WIND DATA REPORT

FALMOUTH, MA

May1, 2004 to May 31, 2004.

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

James F. Manwell
Anthony F. Ellis
Ashwin Gambhir

September 24, 2004

Report template version 1.1

Renewable **E**nergy **R**esearch **L**aboratory
University of Massachusetts, Amherst
160 Governors Drive, Amherst, MA 01003
www.ceere.org/rerl • (413) 545-4359 • rerl@ecs.umass.edu

TABLE OF CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

Wind monitoring at Falmouth commenced on May 1, 2004 and the station is in continuous operation to this day. Wind speed and direction monitoring are being done at three heights 39m, 30m and 10m. This report is for the month of May 2004.

During the period covered by this report, 1st May – 31st May 2004, the mean recorded wind speed at 39 meters was 4.89 m/s (10.9mph); the prevailing wind direction at 39 meters was SW. The mean turbulence intensity at 39 m was 0.23. Wind speeds at 30 m averaged 4.47 m/s (10.0 mph) with a turbulence intensity of 0.26. Finally, the mean wind speed at 10 m was 3.47 m/s (7.76 m/h) with a turbulence intensity of 0.30. Note that 1 m/s = 2.237 mph.

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 99.895%.

2.237

SECTION 1 - Station Location

The monitoring site is located at the town Water Treatment Plant in Falmouth, MA on a level area at a slightly higher elevation than the rest of the plant. The location of the tower base is at 41.606° North, 70.621° West.

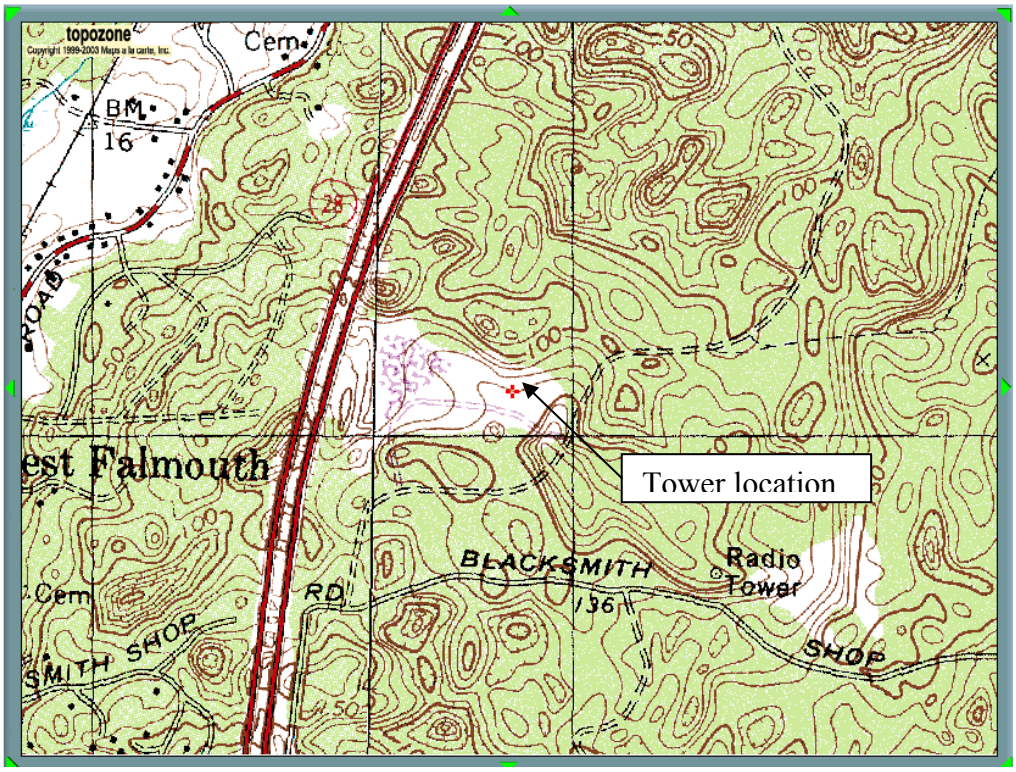

Figure 1 - Site location at Falmouth site.

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a standard NRG 40 m tall 6 in diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 10 m, 30 m, and 39 m. Redundant anemometers exist at 30 m and 39 m.

