WIND DATA REPORT

Scituate Waste Water Treatment Plant, MA

December 1st to February 28th, 2007

Prepared for

Massachusetts Technology Collaborative
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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 preformed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers meteorological data, in particular wind data, at the Scituate waste water treatment plant in Massachusetts, which was installed on June 27, 2006. Two anemometers and one wind vane are mounted at heights of 39 m (127.9 ft), and 30 m (98.4 ft). A single anemometer and wind vane are mounted at 10 m (32.8 ft).

The season covered by this report is December 1, 2006 – February 28, 2007. The quarterly mean wind speed at 39 m was 5.96 m/s (13.33 mph)* and the prevailing wind direction was from the west. For the quarter, the gross data recovery percentage (the actual amount of data received compared to the expected amount of data) was 100 % and the net recovery percentage for the quarter (the percentage of data received which passed all the quality assurance tests) was 99.237 %.

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 station is located at the Scituate waste water treatment plant. The tower base is located at 42.17581° N, -70.72806° E (WGS84/NAD83) (Figure 1). The red cross indicates the approximate location of the tower.

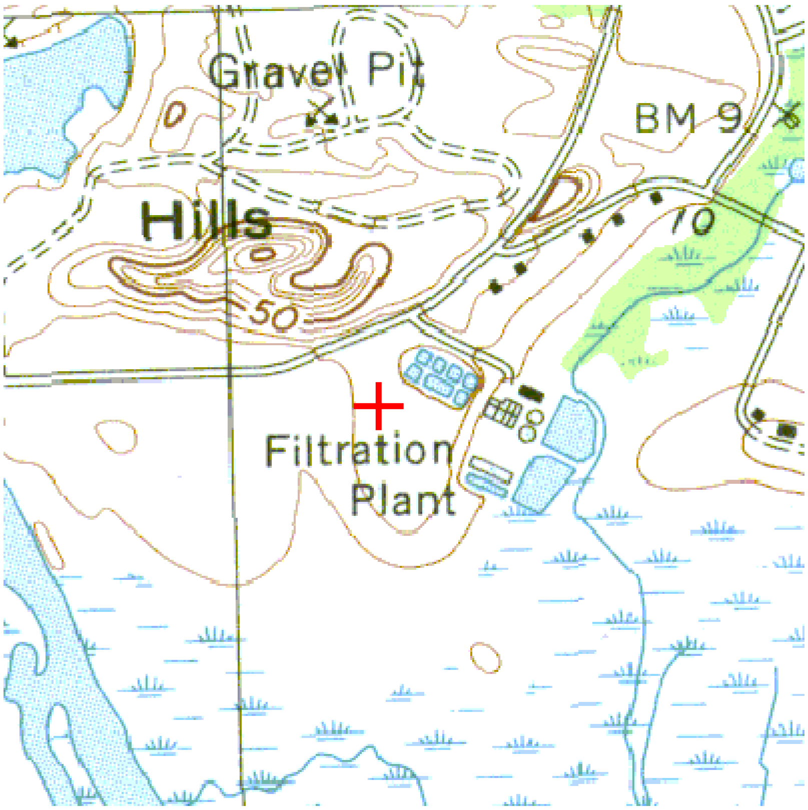

Figure 1 - Scituate Waste Water Treatment Plant Site Location

Source: www.massgis.com

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a NRG Systems 40 m (131.2 ft) meteorological tower. All the remaining monitoring equipment is from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- 5 - #40 Anemometers, stand calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 39 m (127.9 ft), two at 30 m (98.4 ft), and one at 10 m (32.8 ft).

