WIND DATA REPORT

Mass Turnpike Authority
Blandford, MA

January 2012 – March 2012

Prepared for

Massachusetts Clean Energy Center
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by

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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.

Two anemometers and one wind vane are mounted each at the 60 m (197 ft) tower height and at the 40 m (131 ft) tower height. A temperature sensor was installed near the base of the tower.

This report summarizes the wind data collected during the fall of 2011, between October and December. The mean recorded wind speed was 5.59 m/s (12.50 mph*) at 60 meters, and the prevailing wind direction was from the west. The average wind shear component was 0.53 and the average turbulence intensity at 60 meters was 0.21.

The gross data recovery percentage (the actual percentage of expected data received) was 100% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 95%.

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 Wind Energy Center (WEC) and the Massachusetts Technology Collaborative (MTC). This document is found through the RERL website:

http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1 - Station Location

This update summarizes the quarterly data results for the Blandford monitoring site in Blandford, MA. Site coordinates are 42-13-22.8 North, 72-58-4.8 West per the WGS84 standard (the World Geodetic System 1984, an international standard for absolute localization with earthly coordinates). The site is located on the MTA tower in Blandford, MA. The picture below shows the location of the tower, with the red circle indicating the location of the tower base.

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an 80 m (262 ft) lattice communications tower. The wind monitoring equipment comes from several vendors and consists of the following items:

- NRG Symphonie data logger and I-pack cellular modem
- 3 – NRG Max 40 anemometer, std calibration (Slope – 0.765 m/s, offset – 0.35 m/s) located at 40m (131.2 ft)
- 1 – Risoe # 6803 calibrated cup anemometer located at 60 m (164 ft) (Slope 0.62643 m/s, offset 0.21002 m/s)

- 2 – NRG #200P Wind direction vane. One vane is located at 60 m (196.85 ft) , the other vane is located at 40m (131.2 ft)

- NRG 110S temperature sensor located near the base of the tower

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.

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when a large amount of data is missing, the percent of the available data that is 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 ± 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.

Table 1. Wind Speed and Direction Data Summary

Date	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Height	**60 m**	**60 m**	**60 m**	**40 m**	**40 m**	**40 m**
Units	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**	**[m/s]**
Jan 2012	6.03	17.86	W	4.72	15.66	WNW
Feb 2012	5.76	15.44	WNW	4.60	13.67	WNW
Mar 2012	4.99	15.48	W	4.18	13.88	WNW
Jan 2012 - Mar 2012	**5.59**	**16.26**	**W**	**4.50**	**14.40**	**WNW**

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.

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

Table 2. Shear and Turbulence Intensity Data Summary

Date Height Units	Turbulence Intensity at 10 m/s 60 m [-]	Turbulence Intensity at 10 m/s 40 m [-]	Mean Wind Shear Coefficient, α Between 60 m and 40 m [-]
Oct 2011	0.20	0.24	0.60
Nov 2011	0.21	0.22	0.55
Dec 2011	0.22	0.22	0.44
Oct 2011- Dec 2011	**0.21**	**0.23**	**0.53**

SECTION 4- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). 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 a 12-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.

