WIND DATA REPORT

Kingston, MA

March 1, 2006 - May 31, 2006

Prepared for

Massachusetts Technology Collaborative
75 North Drive
Westborough, MA 01581

by

Daniel W. Jaynes
James F. Manwell
Anthony L. Rogers
Anthony F. Ellis

July 13, 2006

Report template version 2.0

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

NOTICE AND ACKNOWLEDGEMENTS

This report was prepared by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Technology Collaborative (MTC), pursuant to work order number 05-1. The opinions expressed in this report do not necessarily reflect those of MTC or the Commonwealth of Massachusetts, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

TABLE OF CONTENTS

TABLE OF FIGURES

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 wind data measured at a meteorological tower installed at the capped Landfill in Kingston, MA. Installed on July 12, 2005, the wind monitoring station has been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 49m (160.8 ft) and 38m (124.7 ft), and an additional vane and anemometer are mounted at 20m (65.6 ft).

The season covered by this report is March 2006 – May 2006 . The mean recorded wind speed for this quarter was 5.85 m/s (13.1 mph)[1] and the prevailing wind direction was from the southwest. 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 99.2%.

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] 1m/s=2.237 mph

SECTION 1 - Station Location

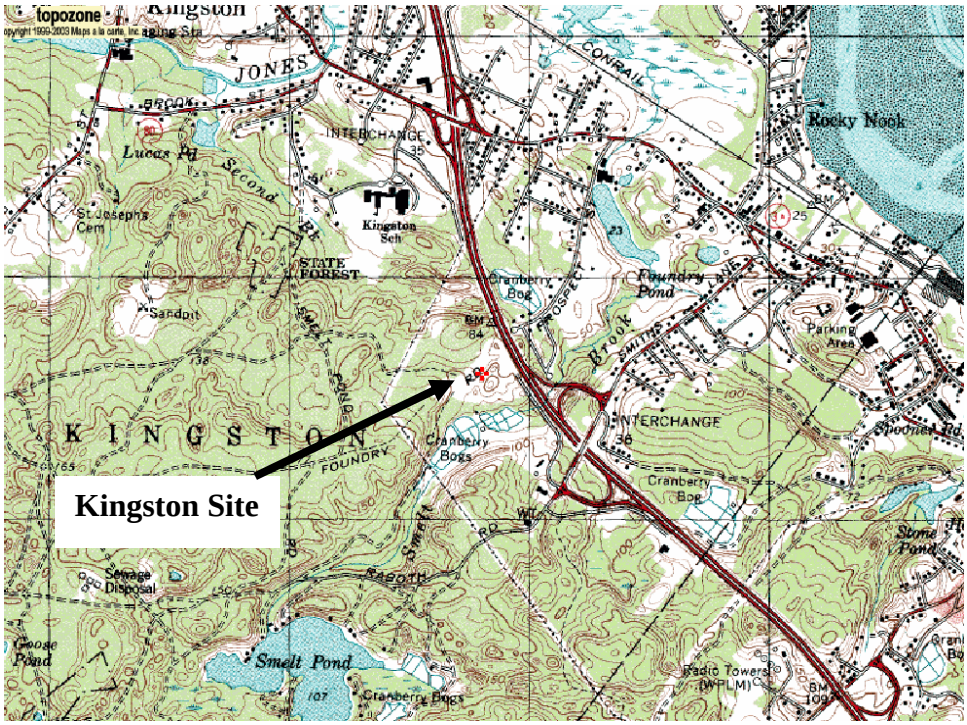

Figure 1 – Location of Kingston Site

The Kingston site is located on the top of the capped town landfill (adjacent to the wastewater treatment plant and transfer station) in Kingston, MA. The site coordinates are 041° 58.702N by 070° 42.925W. These coordinates correspond to the NAD83 datum.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) NRG tower. All the monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- Electrical enclosure box
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 49 m (160.8 ft), two at 38 m (124.7 ft) and one at a height of 20 m (65.6 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 49m (160.8 ft), 38m (124.7 ft) and 20m (65.6 ft) each.
- 5 – Sensor booms, 54” length
- Lightning rod and grounding cable
- Shielded sensor wire

The data from the Symphonie logger is mailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These data 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 quality assurance (QA) tests prior to using the data.