Additional equipment and models include:

- NRG model Symphonie Cellogger
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)
- 3 - #200P Wind direction vanes
- Lightning rod and grounding cable
- NRG 11S temperature Sensor

The data from the Symphonie logger is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These are then combined into 10-minute averages, and along with the standard deviation for those 10-minute periods, are put into a binary file. These binary files are converted to ASCII text files using the NRG software BaseStation®. These text files are then imported into a database software program where they are subjected to QA tests prior to using the data.

SECTION 3- Data Collection and Maintenance

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction	Turbulence Intensity
Heights, units	**39 m, [m/s]**	**39 m, [m/s]**	**39 m, [ ]**	**39 m, [ ]**	**30 m, [m/s]**	**30 m, [m/s]**	**30 m, [ ]**	**10 m, [m/s]**	**10 m, [m/s]**	**10 m, [ ]**	**10 m, [ ]**
May-04	**4.89**	**13.82**	**0.23**	**SW**	**4.47**	**13.08**	**0.26**	**3.47**	**10.64**	**SSW**	**0.3**

SECTION 4 - Significant Meteorological Events

No significant storm events were listed for Barnstable during the month of May 2004. (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms)

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. The high values indicate that the sensor and logger were working correctly.

Gross Data Recovered [%]	100
Net Data Recovered [%]	99.895

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.

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

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 speed (TF2) is less than or equal to Factor 1 (F1), the wind direction standard deviation (TF1) is less 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.

$$[\ TF1 \le F3 \text{ and } TF2 \le F3 \text{ and } abs(TF1 - TF2) > F1\ ]$$
$$\text{or } [\ (TF1 > F3 \text{ or } TF2 > F3) \text{ and } (abs(1 - TF1 / TF2) > F2 \text{ or } abs(1 - TF2 / TF1) > F2)\ ]$$

Sensor Statistics

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). 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. The maximum percentage is between 5 and 6 m/s

- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed from May 2004 - Aug 2004.

- Diurnal – A plot of the average wind speed for each hour of the day. This graph shows a peak wind speed between 1 PM and 4 PM.

- 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. . The summer wind rose shows a prevailing SW wind direction at the 39 m height.