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

Wind Speed Time Series

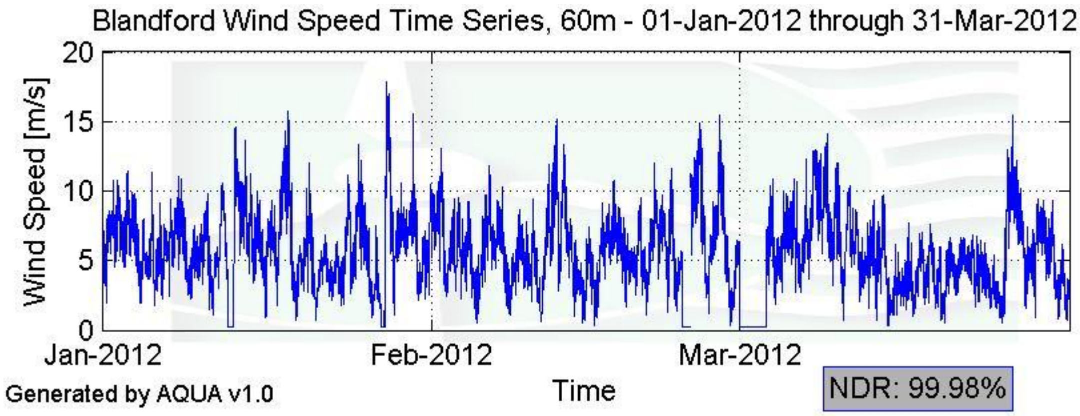

Figure 2 - Wind Speed Time Series, January 2012 - March 2012

Wind Speed Distributions

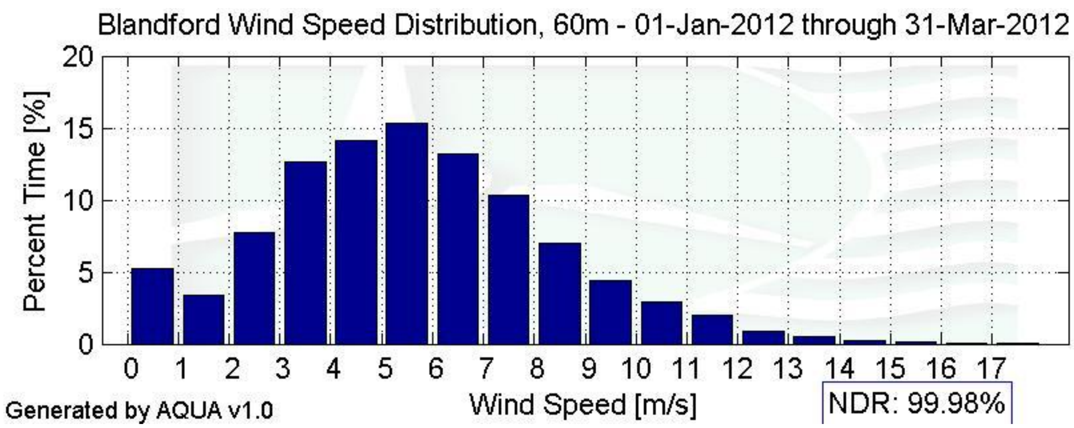

Figure 3 – Wind Speed Distribution, January 2012 - March 2012

Monthly Average Wind Speeds

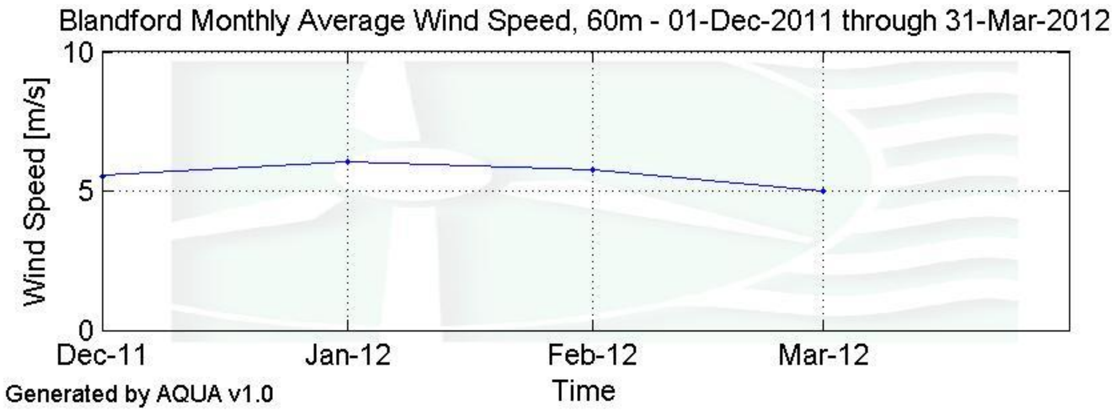

Figure 4 – Monthly Average Wind Speed, December 2011- March 2012

Diurnal Average Wind Speeds

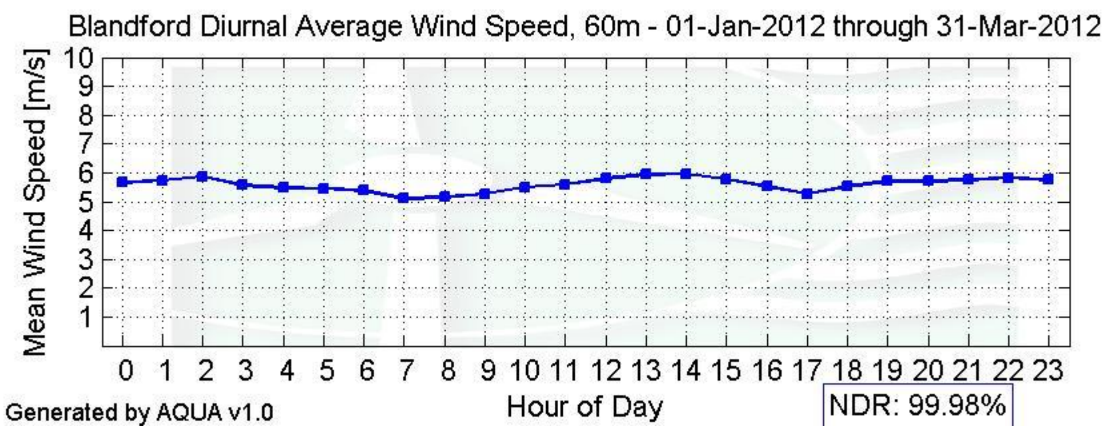

Figure 5 – Diurnal Average Wind Speed, January 2012 - March 2012

Turbulence Intensities

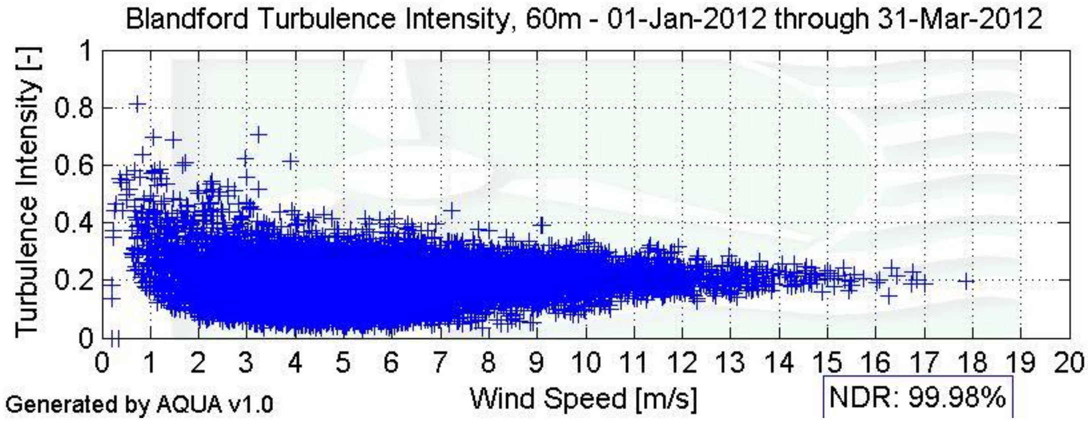