SECTION 3 - Data Collection and Maintenance

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

- No problems with the data were encountered.
- 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	**49 m, [m/s]**	**49 m, [m/s]**	**49 m [ ]**	**49 m [ ]**	**38 m [m/s]**	**38 m [m/s]**	**38 m [ ]**	**38 m [ ]**	**20 m [m/s]**	**20 m [m/s]**	**20 m [ ]**	**20 m [ ]**	**Calc b/t 49 & 38m, [ ]**
Mar 2006	5.89	14.92	0.19	NW	5.46	14.15	0.20	NW	4.50	12.66	0.25	NW	0.31
Apr 2006	5.89	12.31	0.18	SW	5.50	11.72	0.19	SW	4.62	10.80	0.23	SW	0.27
May 2006	5.79	13.71	0.18	NNE	5.41	12.95	0.20	NNE	4.53	11.43	0.24	SW	0.29
Mar – Apr '06	**5.85**	**14.92**	**0.18**	**SW**	**5.46**	**14.15**	**0.20**	**SW**	**4.55**	**12.66**	**0.24**	**SW**	**0.29**

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 amount 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, vertical airflow and 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. The shear coefficient 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

In March, April and May 2006 there were no major meteorological events that would have caused notable fluctuations in wind speed measurements. The average wind speeds for the general Kingston area were close to normal.

Source: http://www.erh.noaa.gov/box/MonthlyClimate2.shtml

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 [%]	99.2%

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 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.

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

Sensor Statistics

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 for all data starting on March 1st, 2006 at 12:00 AM through May 31st, 2006 at 11:50 PM in Figure 2. This plot presents data at 49 meters.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. This plot shows that the wind speeds ranged between 5 and 6 m/s (11.2 and 13.4 mph) 19.0% of the time. See Figure 3 for data representing March 1st, 2006 at 12:00 AM through May 31st, 2006 at 11:50 PM. This plot presents data at 49 meters.

- Monthly Average Wind Speeds – This plot shows the trends in the mean monthly wind speed at a height of 49 m. This graph shows the trends in the wind speed

over the year. The monthly average wind speed plot is shown in Figure 4 from July 2005 through May 2006.

- Diurnal – A plot of the average wind speed for each hour of the day. The hourly average varied between 5.4 and 6.4 m/s (12.1 and 14.3 mph), with the highest average speeds in the afternoon. See Figure 5 for data representing March 1st, 2006 at 12:00 AM through May 31st, 2006 at 11:50 PM. This plot presents data at 49 meters.

- 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. In general, turbulence intensities range from 0.1 to 0.4; for Kingston, the average turbulence intensity was 0.18. In the graph below, the turbulence intensity flattens out between 4 and 5 m/s (8.9 and 11.2 mph). See Figure 6 for data representing March 1st, 2006 at 12:00 AM through May 31st, 2006 at 11:50 PM. This plot represents data at 49 meters.

- 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 wind rose below shows the prevailing direction from the southwest. Wind blew from the southwesterly direction 12.6 % of the time with a mean wind speed of 7.2 m/s (16.1 mph). See Figure 7 for data representing March 1st, 2006 at 12:00 AM through May 31st, 2006 at 11:50 PM at a height of 49 meters.