- 3 - #200P Wind direction vanes. One vane is at each height of 39 m (127.9 ft), 30m (98.4 ft), and 10 m (32.8 ft), respectively.
- #11OS Calibrated thermoster (temperature sensor). The sensor is located 2m (6.6 ft) from the tower base.
- 8 – Sensor booms, five 59" in length, three 53" in length
- Lightning rod and copper grounding cable
- Shielded sensor wire

SECTION 3 - Data Collection and Maintenance

The following maintenance/equipment problems occurred during the report period, and the following corrective actions taken:

- During the raising of the tower the anemometer boom facing 290 degrees at the 39 m level was slightly bent after being caught in a tree. The data is being monitored to ensure the data from that sensor is correct.
- No maintenance operations were needed or performed

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Wind Shear Coeff
Height units	**39 m, [m/s]**	**39 m, [m/s]**	**39 m [ ]**	**39 m [ ]**	**30 m [m/s]**	**30 m [m/s]**	**30 m [ ]**	**30 m [ ]**	**10 m [m/s]**	**10 m [m/s]**	**10 m [ ]**	**10 m [ ]**	**39 & 30m, [ ]**
Dec-'06	5.64	19.37	0.18	WSW	5.13	17.92	0.20	WSW	2.70	12.35	0.25	WSW	0.38
Jan-'07	6.03	15.39	0.19	NW	5.48	14.59	0.21	NW	3.07	10.43	0.20	WNW	0.39
Feb-'07	6.25	15.38	0.20	W	5.75	14.21	0.22	W	3.08	9.54	0.27	W	0.38
Dec '07 – Feb '07	5.96	19.37	0.19	W	5.44	17.92	0.21	WSW	2.94	12.35	0..22	W	0.38

Table 1 – Data Summary Statistics, December 1, 2006 – February 28, 2007

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when larger amounts of data are missing, the percent of the available data that are used to determine the data statistics is noted.

No measurement of wind speed can be perfectly accurate. 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.

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 may not 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.

SECTION 4 - Significant Meteorological Events

There were no extreme meteorological events throughout the quarter. This observation is based on the absence of any extreme fluctuation in the mean wind speed data as seen in the time series plot (Figure 2).

SECTION 5 - 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 [%]	99.237

<u>Test Definitions</u>

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 (F4).

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

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.

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

<u>Sensor Statistics</u>

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*.

SECTION 6 - Data Summary

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). All the graphs are based on data taken from the 39 m sensor level. The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. The wind speed time series is shown in Figure 2.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The predominant wind speed is between 5 and 6 m/s, occurring 15.05% of the time. The wind speed distribution is shown in Figure 3.

- Monthly Average – A plot of the monthly average wind speed since the tower's installation. This graph shows trends in the wind speed from month to month. The monthly average wind speed plot is shown in Figure 4.

- Diurnal – A plot of the average wind speed for each hour of the day. The diurnal variation plot is shown in Figure 5.

- 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. Turbulence intensity varied mostly between 0.05 and 0.35. The turbulence intensity plot is shown in Figure 6.

- 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. The average prevailing wind direction is west. The wind rose is shown in Figure 7.