Figure 6 – Turbulence Intensity, January 2012 - March 2012

Wind Roses

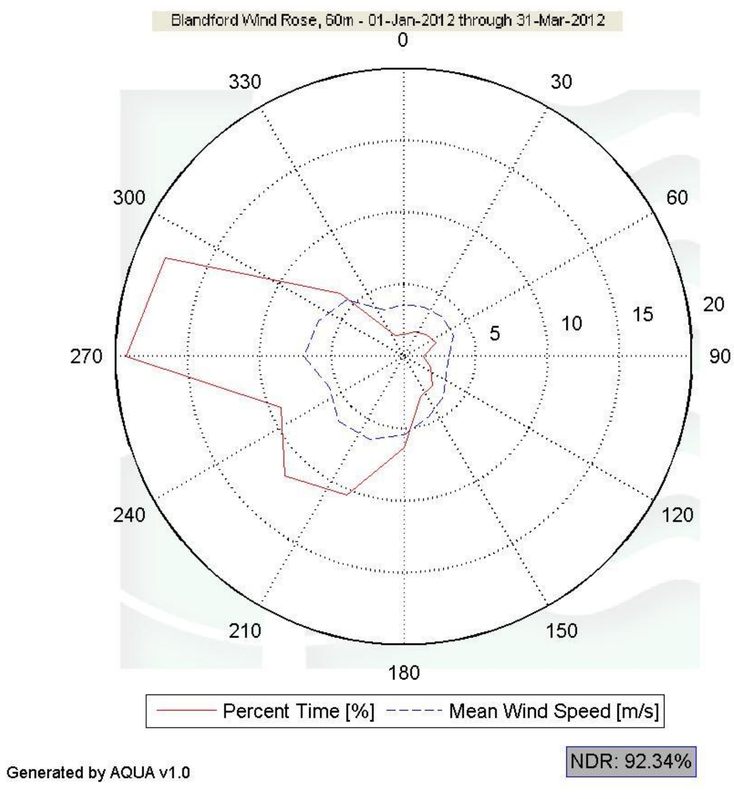

Figure 7 – Wind Rose, January 2012 - March 2012

SECTION 5 - Significant Meteorological Events

The Arctic Oscillations (AO) and the North Atlantic Oscillations are phenomena used to determine the state of atmospheric circulation over the Arctic and over the North Atlantic respectively. When the AO and the NAO are negative, cold air is forced to stay in the north and when they are positive, the reverse is true; cold air is pushed further south. This year, both the AO and the NAO were positive, leading to the lack of normal cold Arctic air reaching northern U.S.