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

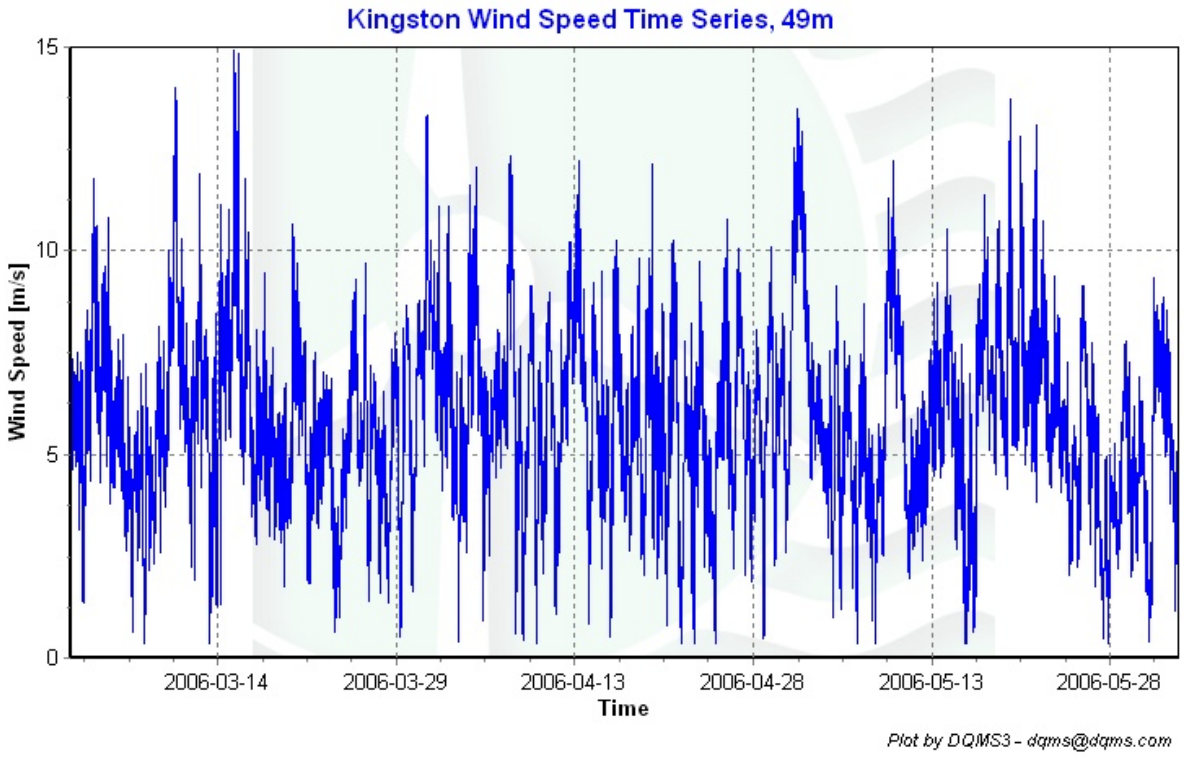

Figure 2 - Wind Speed Time Series, March 1st 2006– May 31st 2006

Wind Speed Distributions

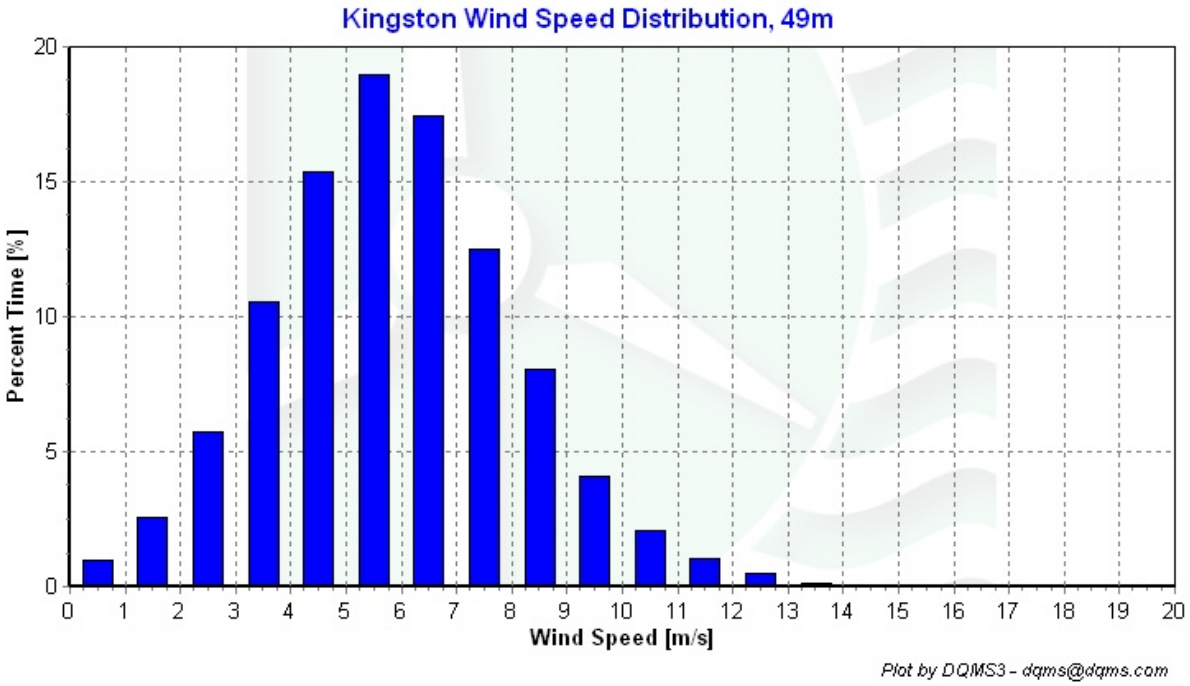

Figure 3 - Wind Speed Distribution, March 1st 2006– May 31st 2006

Monthly Average Wind Speeds

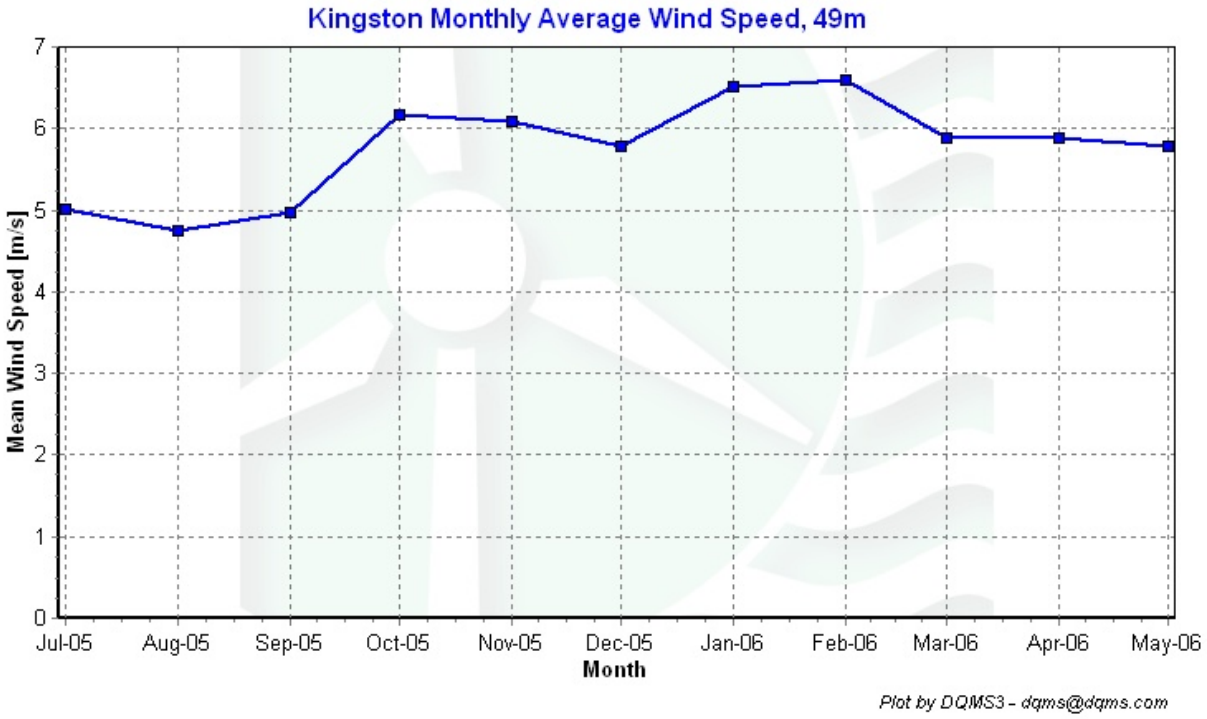

Figure 4 – Monthly Average Wind Speeds, July 2005– May 2006

Diurnal Average Wind Speeds