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

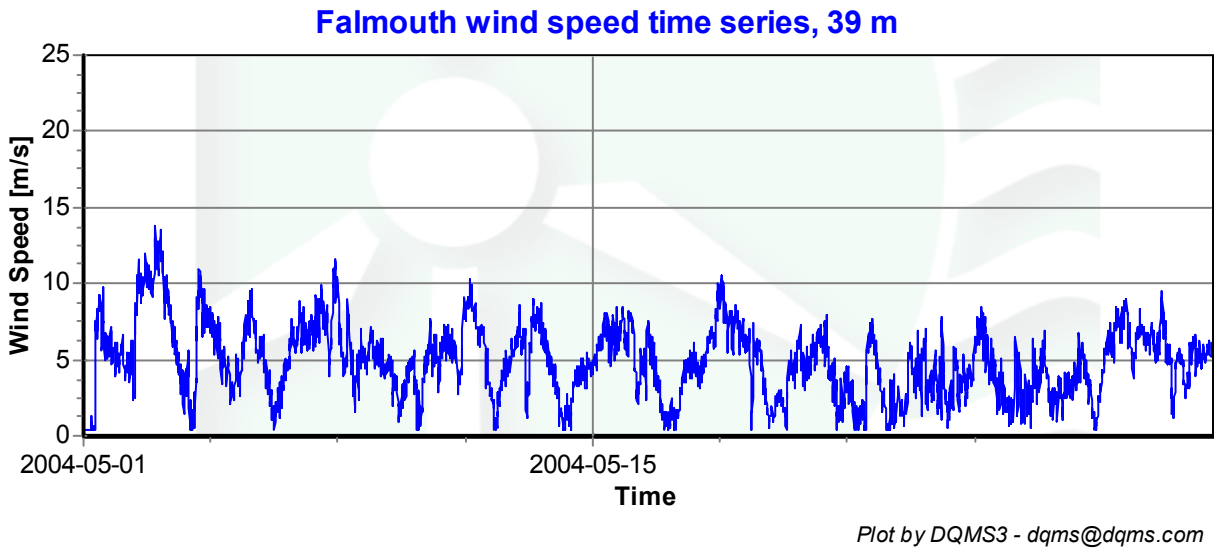

Figure 2 - Wind Speed Time Series, May1, 2004 to May 31, 2004

Wind Speed Distributions

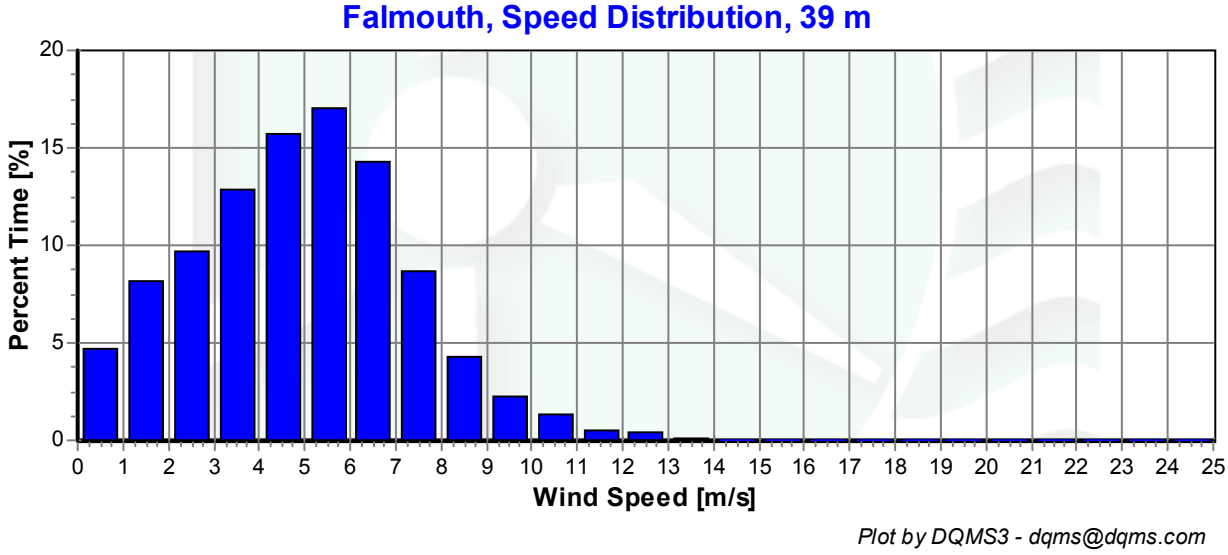

Figure 3 - Wind Speed Distribution, May1, 2004 to May 31, 2004

Monthly Average Wind Speeds

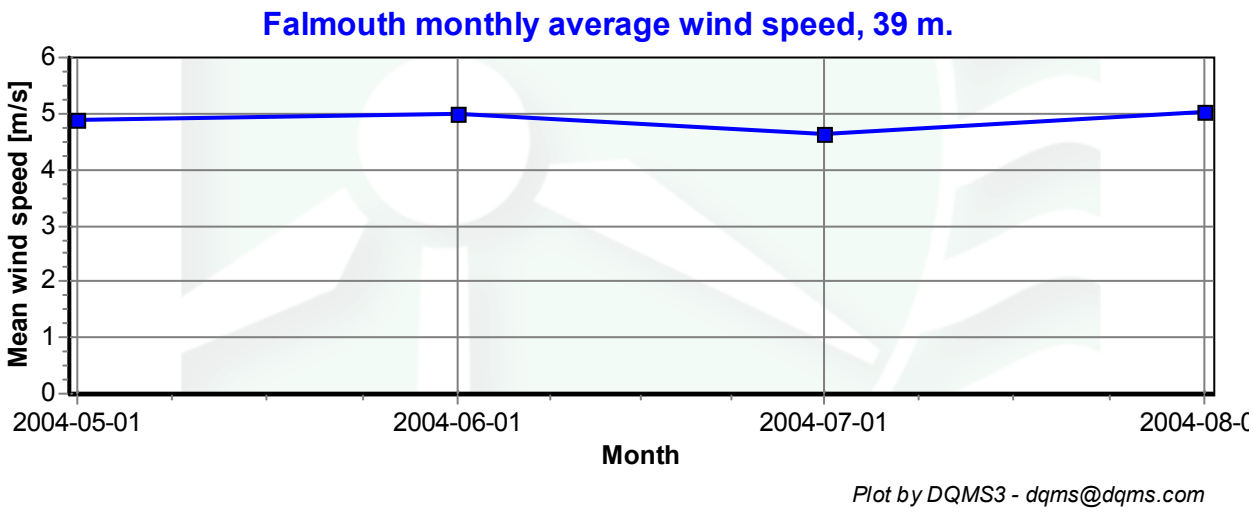

Figure 4 - Monthly average wind speeds

Diurnal Average Wind Speeds

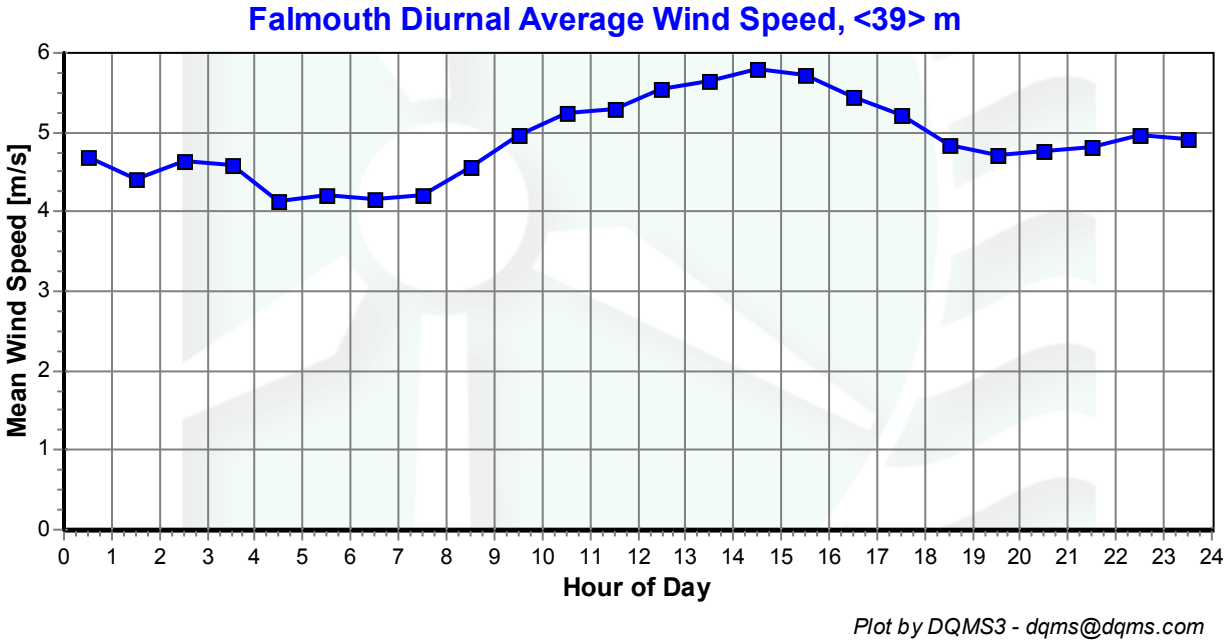

Figure 5 - Diurnal Wind Speed, May1, 2004 to May 31, 2004

Turbulence Intensities

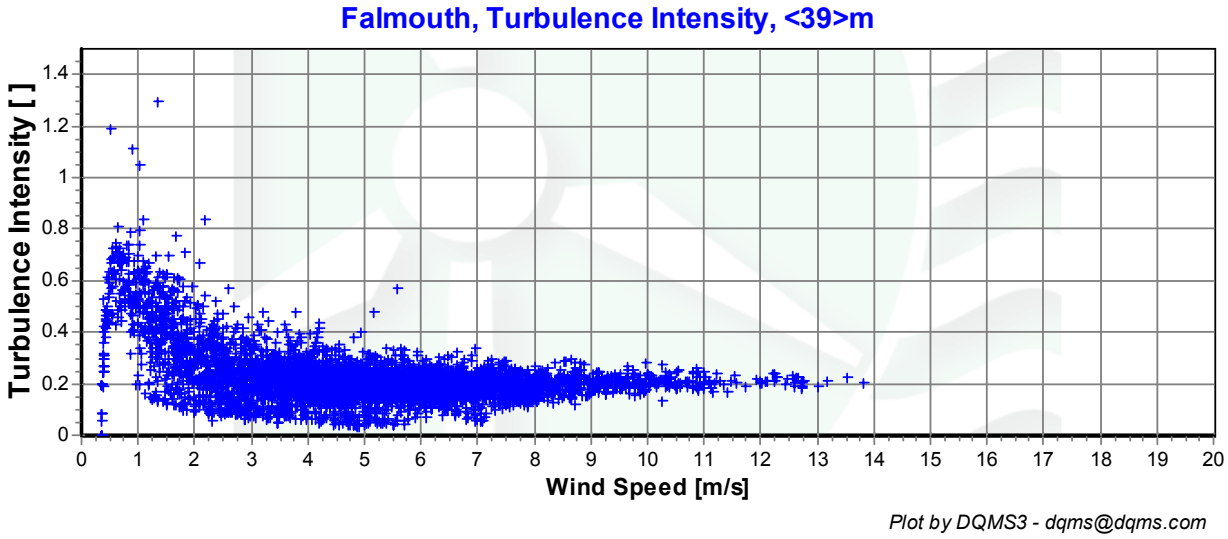

