WIND DATA REPORT

Paxton, MA

March 1 2004 – May 31 2004

Prepared for Diane Dillman, Paxton Light Department

by

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EXECUTIVE SUMMARY

Wind monitoring equipment was first installed at the Yankee Network Tower in Paxton, MA in late June 2003, with data collection starting from the 24th of that month on to the present.

Data collection percentages during the quarterly three month period of March 2004 through May 2004 were very good: the raw data recovery rate was 99.96%, and after quality assurance the percentage of good data was 94.5%. The average wind speed during the quarter was 7.8 m/sec at 78 m height (22 mph at 217.2 ft) – as before, indicative of a strong wind resource. Turbulence intensity for that time period was an average of 0.15. The prevailing wind was from the west north-west.

SECTION 1 - Station Location

The Yankee Network Tower is located on Mount Asnebumskit, southeast of the town of Paxton at an elevation of approximately 420 m. The wind monitoring equipment is mounted higher still, on the tower at 78 m. Site coordinates are 42-18-11.6 North, 71-53-50.9 West per the WGS84 standard (the World Geodetic System 1984, an international standard for absolute localization with earthly coordinates). See the figure below for a map of the tower location.

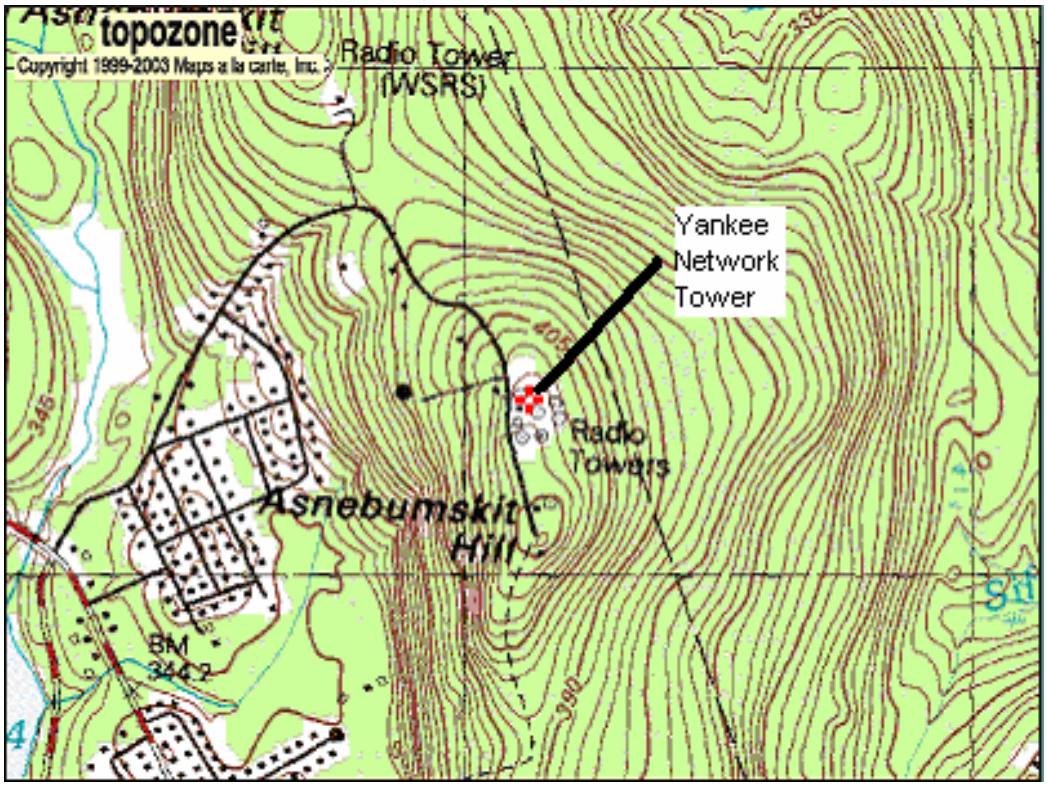

Figure 1 - Site location of Paxton wind monitoring

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 8.2 foot aluminum tube, that is attached vertically to the main network tower. The primary and secondary anemometers and two vanes are attached on short booms off the tube. A picture of the setup is below – note the horizontal booms where the anemometers and vanes are attached:

Figure 2 - Instrumentation at top of Yankee Network Tower – note the anemometers on the left (horizontal boom and at the top of the left-hand vertical tube).