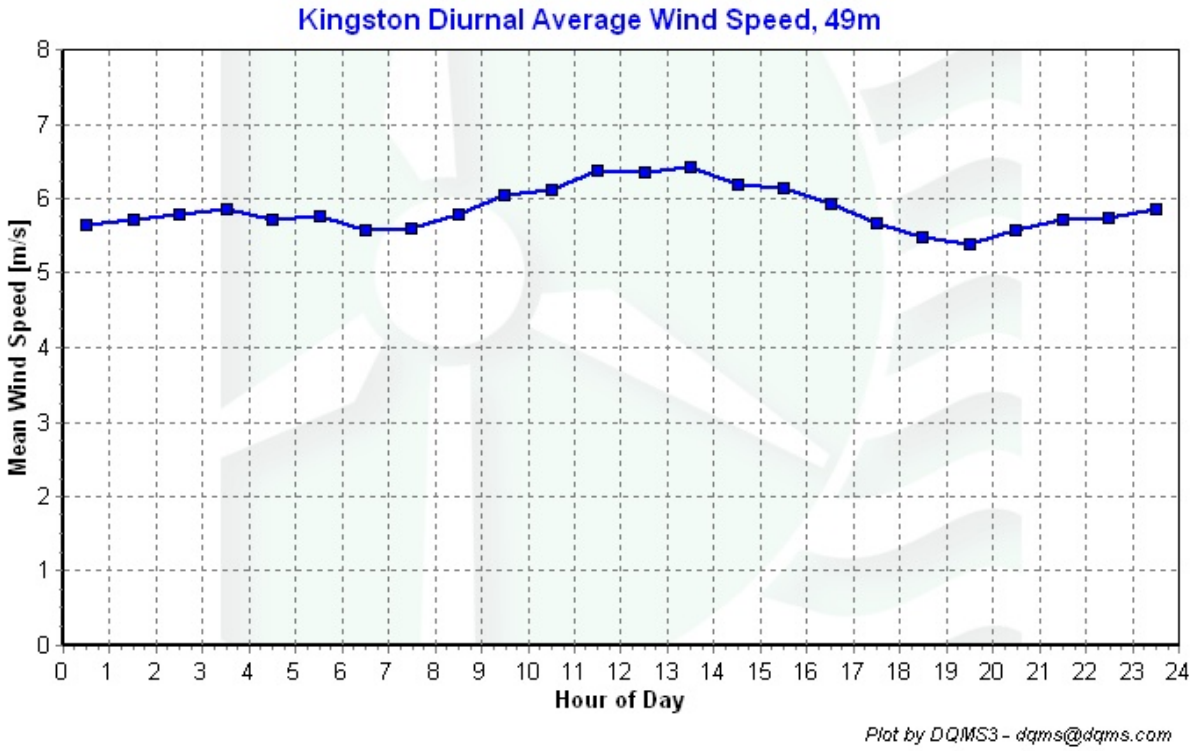

Figure 5 – Diurnal Average Wind Speeds, March 1st 2006– May 31st 2006

Turbulence Intensities

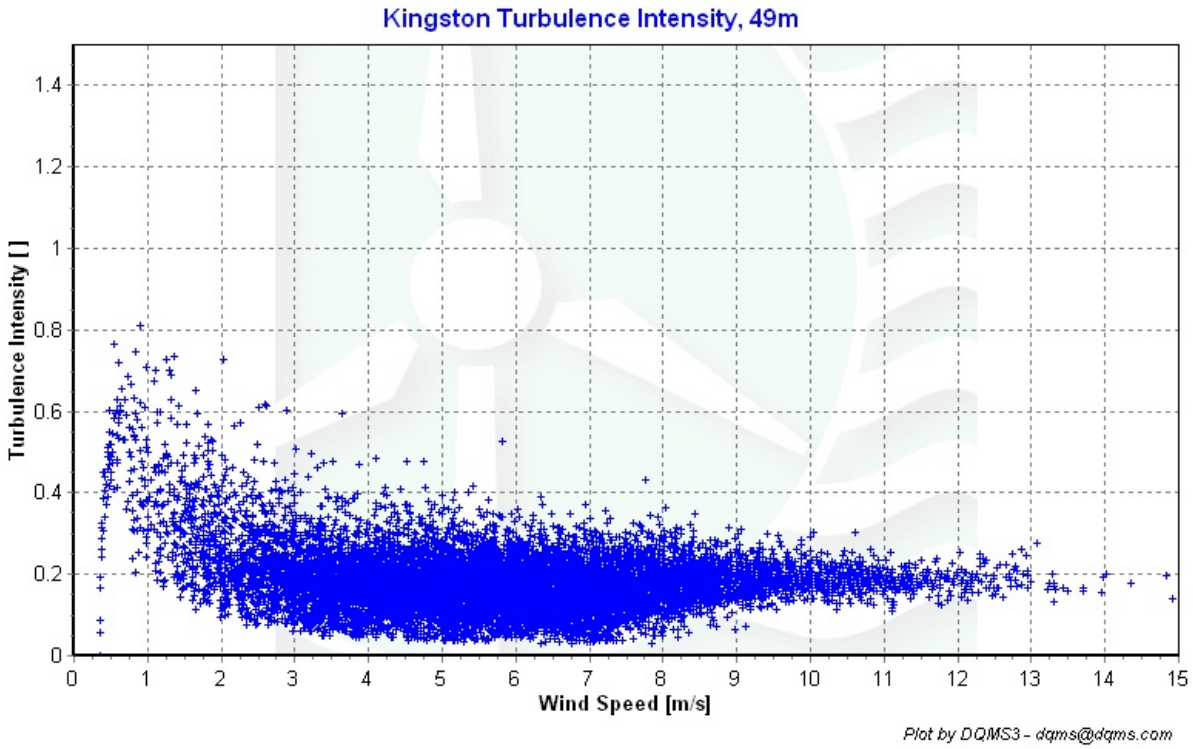

Figure 6 – Turbulence Intensity, March 1st 2006– May 31st 2006

Wind Roses

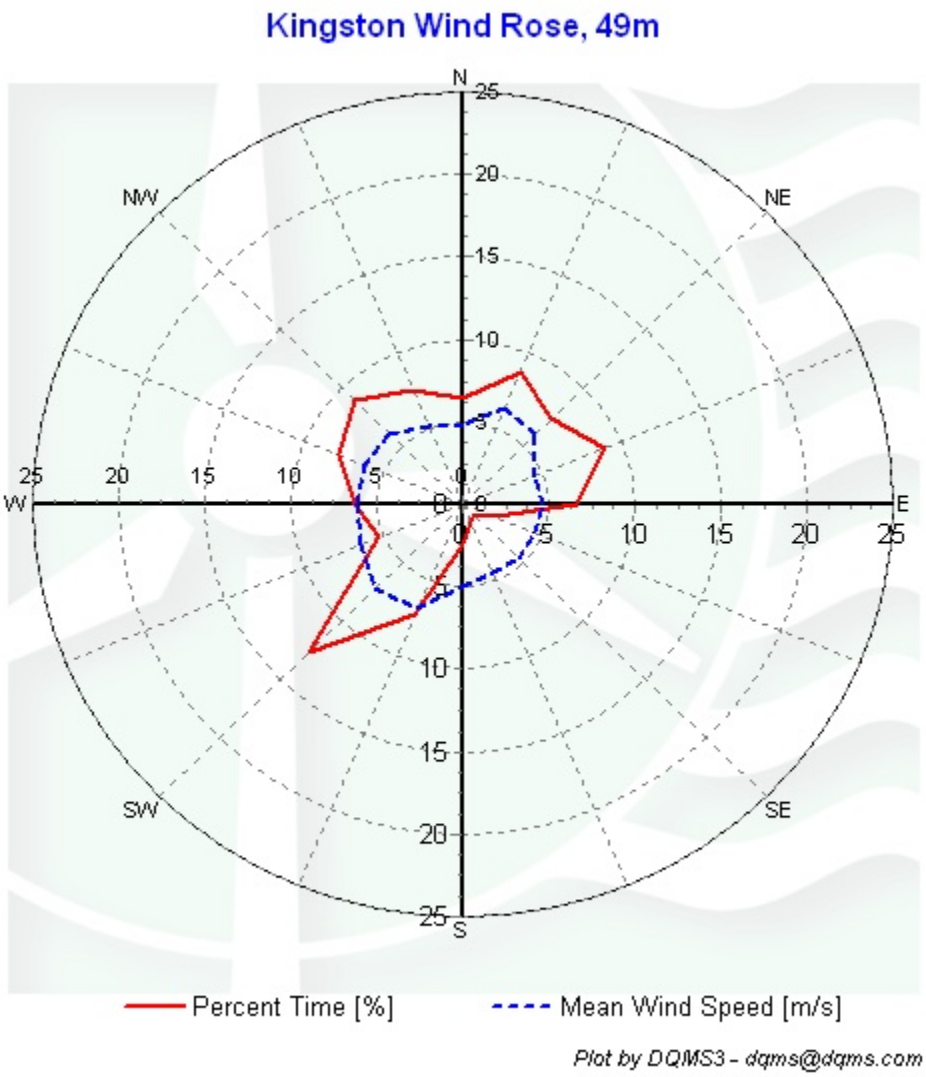

Figure 7 - Wind Rose, March 1st 2006– May 31st 2006

APPENDIX A - Sensor Performance Report

Test Definitions

