross Data Recovered [%]	99.2
Net Data Recovered [%]	35.3

Test Definitions

All raw data were subjected to a series of validation tests, as described below. The sensors tested and the parameters specific to each sensor are given in the Sensor Performance Report which is included in APPENDIX A. Data which were flagged as invalid were not included in the statistics presented in this report.

MinMax Test: All sensors are expected to report data values within a range specified by the sensor and logger manufacturers. If a value falls outside this range, it is flagged as invalid. A data value from the sensor listed in Test Field 1 (TF1) is flagged if it is less than Factor 1 (F1) or greater than Factor 2. This test has been applied to the following

sensors (as applicable): wind speed, wind speed standard deviation, wind direction, temperature, and solar insolation.

$$F1 > TF1 > F2$$

MinMaxT Test: This is a MinMax test for wind direction standard deviation with different ranges applied for high and low wind speeds. A wind direction standard deviation data value (TF1) is flagged either if it is less than Factor 1, if the wind speed (TF2) is less than Factor 4 and the wind direction standard deviation is greater than Factor 2, or if the wind speed is greater than or equal to Factor 4 and the wind direction standard deviation is greater than Factor 3.

$$\begin{aligned} & (TF1 < F1) \\ & \text{or } (TF2 < F4 \text{ and } TF1 > F2) \\ & \text{or } (TF2 \geq F4 \text{ and } TF1 > F3) \end{aligned}$$

Icing Test: An icing event occurs when ice collects on a sensor and degrades its performance. Icing events are characterized by the simultaneous measurements of near-zero standard deviation of wind direction, non-zero wind speed, and near- or below-freezing temperatures. Wind speed, wind speed standard deviation, wind direction, and wind direction standard deviation data values are flagged if the wind direction standard deviation (CF1) is less than or equal to Factor 1 (F1), the wind speed (TF1) is greater than Factor 2 (F2), and the temperature (CF2) is less than Factor 3 (F3). To exit an icing event, the wind direction standard deviation must be greater than Factor 4.

$$CF1 \leq F1 \text{ and } TF1 > F2 \text{ and } CF2 < F3$$

CompareSensors Test: Where primary and redundant sensors are used, it is possible to determine when one of the sensors is not performing properly. For anemometers, poor performance is characterized by low data values. Therefore, if one sensor of the pair reports values significantly below the other, the low values are flagged. At low wind speeds (Test Fields 1 and 2 less than or equal to Factor 3) wind speed data are flagged if the absolute difference between the two wind speeds is greater than Factor 1. At high wind speeds (Test Fields 1 or 2 greater than Factor 3) wind speed data are flagged if the absolute value of the ratio of the two wind speeds is greater than Factor 2.

$$\begin{aligned} & [TF1 \leq F3 \text{ and } TF2 \leq F3 \text{ and } \text{abs}(TF1 - TF2) > F1] \\ & \text{or } [(TF1 > F3 \text{ or } TF2 > F3) \text{ and } (\text{abs}(1 - TF1 / TF2) > F2 \text{ or } \text{abs}(1 - TF2 / TF1) > F2)] \end{aligned}$$

Sensor Statistics

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

Expected Data Points: the total number of sample intervals between the start and end dates (inclusive).

Actual Data Points: the total number of data points recorded between the start and end dates.

% Data Recovered: the ratio of actual and expected data points (this is the *gross data recovered percentage*).

Hours Out of Range: total number of hours for which data were flagged according to MinMax and MinMaxT tests. These tests flag data which fall outside of an expected range.

Hours of Icing: total number of hours for which data were flagged according to Icing tests. This test uses the standard deviation of wind direction, air temperature, and wind speed to determine when sensor icing has occurred.

Hours of Fault: total number of hours for which data were flagged according to CompareSensors tests. These tests compare two sensors (e.g. primary and redundant anemometers installed at the same height) and flag data points where one sensor differs significantly from the other.