SECTION 7- Graphs

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

Wind Speed Time Series

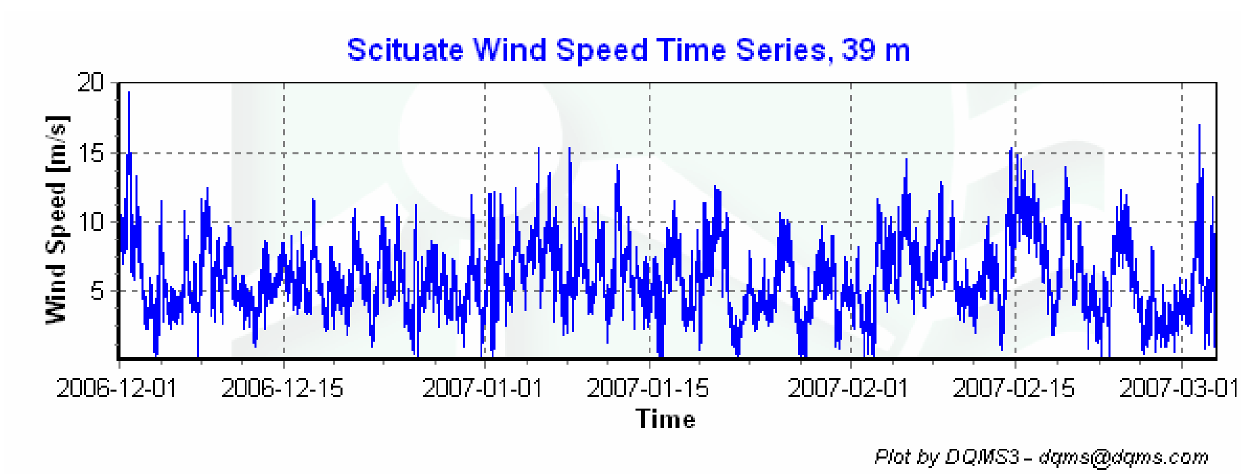

Figure 2 – Wind Speed Time Series, December 1, 2006 – February 28, 2007

Wind Speed Distributions

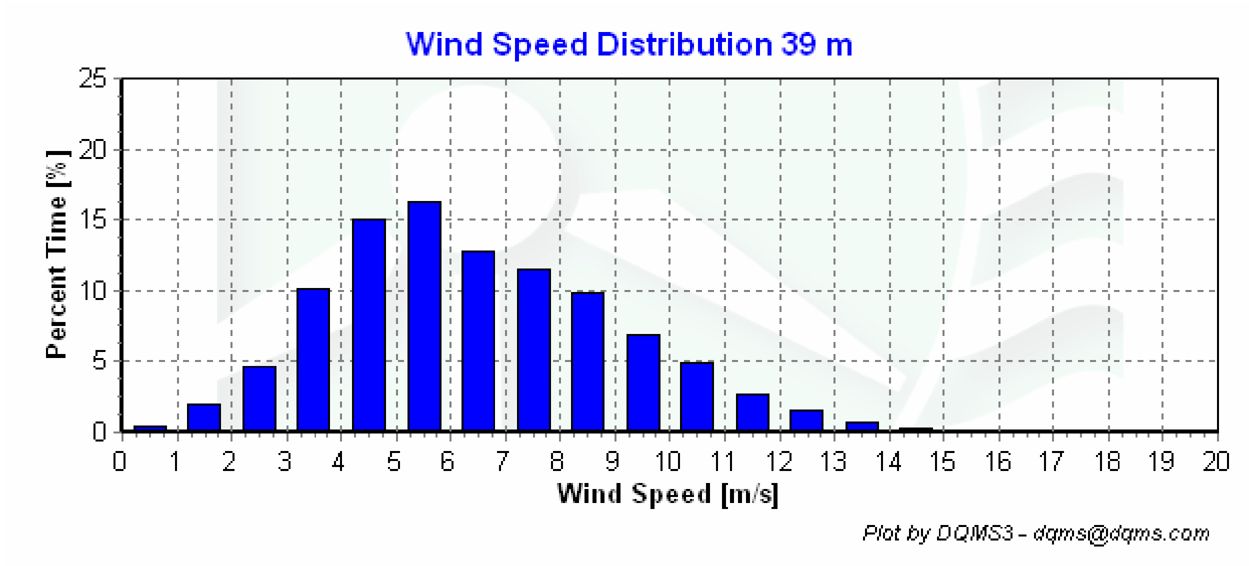