Figure 6 - Turbulence Intensity vs. Wind Speed, May1, 2004 to May 31, 2004

Wind Roses

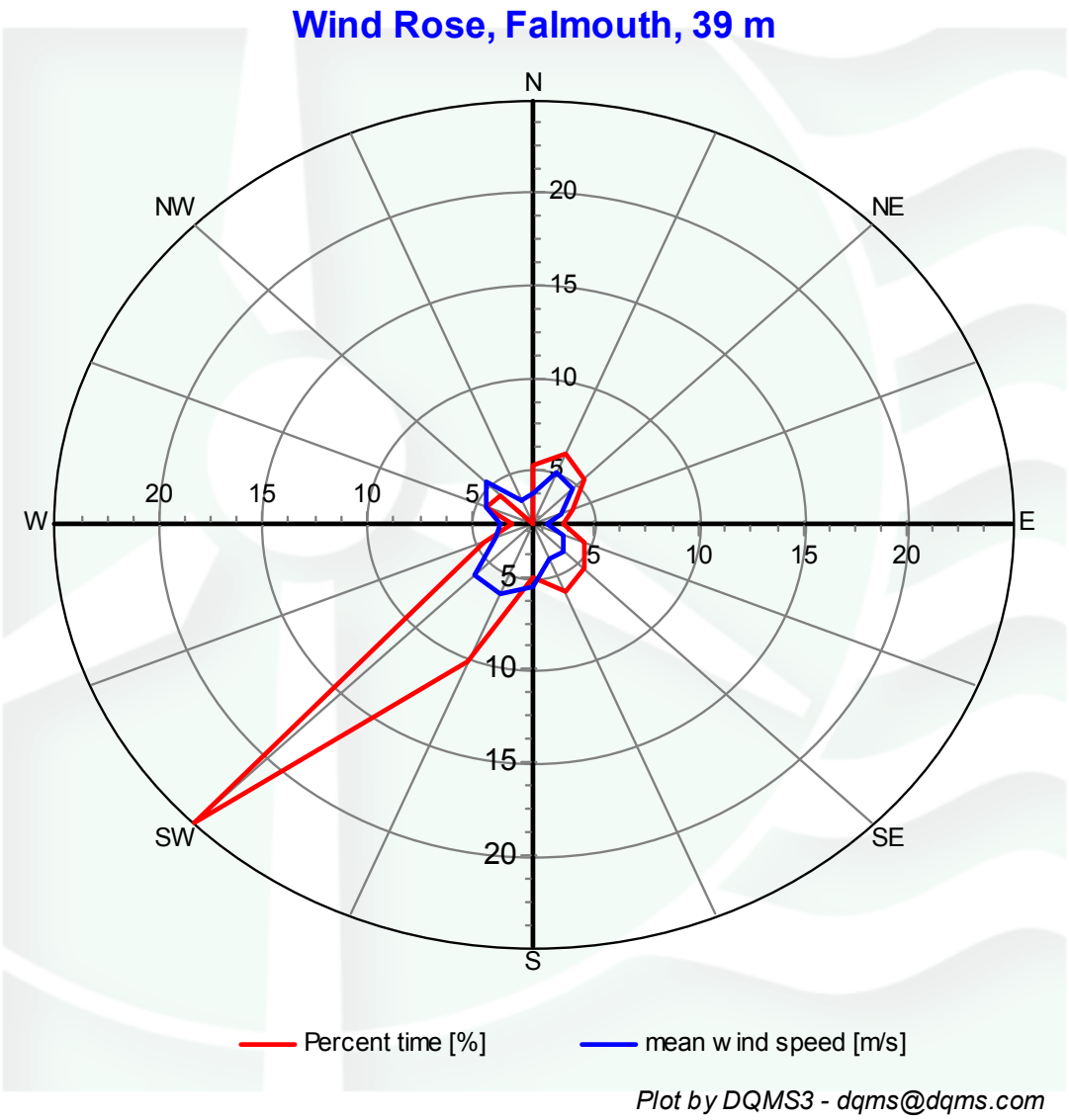

Figure 7 – Wind Rose, May1, 2004 to May 31, 2004.

APPENDIX A - Sensor Performance Report

Test Definitions

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert	0	0	0	0
4	Etmp2aDEGC					MinMax	-30	60	0	0
5	EtmpSD2aDEGC					MinMax	-30	60	0	0
10	Anem10aMS					MinMax	0	90	0	0
11	Anem30aMS					MinMax	0	90	0	0
12	Anem30bMS					MinMax	0	90	0	0
13	Anem39aMS					MinMax	0	90	0	0
14	Anem39bMS					MinMax	0	90	0	0
15	Anem30yMS					MinMax	0	90	0	0
16	Anem39yMS					MinMax	0	90	0	0
20	AnemSD10aMS					MinMax	0	4	0	0
21	AnemSD30aMS					MinMax	0	4	0	0
22	AnemSD30bMS					MinMax	0	4	0	0
23	AnemSD39aMS					MinMax	0	4	0	0
24	AnemSD39bMS					MinMax	0	4	0	0
30	Vane10aDEG					MinMax	0	359.9	0	0
31	Vane30aDEG					MinMax	0	359.9	0	0
32	Vane39aDEG					MinMax	0	359.9	0	0
50	Turb10zNONE					MinMax	0	2	0	0
51	Turb30zNONE					MinMax	0	2	0	0
52	Turb39zNONE					MinMax	0	2	0	0
60	Wshr0zNONE					MinMax	-100	100	0	0
200	VaneSD10aDEG	Anem10aMS				MinMaxT	0	100	100	10
201	VaneSD30aDEG	Anem30yMS				MinMaxT	0	100	100	10
202	VaneSD39aDEG	Anem39yMS				MinMaxT	0	100	100	10
300	Anem10aMS	AnemSD10aMS	Vane10aDEG	VaneSD10aDEG	Etmp2aDEGC	Icing	0.5	1	2	0
301	Anem30aMS	AnemSD30aMS	Vane30aDEG	VaneSD10aDEG	Etmp2aDEGC	Icing	0.5	1	2	0
302	Anem30bMS	AnemSD30bMS	Vane30aDEG	VaneSD30aDEG	Etmp2aDEGC	Icing	0.5	1	2	0
303	Anem39aMS	AnemSD39aMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	0
304	Anem39bMS	AnemSD39bMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	0
400	Anem30aMS	Anem30bMS				CompareSensors	1	0.25	3	0
401	Anem39aMS	Anem39bMS				CompareSensors	1	0.25	3	0
500	Amax10aMS					MinMax	0	90	0	0
501	Amin10aMS					MinMax	0	90	0	0
502	Amax30aMS					MinMax	0	90	0	0
503	Amin30aMS					MinMax	0	90	0	0
504	Amax30bMS					MinMax	0	90	0	0
505	Amin30bMS					MinMax	0	90	0	0

506	Amax39aMS					MinMax	0	90	0	0
507	Amin39aMS					MinMax	0	90	0	0
508	Amax39bMS					MinMax	0	90	0	0
509	Amin39bMS					MinMax	0	90	0	0
540	Vmax10aDEG					MinMax	0	359.9	0	0
541	Vmin10aDEG					MinMax	0	359.9	0	0
542	Vmax30aDEG					MinMax	0	359.9	0	0
543	Vmin30aDEG					MinMax	0	359.9	0	0
544	Vane39aDEG					MinMax	0	359.9	0	0
560	Emax2aDEGC					MinMax	-30	60	0	0
561	Emin2aDEGC					MinMax	-30	60	0	0
562	Vmax39aDEG					MinMax	0	360	0	0
563	Vmin39aDEG					MinMax	0	360	0	0
564	Pwrd10zWMC					MinMax	0	500	0	0
565	Pwrd30zWMC					MinMax	0	500	0	0
566	Pwrd39zWMC					MinMax	0	500	0	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem39aMS	4321	4321	100	0	0	0	100
AnemSD39aMS	4321	4321	100	0	0	0	100
Amax39aMS	4321	4321	100	0	0	0	100
Amin39aMS	4321	4321	100	0	0	0	100
Anem39bMS	4321	4321	100	0	0	1	99.861
AnemSD39bMS	4321	4321	100	0	0	0	100
Amax39bMS	4321	4321	100	0	0	0	100
Amin39bMS	4321	4321	100	0	0	0	100
Anem30aMS	4321	4321	100	0	0	0.5	99.931
AnemSD30aMS	4321	4321	100	0	0	0	100
Amax30aMS	4321	4321	100	0	0	0	100
Amin30aMS	4321	4321	100	0	0	0	100
Anem30bMS	4321	4321	100	0	0	0	100
AnemSD30bMS	4321	4321	100	0	0	0	100
Amax30bMS	4321	4321	100	0	0	0	100
Amin30bMS	4321	4321	100	0	0	0	100
Anem10aMS	4321	4321	100	0	0	0	100
AnemSD10aMS	4321	4321	100	0	0	0	100
Amax10aMS	4321	4321	100	0	0	0	100
Amin10aMS	4321	4321	100	0	0	0	100
Vane39aDEG	4321	4321	100	0	0	0	100
VaneSD39aDEG	4321	4321	100	0.333	0	0	99.954
Vmax39aDEG	4321	4321	100	0	0	0	100
Vmin39aDEG	4321	4321	100	0	0	0	100
Vane30aDEG	4321	4321	100	0	0	0	100
VaneSD30aDEG	4321	4321	100	1.333	0	0	99.815
Vmax30aDEG	4321	4321	100	0	0	0	100
Vmin30aDEG	4321	4321	100	0	0	0	100
Vane10aDEG	4321	4321	100	0	0	0	100
VaneSD10aDEG	4321	4321	100	0.833	0	0	99.884
Vmax10aDEG	4321	4321	100	0	0	0	100
Vmin10aDEG	4321	4321	100	0	0	0	100
Etmp2aDEGC	4321	4321	100	7.833	0	0	98.912
EtmpSD2aDEGC	4321	4321	100	0	0	0	100
Emax2aDEGC	4321	4321	100	7.167	0	0	99.005
Emin2aDEGC	4321	4321	100	8.167	0	0	98.866
Total	155556	155556	100	25.667	0	1.5	99.895

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	4.68
1.5	8.15
2.5	9.7
3.5	12.81
4.5	15.74
5.5	17
6.5	14.33
7.5	8.62
8.5	4.32
9.5	2.26
10.5	1.37
11.5	0.47
12.5	0.45
13.5	0.09
14.5	0
15.5	0
16.5	0
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution, May1, 2004 to May 31, 2004.

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
May 04	4.89

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0	4.69
1	4.42
2	4.64
3	4.59
4	4.15
5	4.21
6	4.16
7	4.21
8	4.56
9	4.96
10	5.24
11	5.29
12	5.54
13	5.65
14	5.79
15	5.71
16	5.44
17	5.23
18	4.83
19	4.72
20	4.78
21	4.81
22	4.96
23	4.91

Table 3 - Diurnal Average Wind Speeds, May1, 2004 to May 31, 2004.

Wind Rose Data

Direction	Percent Time [%], 40 m	Mean Wind Speed [m/s], 50 m
N	5.31	3.77
NNE	6.27	5.1
NE	5.53	4.72
ENE	4.12	3.57
E	3.58	2.79
ESE	4.77	3.69
SE	5.51	4.2
SSE	6.07	4.14
S	5.06	5.5
SSW	10.12	6.19
SW	24.97	5.99
WSW	4.61	3.98
W	3.16	3.68
WNW	4.48	4.57
NW	4.32	5.3
NNW	2.11	3.49

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction,May1, 2004 to May 31, 2004.