% Data Good: the filter results are subtracted from the gross data recovery percentage to yield the *net data recovered percentage*.

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
2	ETemp2DEGC					MinMax	-25	40	0	0
3	ETempSD2DEGC					MinMax	-25	40	0	0
4	ETemp118DEGC					MinMax	-25	40	0	0
5	ETempSD118DEGC					MinMax	-25	40	0	0
6	ITtemp2aDEGC					MinMax	-25	40	0	0
7	Batt1aV					MinMax	5	14	0	0
8	Batt1bV					MinMax	5	14	0	0
10	Anem118aMS					MinMax	0	90	0	0
11	Anem118bMS					MinMax	0	90	0	0
12	Anem87aMS					MinMax	0	90	0	0
13	Anem87bMS					MinMax	0	90	0	0
14	Anem61aMS					MinMax	0	90	0	0
15	Anem61bMS					MinMax	0	90	0	0
16	Anem118yMS					MinMax	0	90	0	0
17	Anem87yMS					MinMax	0	90	0	0
18	Anem61yMS					MinMax	0	90	0	0
20	AnemSD118aMS					MinMax	0	4	0	0
21	AnemSD118bMS					MinMax	0	4	0	0
22	AnemSD87aMS					MinMax	0	4	0	0
23	AnemSD87bMS					MinMax	0	4	0	0
24	AnemSD61aMS					MinMax	0	4	0	0
25	AnemSD61bMS					MinMax	0	4	0	0
26	AnemSD118yMS					MinMax	0	4	0	0
27	AnemSD87yMS					MinMax	0	4	0	0
28	AnemSD61yMS					MinMax	0	4	0	0
30	Vane118aDEG					MinMax	0	359.9	0	0
31	Vane87aDEG					MinMax	0	359.9	0	0
32	Vane61aDEG					MinMax	0	359.9	0	0
50	Turb118zNONE					MinMax	0	2	0	0
51	Turb87zNONE					MinMax	0	2	0	0
52	Turb61zNONE					MinMax	0	2	0	0
70	Pwr118zWMS					MinMax	0	5000	0	0
71	Pwr87zWMS					MinMax	0	5000	0	0
72	Pwr61zWMS					MinMax	0	5000	0	0
200	VaneSD118aDEG	Anem118yMS				MinMaxT	0	100	100	10
201	VaneSD87aDEG	Anem87yMS				MinMaxT	0	100	100	10

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
ws8	49536.000	49142.000	99.205	6098.500	0.000	0.000	25.335
an18	49536.000	49142.000	99.205	5880.000	0.000	0.000	27.978
wd8	49536.000	49142.000	99.205	6270.333	0.000	0.000	23.254
ws18	49536.000	49142.000	99.205	5888.000	0.000	0.000	27.885
ws6	49536.000	49142.000	99.205	6429.000	0.000	0.000	21.332
wd6	49536.000	49142.000	99.205	6426.833	0.000	0.000	21.358
ws17	49536.000	49142.000	99.205	3886.167	0.000	0.000	52.132
ws4	49536.000	49142.000	99.205	436.667	0.000	0.000	93.916
an4	49536.000	49142.000	99.205	432.833	0.000	0.000	93.962
ws5	49536.000	49142.000	99.205	8159.833	0.000	0.000	0.369
wd5	49536.000	49142.000	99.205	8158.000	0.000	0.000	0.390
Total	544896.000	540562.000	99.205	58066.167	0.000	0.000	35.265

APPENDIX B- Plot Data

Wind Speed Distribution Data

Bin Center [m/s]	Percent Time [%]			
	Q1	Q2	Q3	Q4
0.5	0	0	0	0
1.5	0.04	0.03	0.02	0.05
2.5	6.09	4.95	5.07	7.15
3.5	7.6	8.27	6.19	7.37
4.5	10.55	12.11	8.43	10.22
5.5	11.71	12.91	9.13	11.17
6.5	12.66	11.76	9.01	14.47
7.5	11.69	11.06	9.55	13.96
8.5	10.13	10.79	8.97	11.45
9.5	8.38	10.14	8.33	8.18
10.5	5.79	6.43	7.24	5.11
11.5	4.49	4.67	6.6	3.55
12.5	3.33	2.22	5.94	2.84
13.5	2.31	1.03	4.11	2.31
14.5	1.52	0.47	2.97	1.34
15.5	0.96	0.47	2.22	0.48
16.5	0.8	0.4	2.09	0.24
17.5	0.65	0.53	1.57	0.1
18.5	0.48	0.42	1.17	0.02
19.5	0.25	0.32	0.54	
20.5	0.13	0.23	0.2	
21.5	0.12	0.16	0.21	
22.5	0.11	0.25	0.11	
23.5	0.07	0.11	0.09	
24.5	0.04	0.05	0.07	
25.5	0.04	0.1	0.03	
26.5	0.02	0.05	0.02	
27.5	0.02	0.05	0.03	
28.5	0.01	0.02	0.04	
29.5	0.01	0.02	0.01	
30.5			0.02	

Monthly Average Wind Speed Data

Month	Wind Speed at 118 m 10 min Average [m/s]
12-Jul	6.298
12-Aug	5.903
12-Sep	6.583
12-Oct	7.581
12-Nov	8.024
12-Dec	8.082
13-Jan	8.844
13-Feb	9.07
13-Mar	8.401
13-Apr	7.86
13-May	6.592
13-Jun	7.006

Diurnal Average Wind Speed Data

Hour of Day	Q1	Q2	Q3	Q4
	Mean Wind Speed	Mean Wind Speed	Mean Wind Speed	Mean Wind Speed
	[m/s]	[m/s]	[m/s]	[m/s]
0	6.92	7.84	8.9	7.64
1	6.84	7.93	8.65	7.48
2	6.58	8.04	8.64	7.11
3	6.28	8.06	8.63	7.04
4	6.16	8.03	8.79	6.81
5	6.04	8.12	8.83	6.82
6	5.97	8	8.85	6.55
7	5.7	7.92	8.93	6.46
8	5.34	7.95	9	6.34
9	5.3	7.86	8.85	6.15
10	5.23	7.8	8.47	6.42
11	5.32	7.78	8.46	6.4
12	5.51	7.74	8.48	6.77
13	5.84	7.73	8.8	7.28
14	5.87	7.82	9.06	7.54
15	5.97	7.72	9.05	7.54
16	6.21	7.71	9.1	7.67
17	6.39	7.65	8.76	7.78
18	6.64	7.84	8.77	7.73
19	7.04	7.91	8.7	7.72
20	7.09	8	8.66	7.58
21	7.18	8.18	8.6	7.54
22	6.85	8.12	8.66	7.45
23	6.97	7.83	8.6	7.53

Wind Rose Data

	Q1		Q2		Q3		Q4	
Direction Sector [deg]	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]	Percent Time [%]	Mean Wind Speed [m/s]
0	1.72	4.63	0.58	7.02				
22.5	2.46	5.08	1.12	11.71				
45	2.59	5.5	4.16	11.67				
67.5	3.77	5	11.24	8.67				
90	4.84	5.04	3.43	5.39				
112.5	5	5.04	4.52	5.44				
135	2.89	4.57	4.66	7.46				
157.5	2.62	5.2	1.84	5.57				
180	6.18	7.67	2.42	5.96				
202.5	18.08	6.7	11.1	8.1				
225	14.18	6.01	10.48	7.28				
247.5	9.55	5.89	9.29	6.79				
270	9.28	4.89	13.81	7.25				
292.5	7.23	5.19	13.16	9.5				
315	5.34	5.46	6	7.42				
337.5	4.28	6.16	2.2	7.17				

Note: Wind direction data is not available for Quarters 3 and 4 because all wind vanes failed.