Figure 3 – Wind Speed Distribution, December 1, 2006 – February 28, 2007

Monthly Average Wind Speeds

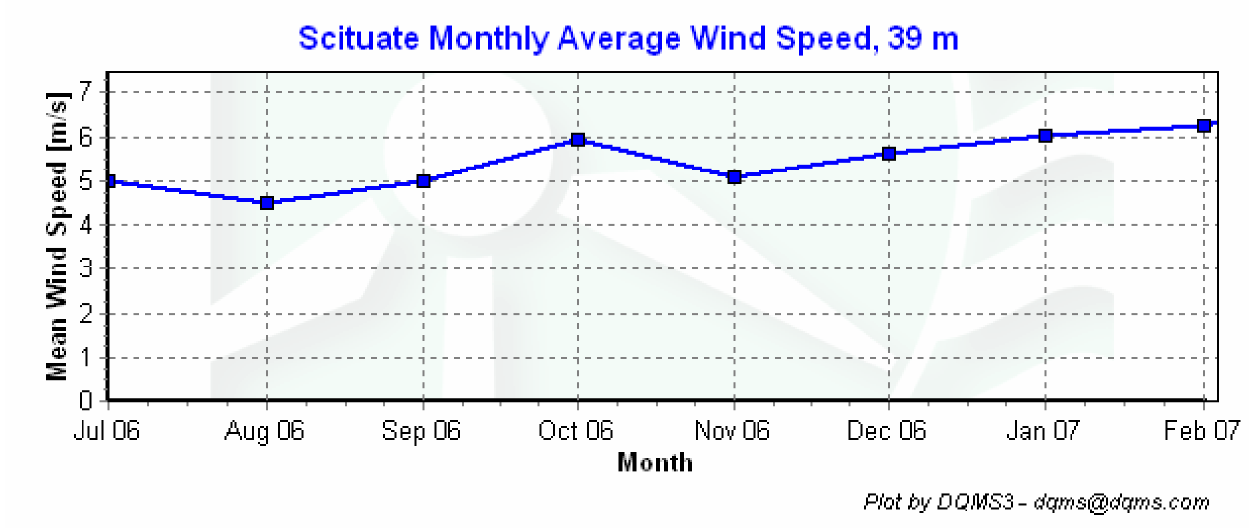

Figure 4 – Monthly Average Wind Speed, July 1, 2006 – February 28, 2007

Diurnal Average Wind Speeds

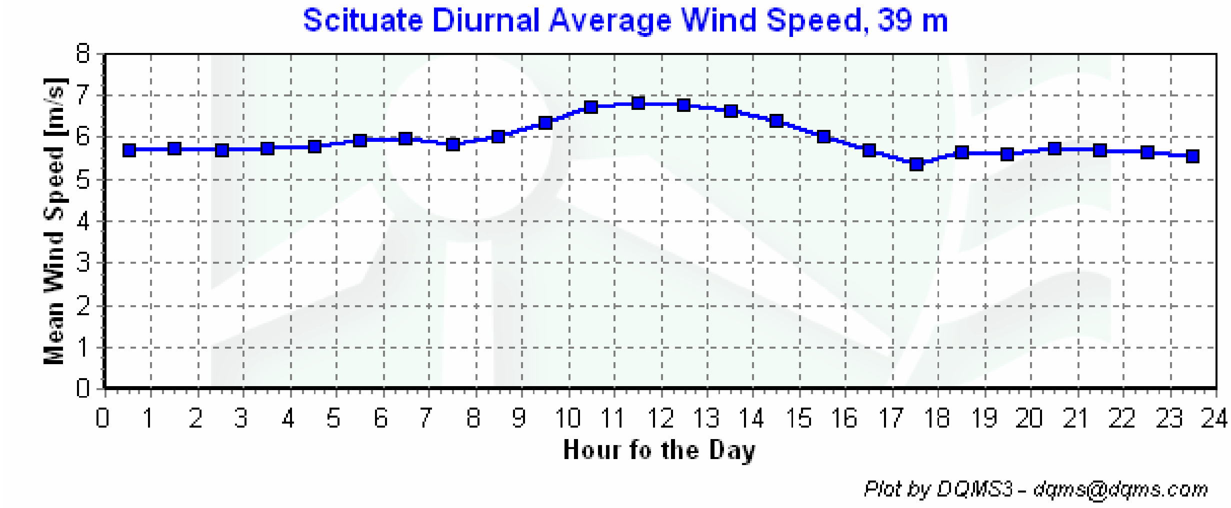

Figure 5 – Diurnal Wind Speed, December 1, 2006 – February 28, 2007

Turbulence Intensities

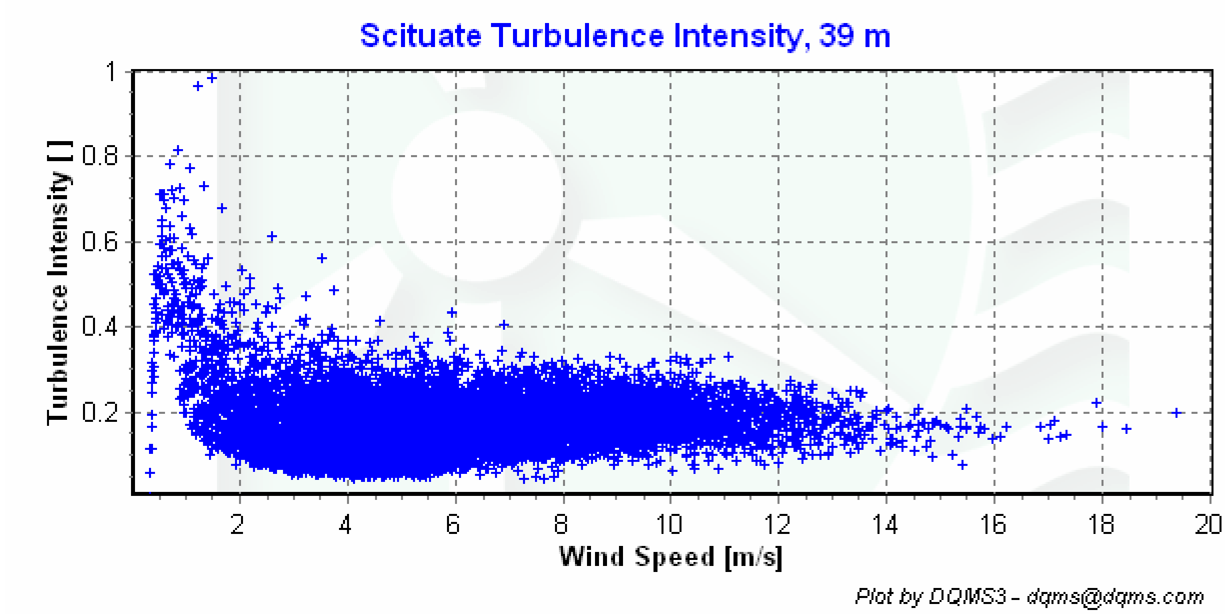

Figure 6 – Turbulence Intensity vs. Wind Speed, December 1, 2006 – February 28, 2007