TstOrd	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Fcr1	Fcr2	Fcr3	Fcr4
1						TimeTest Insert	0	0	0	0
2	Etmp2aDEGC					MinMax	-30	60	0	0
3	Etmx2aDEGC					MinMax	-30	60	0	0
4	Etmn2aDEGC					MinMax	-30	60	0	0
5	EtmpSD2aDEGC					MinMax	-30	60	0	0
10	Anem50aMS					MinMax	0	90	0	0
11	Anem50bMS					MinMax	0	90	0	0
12	Anem38aMS					MinMax	0	90	0	0
13	Anem38bMS					MinMax	0	90	0	0
14	Anem20aMS					MinMax	0	90	0	0
15	Anem50yMS					MinMax	0	90	0	0
16	Anem38yMS					MinMax	0	90	0	0
20	AnemSD50aMS					MinMax	0	4	0	0
21	AnemSD50bMS					MinMax	0	4	0	0
22	AnemSD38aMS					MinMax	0	4	0	0
23	AnemSD38bMS					MinMax	0	4	0	0
24	AnemSD20aMS					MinMax	0	4	0	0
25	AnemSD50yMS					MinMax	0	4	0	0
26	AnemSD38yMS					MinMax	0	4	0	0
30	Vane50aDEG					MinMax	0	359.9	0	0
31	Vane38aDEG					MinMax	0	359.9	0	0
32	Vane20aDEG					MinMax	0	359.9	0	0
50	Turb50zNONE					MinMax	0	2	0	0
51	Turb38zNONE					MinMax	0	2	0	0
60	Wshr0zNONE					MinMax	-100	100	0	0
70	Pwrd50zWMS					MinMax	0	5000	0	0
71	Pwrd38zWMS					MinMax	0	5000	0	0
200	VaneSD50aDEG	Anem50yMS				MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS				MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS				MinMax	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
400	Anem50aMS	Anem50bMS				CompareSensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS				CompareSensors	1	0.25	3	0
500	Amax50aMS					MinMax	0	90	0	0