Figure 3 – Bottom view of sensor array, anemometer is at photo top and wind vanes are mounted on the shorter side booms.

The installed equipment of note comprises:

- Symphonie data logger, serial #3090-0047
- Two #40 anemometers, standard calibration (slope 0.765 m/s, offset 0.350 m/s)
- Two #200P wind direction vanes
- Short booms for vanes, 14” from mast
- Long side booms for anemometers, 43” from mast
- Lightning rod and grounding cable
- Shielded sensor wire

SECTION 3 - Data Collection and Maintenance

During the period of March 2004 through May 2004 no maintenance events occurred.

Data collection during this period was fair, with results summarized below.

Date	Mean 10 min [m/s]	Max 10 min [m/s]	Turbulence Intensity [ ]	Prevailing Wind Direction [ ]
2004 March	7.99	20.99	0.15	315
April	8.13	18.4	0.15	315
May	7.16	17.4	0.15	248
March 04 – May 04	**7.76**	**18.9**	**0.15**	**293, WNW**

SECTION 4 - Significant Meteorological Events

No meteorological events of note were recorded during this reporting period.

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 [%]	99.96
Net Data Recovered [%]	89.2

N.B. As of mid-September 2004, we are in the midst of resolving a processing bug in the tests, which cause the net data recovered to be less than the true value; the true percentage recovery is approximately 99%.

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 is 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, the wind speed (TF1) is greater than Factor 2, and the temperature (CF2) is less than Factor 3.

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

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.

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

Sensor Statistics

Sensor statistics are presented in Appendix A; the definitions of the data in Appendix A are:

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.
- 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.