Wind Roses

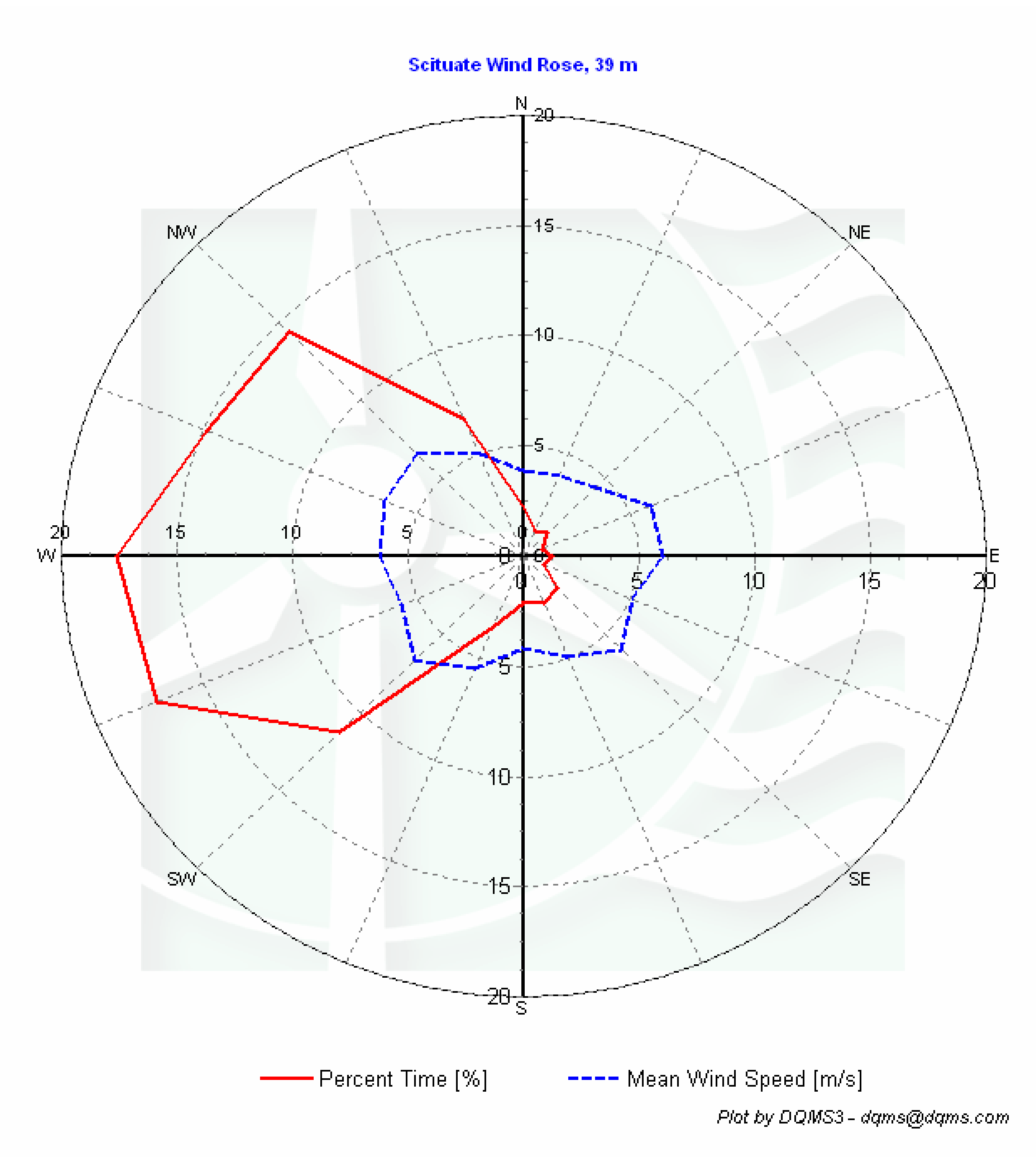

Figure 7 – Wind Rose, December 1, 2006 – February 28, 2007

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	CalcField3	TestType	Factor1	Factor2	Factor3
1				TimeTest Insert	0	0	0
4	Etemp2aDEGC			MinMax	-30	60	0
5	Etemp2SDaDEGC			MinMax	0	1	0
10	Anem39aMS			MinMax	0	90	0
11	Anem39bMS			MinMax	0	90	0
12	Anem30aMS			MinMax	0	90	0
13	Anem30bMS			MinMax	0	90	0
14	Anem10aMS			MinMax	0	90	0
20	AnemSD39aMS			MinMax	0	4	0
21	AnemSD39bMS			MinMax	0	4	0
22	AnemSD30aMS			MinMax	0	4	0
23	AnemSD30bMS			MinMax	0	4	0
24	AnemSD10aMS			MinMax	0	4	0
30	Vane39aDEG			MinMax	0	359.9	0
31	Vane30aDEG			MinMax	0	359.9	0
32	Vane10aDEG			MinMax	0	359.9	0
50	Turb39zNONE			MinMax	0	2	0
51	Turb30zNONE			MinMax	0	2	0
52	Turb10zNONE			MinMax	0	2	0
60	Wshr0zNONE			MinMax	-100	100	0
200	VaneSD39aDEG	Anem39yMS	MinMaxT	0	100	100	10
201	VaneSD30aDEG	Anem30yMS	MinMaxT	0	100	100	10
203	VaneSD10aDEG	Anem10aMS	MinMaxT	0	100	100	10
400	Anem39aMS	Anem39bMS	CompareSensors	1	0.25	3	0
401	Anem30aMS	Anem30bMS	CompareSensors	1	0.25	3	0

Table 2 – Scituate Test Definitions

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Etemp2aDEGC	12960	12960	100	0	0	0	100
Etemp2SDaDEGC	12960	12960	100	0.167	0	0	99.992
Anem39aMS	12960	12960	100	0	16.667	0.667	99.198
AnemSD39aMS	12960	12960	100	0	16.667	0.667	99.198
Vane39aDEG	12960	12960	100	0.667	16.667	0	99.198
VaneSD39aDEG	12960	12960	100	0.667	16.667	0	99.198
Anem30aMS	12960	12960	100	0.167	14.833	0	99.306
AnemSD30aMS	12960	12960	100	0.167	14.833	0	99.306
Vane30aDEG	12960	12960	100	0.5	14.833	0	99.29
VaneSD30aDEG	12960	12960	100	0.5	14.833	0	99.29
Anem10aMS	12960	12960	100	0	23.5	0	98.912
AnemSD10aMS	12960	12960	100	0	23.5	0	98.912
Vane10aDEG	12960	12960	100	0.833	23.5	0	98.873
VaneSD10aDEG	12960	12960	100	0.833	23.5	0	98.873
Total	181440	181440	100	4.5	220	1.334	99.273

Table 3 – Sensor Statistics, 39 m, December 1, 2006 – February 28, 2007

APPENDIX B - Plot Data

Wind Speed Distribution Data

anem39yms	Percent
0.5	0.43
1.5	1.96
2.5	4.67
3.5	10.15
4.5	15.05
5.5	16.35
6.5	12.74
7.5	11.58
8.5	9.88
9.5	6.84
10.5	4.87
11.5	2.67
12.5	1.61
13.5	0.69
14.5	0.23
15.5	0.19
16.5	0.03
17.5	0.04
18.5	0.02
19.5	0.01
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 4 – Wind Speed Distribution, 39 m, December 1, 2006 – February 28, 2007

Monthly Average Wind Speed Data

Date	Mean Wind Speed %
Sep 06	5.01
Oct 06	5.95
Nov 06	5.10
Dec 06	5.64
Jan 07	6.03
Feb 07	6.25

Table 5 – Monthly Average Wind Speeds, 39 m, September 1, 2006 – February 28, 2007

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.69
1.5	5.72
2.5	5.71
3.5	5.72
4.5	5.78
5.5	5.95
6.5	5.98
7.5	5.86
8.5	6.01
9.5	6.34
10.5	6.73
11.5	6.83
12.5	6.77
13.5	6.64
14.5	6.38
15.5	6.04
16.5	5.72
17.5	5.35
18.5	5.63
19.5	5.58
20.5	5.74
21.5	5.69
22.5	5.63
23.5	5.56

Table 6 – Diurnal Average Wind Speeds, 39 m, December 1, 2006 – February 28, 2007

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent of Time [%}
N	2.22	3.9
NNE	1.24	3.92
NE	1.47	4.37
ENE	0.88	5.96
E	1.25	6.04
ESE	0.92	5.06
SE	2.06	5.98
SSE	2.32	4.94
S	2.15	4.18
SSW	3.46	5.5
SW	11.29	6.67
WSW	17.21	5.71
W	17.59	6.23
WNW	14.83	6.5
NW	14.38	6.52
NNW	6.73	5.02

Table 7 – Diurnal Average Wind Speeds, 39 m, December 1, 2006 – February 28, 2007