For more information, see: http://www.nc-climate.ncsu.edu/climate/patterns/NAO.html

SECTION 6- Data Collection and Maintenance

The secondary anemometer at 40m height gave good data for the whole period. The data was compared with data from another site in the region and looks to be fine. However, AQUA(data processing tool used) flagged the data for most of the period and it is reflected in the sensor statistics in Section 7. This seems to be a bug in the program and is being revised.

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 [%]	100 %
Net Data Recovered [%]	95 %

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.

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

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 is greater than Factor 2.

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

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	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1	Channel 4>WS_max						MinMax	0	50	0	0
2	Channel 6>WS_max						MinMax	0	50	0	0
3	Channel 5>WS_max						MinMax	0	50	0	0
4	Channel 2>WS_max						MinMax	0	50	0	0
5	Channel 4>WS_val	Channel 6>WS_val					CompareSensors	1	0.25	3	0
6	Channel 4>WS_val	Channel 4>WS_SD	Channel 8>WD_val	Channel 8>WD_SD	Channel 10>T_val		Icing	0.5	1	2	4
7	Channel 6>WS_val	Channel 6>WS_SD	Channel 8>WD_val	Channel 8>WD_SD	Channel 10>T_val		Icing	0.5	1	2	4
8	Channel 2>WS_val	Channel 2>WS_SD	Channel 7>WD_val	Channel 7>WD_SD	Channel 10>T_val		Icing	0.5	1	2	4

Sensor Statistics

	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
Ch10 Etmp	13104	13104	100	0	0	0	100
Ch11 Batt	13104	13104	100	0	0	0	100
Ch3 Anem40a	13104	13104	100	0.167	117.167	0	94.628
Ch8 Vane40b	13104	13104	100	0.333	117.167	0	94.62
Ch4 Anem40b	13104	13104	100	0	0	1957.833	10.356
Ch7 Vane60a	13104	13104	100	0	167.167	0	92.346
Ch5 Riso60a	13104	13104	100	0.5	0	0	99.977
Ch2 Anem60a	13104	13104	100	0.333	167.167	0	92.338
Total	104832	104832	100	1.333	568.667	1957.833	85.533

APPENDIX B - Plot Data

Distribution Data

Bin Center [m/s]	Percent Time [%]
0.5	5.21
1.5	3.4
2.5	7.72
3.5	12.62
4.5	14.09
5.5	15.33
6.5	13.22
7.5	10.3
8.5	6.95
9.5	4.41
10.5	2.95
11.5	1.97
12.5	0.89
13.5	0.52
14.5	0.24
15.5	0.11
16.5	0.06
17.5	0.02

Monthly Average Wind Speed Data

Month	Mean Wind Speed |[m/s]
Jan-11	3.94
Feb-11	5.83
Mar-11	5.93
July-11	5.74
Aug-11	4.92
Jun-11	4.47
Jul-11	4.62
Aug-11	4.81
Sep-11	4.17
Oct-11	5.31
Nov-11	5.63
Dec-11	5.55
Jan-12	6.03
Feb-12	5.76
Mar-12	5.00

Diurnal Average Wind Speed Data

Hour of Day	Mean Wind Speed [m/s]
0	5.65
1	5.73
2	5.86
3	5.57
4	5.47
5	5.44
6	5.39
7	5.11
8	5.15
9	5.27
10	5.5
11	5.6
12	5.8
13	5.93
14	5.96
15	5.77
16	5.52
17	5.27
18	5.51
19	5.7
20	5.7
21	5.74
22	5.82
23	5.76

Wind Rose Data

Bin Center [deg]	Percent Time [%]	Mean Wind Speed [m/s]
0	1.53	3.64
22.5	1.88	3.69
45	2.17	3.84
67.5	2.41	3.73
90	1.36	3.14
112.5	2	3.2
135	2.85	3.93
157.5	3.01	4.51
180	6.36	5.46
202.5	10.43	6.23
225	11.72	6.4
247.5	9.24	5.6
270	19.31	6.96
292.5	17.95	6.43
315	6.21	5.58
337.5	1.58	3.51