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

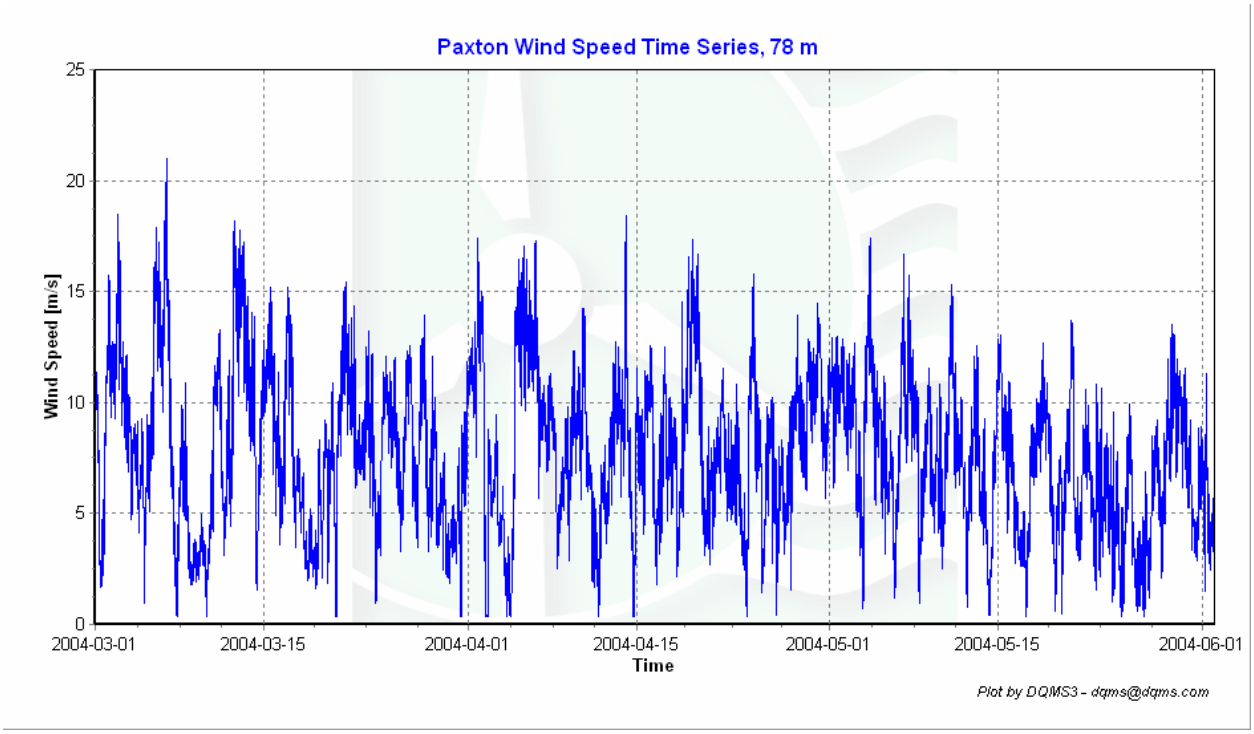

Figure 4 – Paxton wind speed time series, March 1 2004 – May 31 2004

Wind Speed Distributions

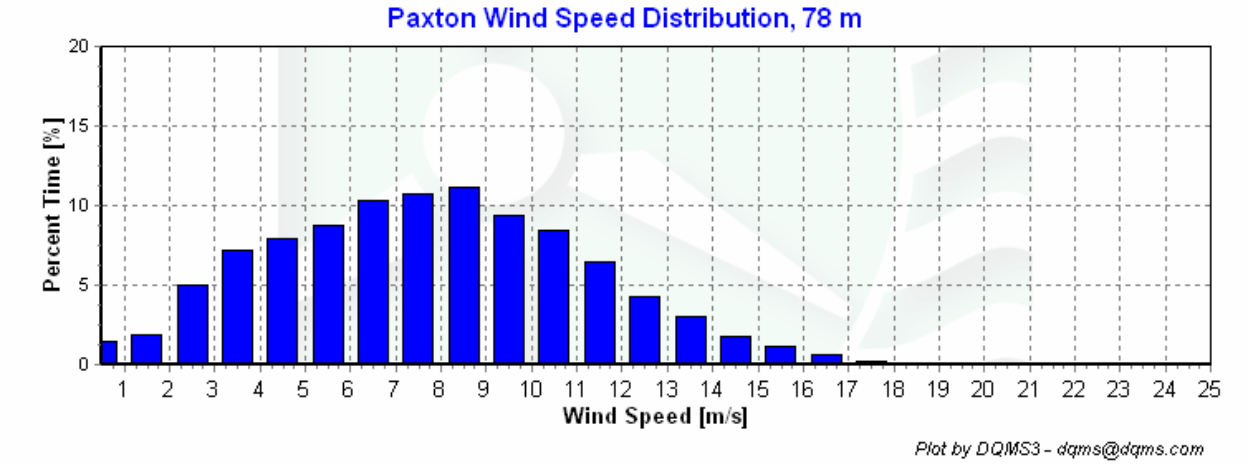

Figure 5 - Paxton wind speed distribution, March 1 2004 – May 31 2004

Monthly Average Wind Speeds

Note that the plot below is somewhat distorted since we are only considering nine monthly averages, July 2003 through February 2004 – i.e. the readings for missing months are not really zero as graphically implied.