501	Amax50bMS					MinMax	0	90	0	0
502	Amax38aMS					MinMax	0	90	0	0
503	Amax38bMS					MinMax	0	90	0	0
504	Amax20aMS					MinMax	0	90	0	0
510	Amin50aMS					MinMax	0	90	0	0
511	Amin50bMS					MinMax	0	90	0	0
512	Amin38aMS					MinMax	0	90	0	0
513	Amin38bMS					MinMax	0	90	0	0
514	Amin20aMS					MinMax	0	90	0	0
520	Vmax50aDEG					MinMax	0	359.9	0	0
521	Vmax38aDEG					MinMax	0	359.9	0	0
522	Vmax20aDEG					MinMax	0	359.9	0	0
530	Vmin50aDEG					MinMax	0	359.9	0	0
531	Vmin38aDEG					MinMax	0	359.9	0	0
532	Vmin20aDEG					MinMax	0	359.9	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
Etmp2aDEGC	13248	13248	100	0	0	0	100
EtmpSD2aDEGC	13248	13248	100	0	0	0	100
Anem50ams	13248	13248	100	0	16.833	39.167	97.464
AnemSD50ams	13248	13248	100	0	16.833	39.167	97.464
Vane50aDEG	13248	13248	100	0.5	17.167	0	99.2
VaneSD50aDEG	13248	13248	100	0.5	17.167	0	99.2
Anem38aMS	13248	13248	100	0	14.833	0.167	99.321
AnemSD38aMS	13248	13248	100	0	14.833	0.167	99.321
Vane38aDEG	13248	13248	100	0.167	14.833	0	99.321
VaneSD38aDEG	13248	13248	100	0.167	14.833	0	99.321
Anem20aMS	13248	13248	100	0	9.5	0	99.57
AnemSD20aMS	13248	13248	100	0	9.5	0	99.57
Vane20aDEG	13248	13248	100	0.167	9.5	0	99.562
VaneSD20aDEG	13248	13248	100	0.167	9.5	0	99.562
Total	**185472**	**185472**	**100**	**1.667**	**165.333**	**78.667**	**99.205**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent Time
0.5	0.96
1.5	2.59
2.5	5.76
3.5	10.55
4.5	15.35
5.5	18.97
6.5	17.43
7.5	12.52
8.5	8.02
9.5	4.09
10.5	2.09
11.5	1.03
12.5	0.51
13.5	0.11
14.5	0.03
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 – Quarterly Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Jun 2005	-----
Jul	5.01
Aug	4.75
Sep	4.97
Oct	6.16
Nov	6.09
Dec	5.78
Jan 2006	6.52
Feb	6.59
Mar	5.89
Apr	5.89
May	5.79

Table 2 - Monthly Average Wind Speeds

Diurnal Average Wind Speed Data

hr	Average Wind Speed [m/s]
0.5	5.65
1.5	5.71
2.5	5.78
3.5	5.86
4.5	5.71
5.5	5.76
6.5	5.57
7.5	5.6
8.5	5.79
9.5	6.05
10.5	6.13
11.5	6.37
12.5	6.34
13.5	6.42
14.5	6.19
15.5	6.14
16.5	5.94
17.5	5.67
18.5	5.49

19.5	5.38
20.5	5.58
21.5	5.71
22.5	5.75
23.5	5.85

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	4.87	6.41
NNE	6.25	8.69
NE	5.99	7.3
ENE	4.53	8.94
E	4.69	6.63
ESE	4.59	1.99
SE	4.65	0.91
SSE	4.43	1.22
S	5.02	2.41
SSW	6.84	7.21
SW	7.24	12.62
WSW	6.43	5.23
W	6.2	6.24
WNW	6.22	7.81
NW	6.05	8.93
NNW	5.15	7.46

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction