WIND DATA REPORT

New Bedford Waste Water Treatment Facility

November 1st 2008 – October 31st 2009

Prepared for

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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.

Wind monitoring equipment was installed in New Bedford in October 2008 and removed in early Janury 2010. The base of the 50 meter meteorological tower is installed 4 meters above sea level. Anemometers and wind direction vanes are installed at 38 and 49 meters (125 and 160 feet) above the base of the tower. There are redundant anemometers at both heights. There is a temperature sensor installed near the base of the tower.

This report summarizes the wind data collected during the measurement period with a full calendar year defined for the purpose of analysis between November 1st, 2008 and October 31st, 2009. The mean recorded wind speed was 6.53 m/s (14.61 mph) at 49 meters and the prevailing wind direction was from the southwest. The average wind shear exponent was 0.103. The average turbulence intensity at 49m was 0.171.

The gross data recovery percentage (the actual percentage of expected data received) was 99.12% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 97.78%.

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

http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

* 1 m/s = 2.237 mph.

SECTION 1- Station Location

The New Bedford monitoring tower is located on a concrete pad owned by the Waste Water Treatment Plant. The 49 (161 ft) meter is located at 41° 35.638' North, 70° 54.331' West, shown below in

Figure 1. The tower base is 4 meters (13 feet) above sea level.

Figure 1 – Site Location

SECTION 2 - Instrumentation and Equipment

The 49 m (161 ft) monitoring tower is supplied by SecondWind, the sensors and logger are supplied by NRG systems. The wind speed and direction were measured at both 38 and 49 m height. The monitoring equipment consists of the following items:

- Symphonie Data Logger, serial #3204
- SecondWind 50m tower

- 2-#200P Wind direction vanes (Slope 1.0, Offset 0.0)
- 4-#40 Anemometers, standard calibration (Slope 0.765, Offset 0.350)
- #110S Temperature sensor (Slope 0.138, Offset -86.383)
- 4- Sensor booms for anemometers, 54” length
- 2- Sensor booms for vanes, 44” length
- Lightning rod and grounding cable
- Shielded sensor wire

The logger samples data from the sensors once every two seconds. These samples are combined into 10-minute averages and are put into a binary file along with the standard deviation for each 10-minute interval. These binary files are emailed to the University of Massachusetts, Amherst every morning. Using the NRG software BaseStation®, the binary files are converted into ASCII text files.

SECTION 3 - Data Summary

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1, which 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 larger amount of data is missing, the percent of the available data that is used to determine the data statistics is noted.

Table 1. Wind Speed and Direction Data Summary

Date Height Units	Mean Wind Speed 49 m [m/s]	Max Wind Speed 49 m [m/s]	Prevailing Wind Direction 49 m [deg]	Mean Wind Speed 38 m [m/s]	Max Wind Speed 38 m [m/s]	Prevailing Wind Direction 38 m [deg]
Nov 2008	6.475	19.23	WSW	6.073	17.96	WSW
Dec 2008	8.074	21.66	SW	7.706	20.4	SW
Jan 2009	6.381	18.69	WNW	6.064	17.39	WNW
Feb 2009	7.479	17.15	WNW	7.069	16.91	W
Mar 2009	6.737	18.6	SW	6.412	18.45	SW
Apr 2009	7.338	18.7	SW	7.034	17.81	SW
May 2009	6.255	16.71	SW	6.083	15.97	SW
Jun 2009	5.374	14.98	NNE	5.155	14.29	N
Jul 2009	5.812	18.12	SSW	5.657	17.75	SSW
Aug 2009	5.245	12.76	SW	5.084	12.73	SW
Sept 2009	5.884	15.1	SW	5.694	14.49	SW
Oct 2009	7.224	20.45	NNE	6.871	19.61	NNE
Nov 2009	6.782	17.04	NNE	6.479	16.53	NE
Dec 2009	7.692	21.99	WNW	7.21	20.82	WNW
Nov 2008 – Oct 2009	**6.53**	**21.66**	**SW**	**6.26**	**20.4**	**SW**

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.