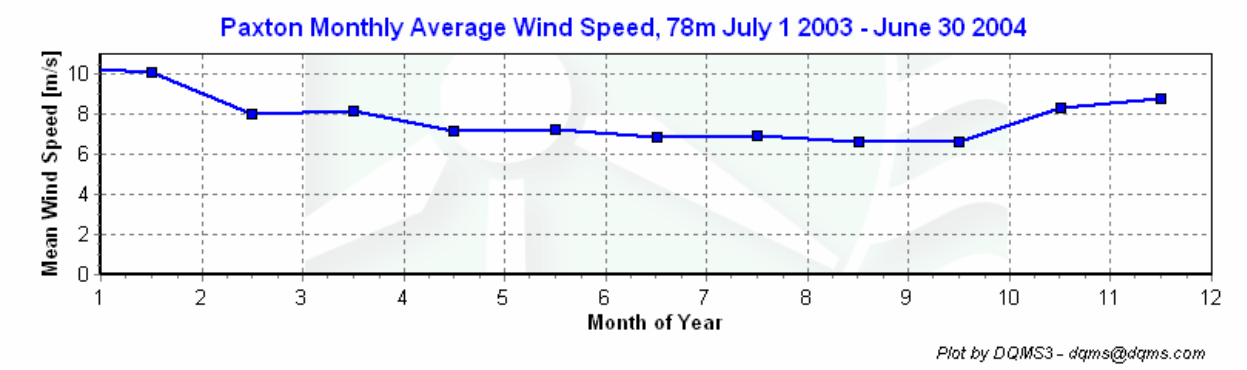

Figure 6 – Paxton monthly average wind speed for July 2003 through May 2004

Diurnal Average Wind Speeds

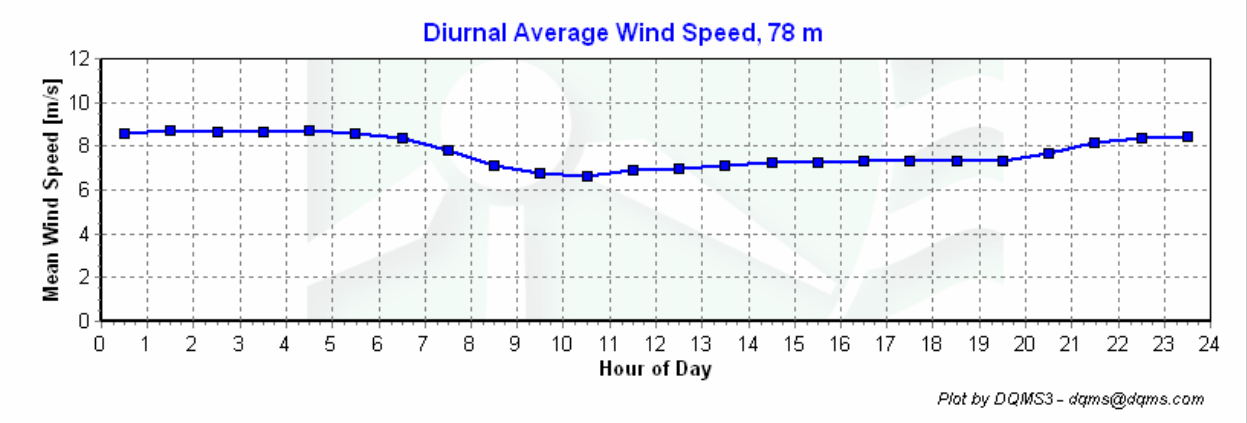

Figure 7 - Diurnal Wind Speed, March 2004 - May 2004

Turbulence Intensities

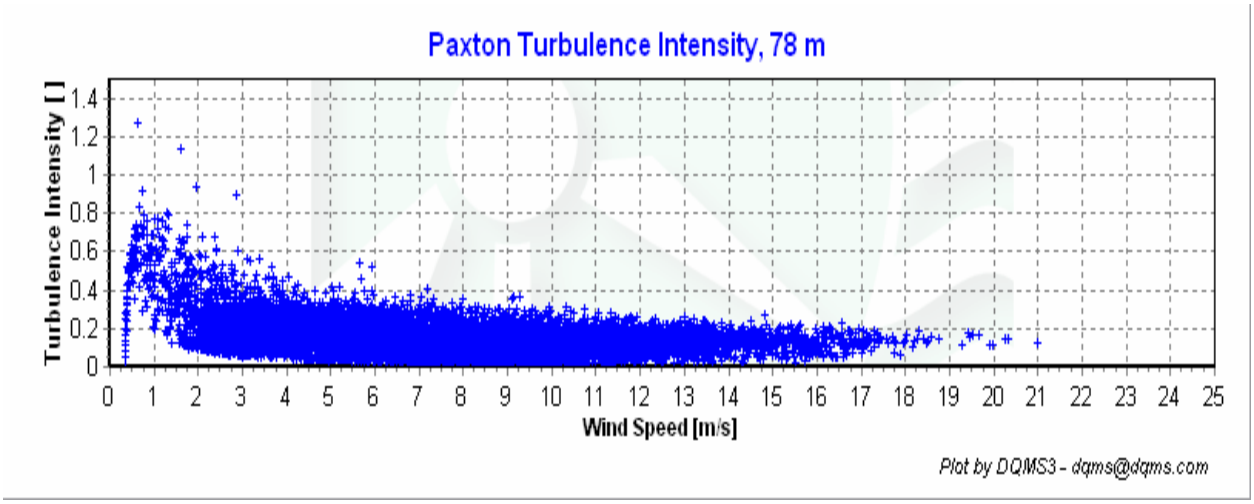

Figure 8 - Turbulence Intensity vs. Wind Speed, March 2004 – May 2004

Wind Roses

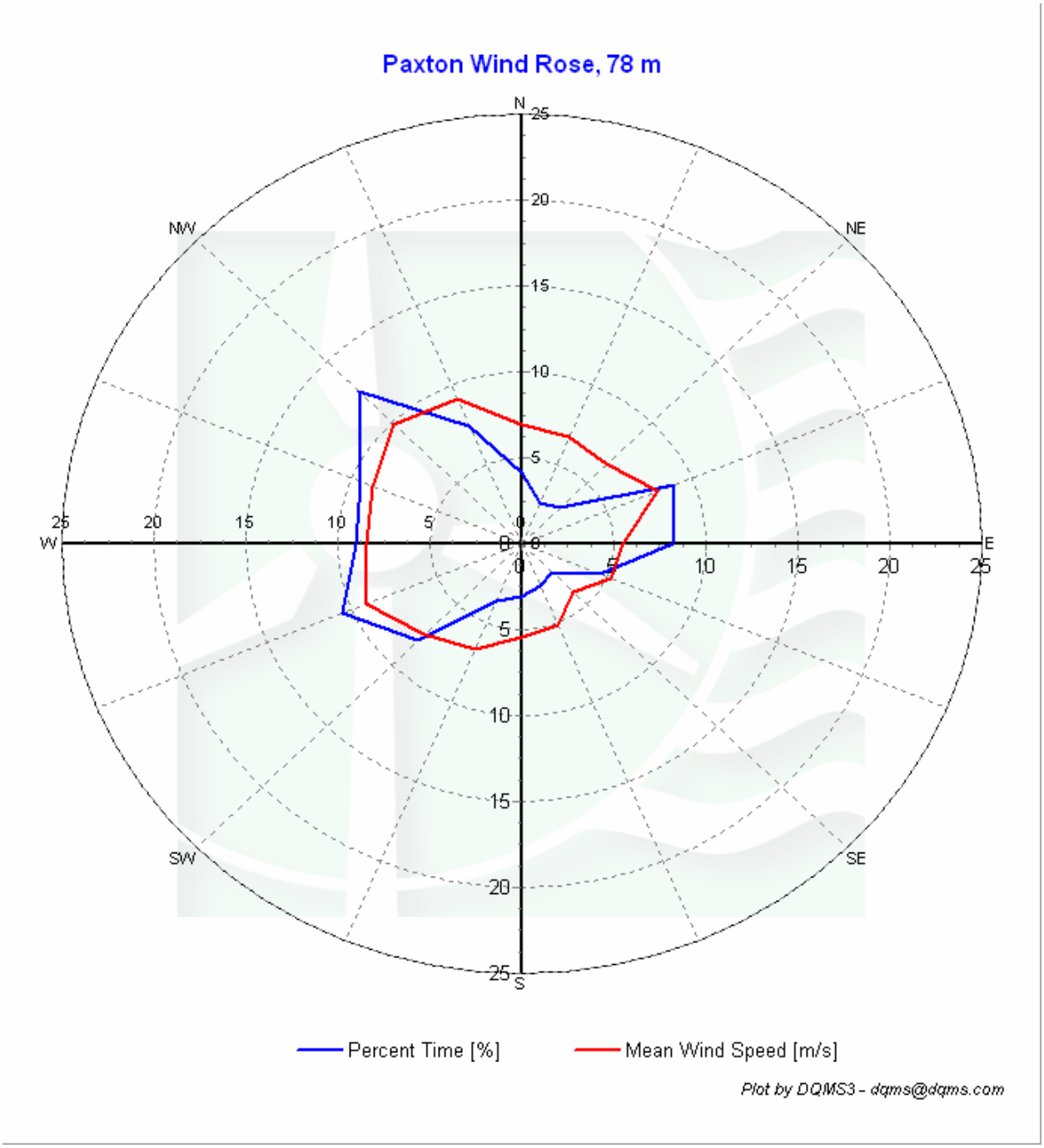

Figure 9 – Paxton Wind Rose, March 2004 – May 2004

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	Test Field1	Test Field2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor 1	Factor 2	Factor 3	Factor 4
1							TimeTest Insert				
2	Etmp2aC						MinMax	-30	60		
3	EtmpSD2aC						MinMax	-30	60		
4	Emax2aC						MinMax	-30	60		
5	Emain2aC						MinMax	-30	60		
10	Anem78aMS						MinMax	0	90		
11	Anem78bMS						MinMax	0	90		
20	AnemSD78aMS						MinMax	0	4	0	0
21	AnemSD78bMS						MinMax	0	4	0	0
30	Vane77aDEG						MinMax	0	359.9		
31	Vane77bDEG						MinMax	0	359.9		
40	Turb78zNONE						MinMax	0	2		
60	VaneSD77aDEG	Anem78yMS					MinMaxT	0	100	100	10
61	VaneSD77bDEG	Anem78yMS					MinMaxT	0	100	100	10
100	Anem78aMS	AnemSD78aMS	Vane77aDEG	VaneSD77aDEG	Etmp2aC		Icing	0.5	1	2	2
101	Anem78bMS	AnemSD78bMS	Vane77aDEG	VaneSD77aDEG	Etmp2aC		Icing	0.5	1	2	2
200	Amax78aMS	Anem78bMS					CompareSensors	1	0.35	3	0
201	Amin78aMS						MinMax	0	90		
202	Amax78bMS						MinMax	0	90		
203	Amin78bMS						MinMax	0	90		
206	Vmax77aDEG						MinMax	0	359		
207	Vmin77aDEG						MinMax	0	359		
208	Vmax77bDEG						MinMax	0	359		
209	Vmin77bDEG						MinMax	0	359		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem78aMS	13248	13242	99.955	0.667	0	0	99.925
AnemSD78aMS	13248	13242	99.955	0.667	0	0	99.925
Anem78bMS	13248	13242	99.955	0.333	0	1188.333	46.12
AnemSD78bMS	13248	13242	99.955	0.333	0	1188.333	46.12
Vane77aDEG	13248	13242	99.955	0.667	0	0	99.925
VaneSD77aDEG	13248	13242	99.955	0.667	0	0	99.925
Vane77bDEG	13248	13242	99.955	0.167	0	0	99.947
VaneSD77bDEG	13248	13242	99.955	0.167	0	0	99.947
Etmp2aC	13248	13242	99.955	0	0	0	99.955
EtmpSD2aC	13248	13242	99.955	0	0	0	99.955
Total	**132480**	**132420**	**99.96%**	**3.668**	**0**	**2376.7**	**89.2%**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	March – May 2004
0.5	1.48%
1.5	1.87%
2.5	5.02%
3.5	7.18%
4.5	7.95%
5.5	8.71%
6.5	10.33%
7.5	10.72%
8.5	11.10%
9.5	9.40%
10.5	8.47%
11.5	6.48%
12.5	4.32%
13.5	2.99%
14.5	1.80%
15.5	1.11%
16.5	0.63%
17.5	0.26%
18.5	0.08%
19.5	0.05%
20.5	0.02%
21.5	0.00%
22.5	0.00%
23.5	0.00%
24.5	0.00%

Monthly Average Wind Speed Data

Date	Mean 10 min. [m/s]
2004 March	7.99
April	8.13
May	7.16
March – May 2004	**7.76**

Diurnal Average Wind Speed Data

Hour of Day	March – May 2004
0	8.58
1	8.72
2	8.65
3	8.68
4	8.75
5	8.59
6	8.39
7	7.8
8	7.09
9	6.76
10	6.66
11	6.93
12	7
13	7.09
14	7.25
15	7.26
16	7.29
17	7.3
18	7.33
19	7.33
20	7.68
21	8.19
22	8.34
23	8.47

Wind Rose Data

	March – May 2004	
Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	4.15%	6.92
NNE	2.60%	6.71
NE	2.95%	6.52
ENE	8.95%	8
E	8.17%	5.5
ESE	4.65%	5.21
SE	2.33%	3.95
SSE	2.66%	5.1
S	3.04%	5.45
SSW	3.58%	6.68
SW	7.99%	7.5
WSW	10.56%	9.12
W	9.00%	8.48
WNW	9.46%	8.8
NW	12.51%	9.82
NNW	7.41%	9.15