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	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, α
Height Units	49 m [-]	38 m [-]	Between 49 m and 38 m [-]
Nov 2008	0.1054	0.114	0.254
Dec 2008	0.1101	0.114	0.184
Jan 2009	0.1229	0.1424	0.201
Feb 2009	0.1169	0.1289	0.222
Mar 2009	0.109	0.1181	0.195
Apr 2009	0.1023	0.1042	0.166
May 2009	0.0889	0.0921	0.109
Jun 2009	0.09917	0.1343	0.164
Jul 2009	0.08404	0.08005	0.107
Aug 2009	0.08039	0.1132	0.123
Sept 2009	0.08762	0.08942	0.129
Oct 2009	0.1059	0.1091	0.197
Nov 2009	0.0997	0.1014	0.180
Dec 2009	0.1313	0.1355	0.255
Nov 2008 – Oct 2009	**0.103**	**0.113**	**0.171**

SECTION 4 - 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 the BUZM3 buoy between May 13, 1997 and December 31st, 2008 is used as reference in the case of New Bedford. Correlation between the two sites are obtained from concurrent data between November 1st 2008 – October 31st 2009. The long term mean at New Bedford at 50 m is estimated to be 6.63 m/s with an uncertainty of 6% 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 7.05 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 7.21 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 0.327.

SECTION 5 - Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from one calendar year (November 1, 2008 – October 31, 2009). 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

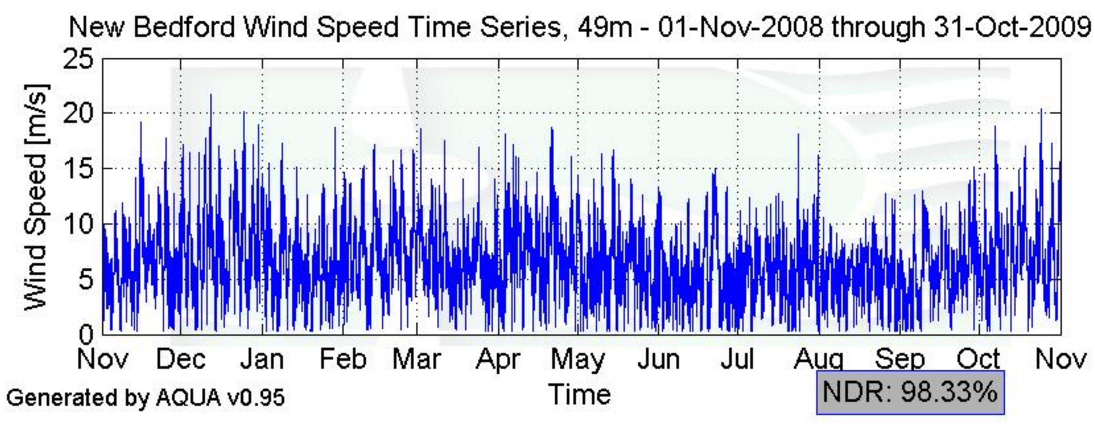

Figure 2 - Wind Speed Time Series, November 1, 2008 – October 31, 2009

Wind Speed Distributions

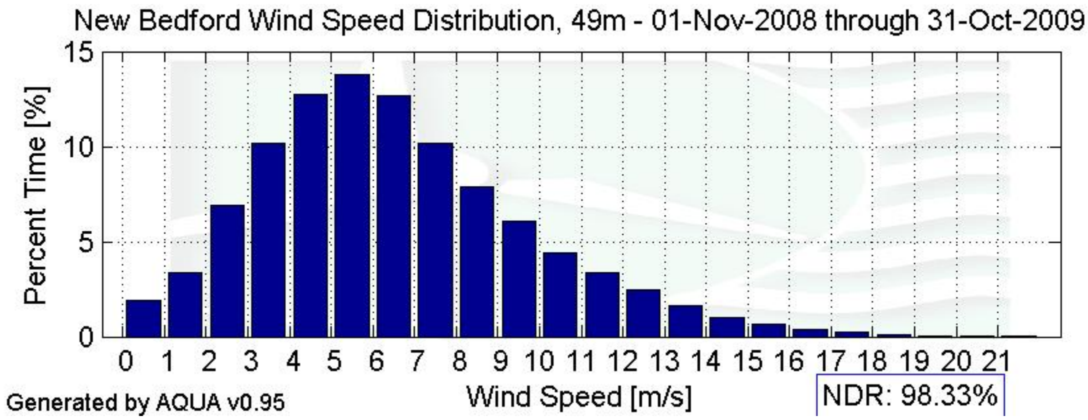

Figure 3 - Wind Speed Distribution, November 1, 2008 – October 31, 2009

Monthly Average Wind Speeds

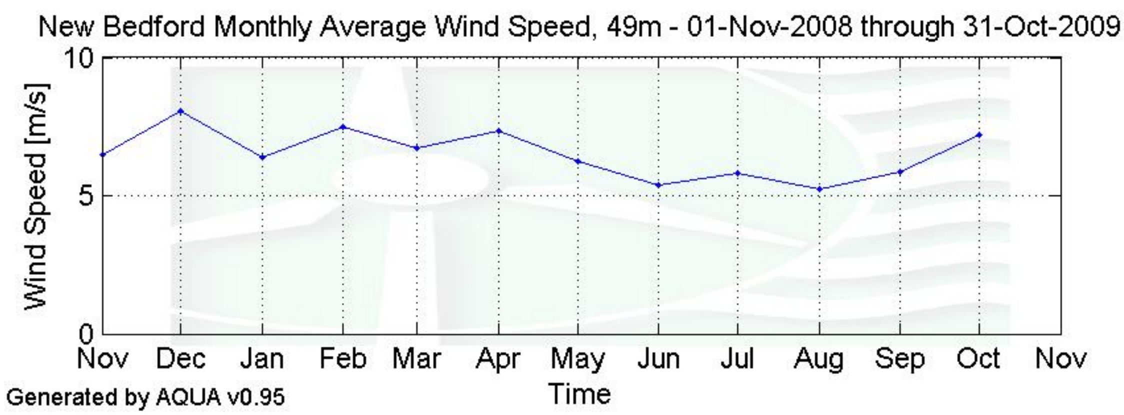

Figure 4 - Monthly Average Wind Speed, November 1, 2008 – October 31, 2009

Diurnal Average Wind Speeds

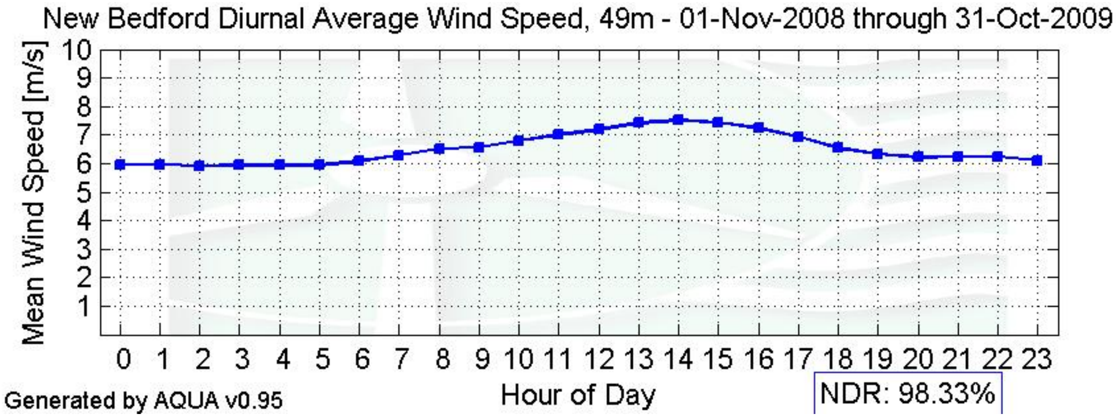

Figure 5 - Diurnal Average Wind Speed, November 1, 2008 – October 31, 2009

Turbulence Intensities

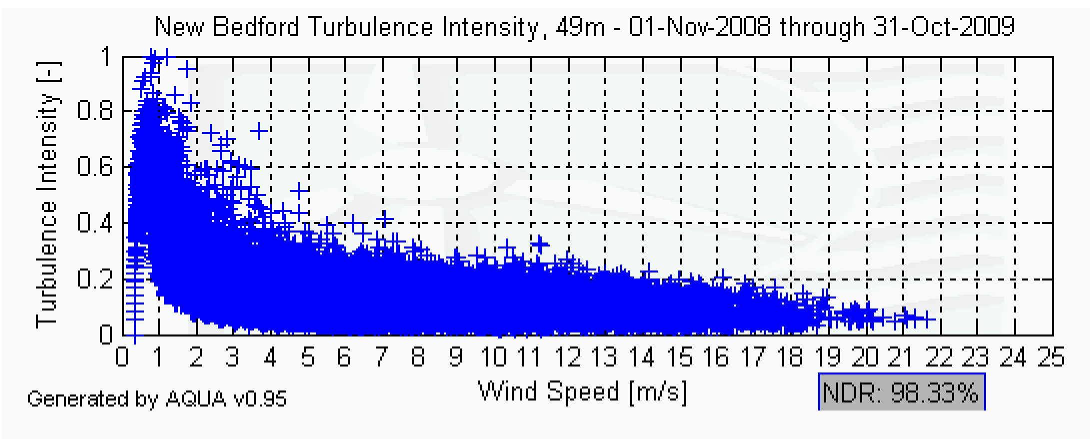

Figure 6 - Turbulence Intensity, November 1, 2008 – October 31, 2009

Wind Roses

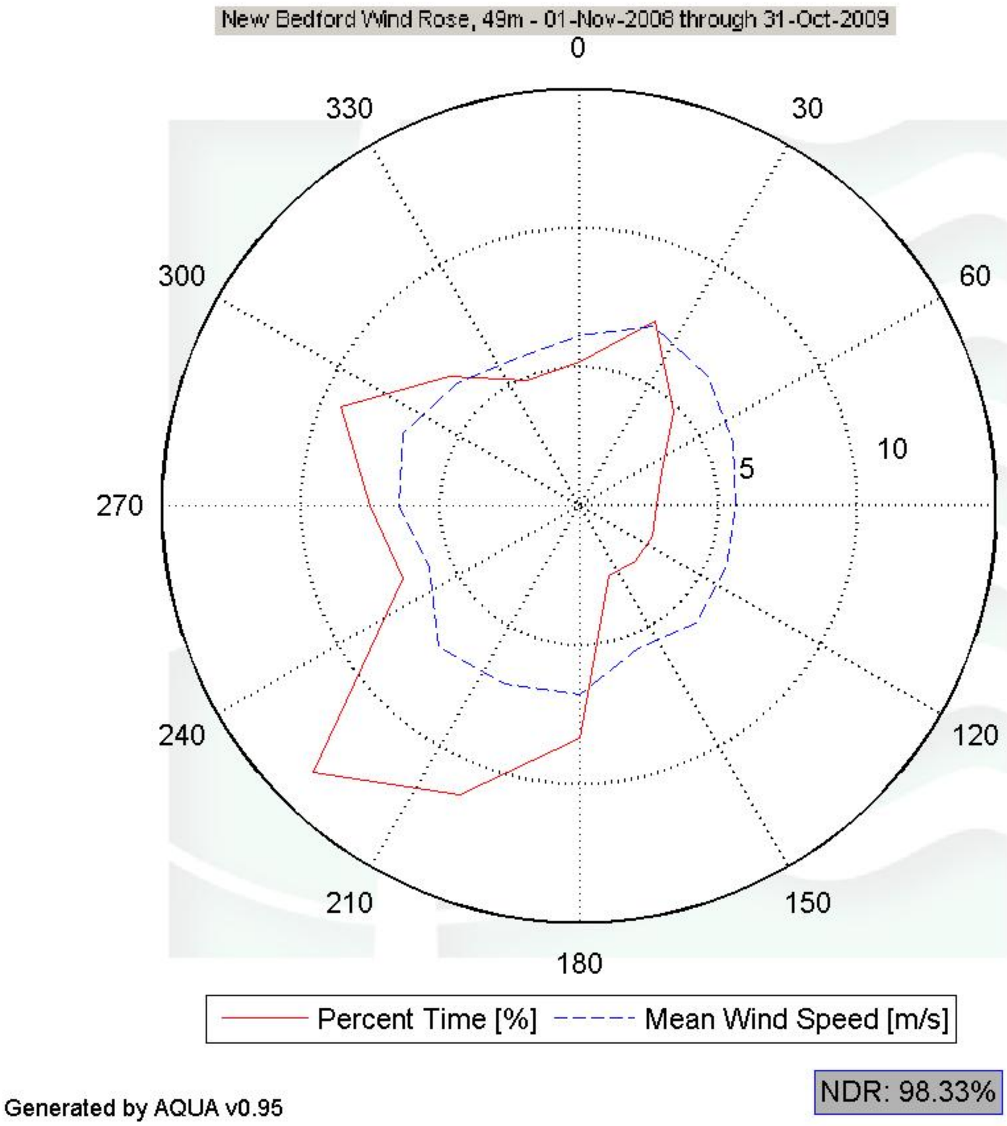

Figure 7 - Wind Rose, November 1, 2008 – October 31, 2009

SECTION 6 - Significant Meteorological Events

The following significant meteorological events occurred during the measurement period:

- 12/19/2008 – Heavy snow storms across all of Bristol county
- 6/21/2009 – Strong winds
- 7/1/2009 – Heavy rains caused flooding across region

The wind and precipitation conditions were close to average for the rest of the year.

Sources:
http://www.erh.noaa.gov/box/MonthlyClimate2.shtml
http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms

SECTION 7 - Data Collection and Maintenance

Data collection began on October 24, 2008 and ended when the measurement tower was taken down on January, 7, 2010. Data was transmitted to WEC daily by the cellular telephone installed in the logger. No problems with the data were encountered during the yearlong measurement campaign and no maintenance operations were needed or performed on the equipment.

SECTION 8 - 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. [Statistics over whole period of data collection].

Gross Data Recovered [%]	99.123
Net Data Recovered [%]	97.777

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	Test Field 1	Test Field 2	Test Field 3	Calc Field 1	Calc Field 2	Test Type	Factor 1	Factor 2	Factor 3	Factor 4
1						Time Test Insert	0	0	0	0
3	Batt0aVDC					MinMax	10.5	15	0	0
4	Etmp0aDEGC					MinMax	-30	60	0	0
5	EtmpSD0aDEGC					MinMax	-30	60	0	0
10	Anem49aMS					MinMax	0	90	0	0
11	Anem49bMS					MinMax	0	90	0	0
12	Anem38aMS					MinMax	0	90	0	0
13	Anem49yMS					MinMax	0	90	0	0
14	Anem38yMS					MinMax	0	90	0	0
16	Anem38bMS					MinMax	0	90	0	0
20	AnemSD49aMS					MinMax	0	4	0	0
21	AnemSD49bMS					MinMax	0	4	0	0
22	AnemSD38aMS					MinMax	0	4	0	0
23	AnemSD38bMS					MinMax	0	4	0	0
30	Vane49adeg					MinMax	0	359.9	0	0
31	Vane38aDEG					MinMax	0	359.9	0	0
32	VMax49aDEG					MinMax	0	359	0	0
33	Vmin49aDEG					MinMax	0	359	0	0
34	VMax38DEG					MinMax	0	359	0	0
35	Vmin38DEG					MinMax	0	359	0	0
210	VaneSD49aDEG	Anem49aMS				MinMaxT	0	100	100	10
211	VaneSD38aDEG	Anem38aMS				MinMaxT	0	100	100	10
300	Anem49aMS	AnemSD 49aMS	Vane49adeg	VaneSD 49aDEG	Etmp 0aDEGC	Icing	0.5	1	2	4
301	Anem49bMS	AnemSD 49bMS	Vane49bdeg	VaneSD 49aDEG	Etmp 0aDEGC	Icing	0.5	1	2	4
302	Anem38aMS	AnemSD 38aMS	Vane38aDEG	VaneSD 49aDEG	Etmp 0aDEGC	Icing	0.5	1	2	4
400	Anem49aMS	Anem49bMS				Compare Sensor	1	0.25	3	0

Sensor Statistics

New Bedford Sensor Statistics	November 1, 2008 – October 31, 2009						
	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	%Data Good
Etemp2aDegC	52554	52278	99.475	0	0	0	99.475
Anem38aMS	52554	52278	99.475	0.667	72.833	41.5	98.162
Vane38aDeg	52554	52278	99.475	1.167	74.333	0	98.613
Anem38bMS	52554	52278	99.475	0.667	74.333	5.833	98.607
Anem49aMS	52554	52278	99.475	1.167	96.333	107.833	97.188
Vane49adeg	52554	52278	99.475	0.833	98.833	0	98.337
Anem49bMS	52554	50982	97.009	0.833	98.833	168	94.059
Total	367878	364650	99.123	5.333	515.5	323.167	97.777

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	November 1, 2008 – October 31, 2009 [%]
0.5	1.92
1.5	3.4
2.5	6.91
3.5	10.18
4.5	12.72
5.5	13.77
6.5	12.64
7.5	10.16
8.5	7.9
9.5	6.06
10.5	4.39
11.5	3.38
12.5	2.48
13.5	1.65
14.5	1.03
15.5	0.64
16.5	0.36
17.5	0.25
18.5	0.1
19.5	0.04
20.5	0.02
21.5	0.01

Monthly Average Wind Speed Data

Date	50m Mean 10 min [m/s]
Nov 2008	6.475
Dec 2008	8.074
Jan 2009	6.381
Feb 2009	7.479
Mar 2009	6.737
Apr 2009	7.338
May 2009	6.255
Jun 2009	5.374
Jul 2009	5.812
Aug 2009	5.245
Sept 2009	5.884
Oct 2009	7.224
Nov 2008 – Oct 2009	**6.53**

Diurnal Average Wind Speed Data

November 1, 2008 – October 31, 2009	
Hour of Day	Mean Wind Speed [m/s]
0	5.95
1	5.95
2	5.92
3	5.94
4	5.93
5	5.94
6	6.08
7	6.28
8	6.51
9	6.57
10	6.79
11	7
12	7.19
13	7.43
14	7.52
15	7.45
16	7.24
17	6.94
18	6.53
19	6.33
20	6.22
21	6.24
22	6.25
23	6.09

Wind Rose Data

	November 1, 2008 – October 31, 2009	
Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	5.2	6.12
NNE	7.18	6.99
NE	4.79	6.56
ENE	3.23	5.97
E	2.77	5.64
ESE	2.87	5.75
SE	2.85	5.95
SSE	2.74	5.56
S	8.35	6.78
SSW	11.25	6.97
SW	13.55	7.16
WSW	6.87	5.84
W	7.55	6.47
WNW	9.29	6.85
NW	6.59	6.22
NNW	4.91	5.78