ABS Consulting
AN ABS GROUP COMPANY

Report No. R-1903966-01
Revision 0

Effect of Plant Structures on the Wind Speed and Direction at the Meteorological Tower at the Susquehanna Steam Electric Plant

April 2008

Prepared by:
T. Edward Fenstermacher

Prepared for:
UniStar Nuclear
750 East Pratt Street
Baltimore, MD 21202

Contents

Tables

Figures

1. Introduction

The purpose of this report is to document calculations of the effects of the presence of plant structures on the meteorological data collected at the Susquehanna Steam Electric Station. The structures included in the modeling are the cooling towers, turbine building, reactor building, control building, and radwaste building. Two methods are used to estimate the effects of these structures. The first is an analysis of the building wake using methods taken from Hosker (Reference 1). The second is to examine the differences between the windfields generated by the urban model in the MIDAS-AT code (Reference 2) when the structures are absent or present.

2. Methodology

2.1 Wake Effects Methodology

The cavity length is estimated using an equation for the wake of a rectangular prism of length *L* in the downwind direction, width *W* in the crosswind direction, and height *H* (Reference 1). Because the cooling towers are rounded, and the wakes of rounded objects are smaller than rectangular objects of the same dimensions, this will give an upper bound for the cavity length of the cooling tower. Equation 7.1 from Reference 1 is

$$\begin{aligned} \frac{x_r}{H} &= \frac{L}{H} + \frac{A\left(\frac{W}{H}\right)}{1.0 + B\left(\frac{W}{H}\right)} \\ A &= -2.0 + 3.7\left(\frac{L}{H}\right)^{-\frac{1}{3}} \\ B &= -0.15 + 0.305\left(\frac{L}{H}\right)^{-\frac{1}{3}} \end{aligned} \qquad (1)$$

where the cavity is measured from the leading edge of the block. For the cooling towers, the desired result is the length of the wake from the center of the cooling tower (x_c), the first line of Equation 7.1 is modified by subtracting half of the length, and the length and width are both taken to be equal to the diameter, *D*. Thus, the final form of the equation for the cooling tower is:

$$x_c = 0.5D + H \cdot \frac{A\left(\frac{D}{H}\right)}{1.0 + B\left(\frac{D}{H}\right)}$$

$$A = -2.0 + 3.7\left(\frac{D}{H}\right)^{-\frac{1}{3}} \qquad (2)$$

$$B = -0.15 + 0.305\left(\frac{D}{H}\right)^{-\frac{1}{3}}$$

A schematic representation of the cooling tower and cavity (of length x_c) are shown in Figure 1.

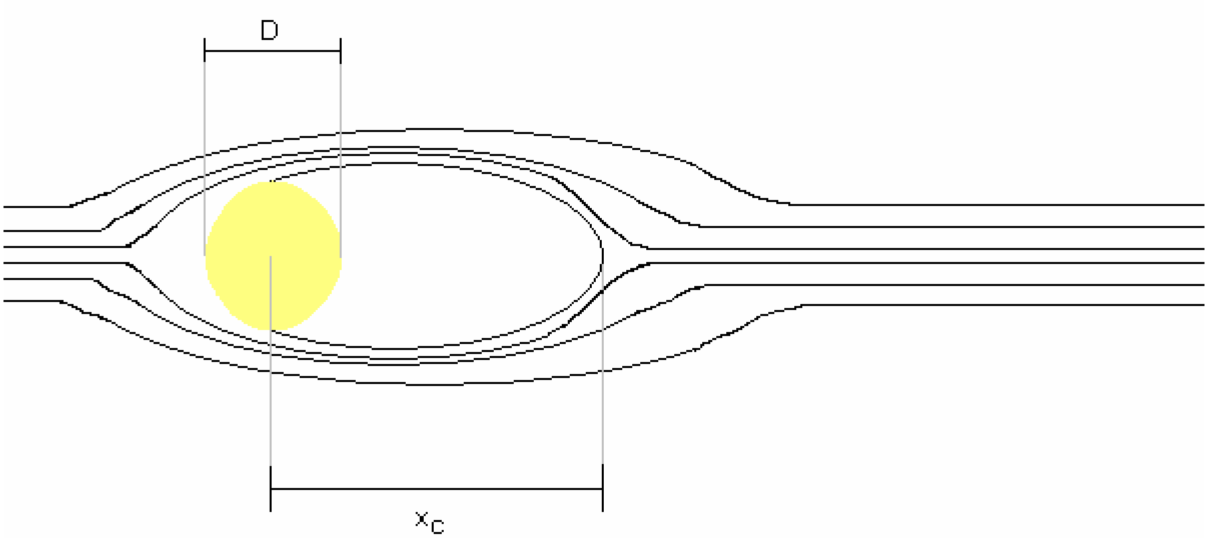

Figure 1. Schematic diagram of wake cavity from the cooling tower

In section 7-4.3 of Reference 1, the maximum wake defect for a block with a square upwind face, which is the closest approximation available to the shape of both the cooling towers and the other site buildings, decays with distance as follows:

$$\Delta U(x) = \Delta U(x_{\min})\left(\frac{x}{x_{\min}}\right)^{-2.6} \qquad (3)$$

The choice of:

$$x_{\min} = x_c \tag{4}$$

with

$$\Delta U(x_{\min}) = -1 \tag{5}$$

results in the most conservative estimate of the effect of the building wake on wind speed. In actuality, because the streamlines converge just beyond this point, the actual effect will be much smaller in magnitude. This gives a maximum wake defect of

$$|\Delta U_{\max}| = \left(\frac{x}{x_c}\right)^{-2.6} \tag{6}$$

The same equation applies to the wake from a block, except that for a block, the wake separation occurs at the leading edge instead of at the maximum diameter, so in this case x_r is used in place of x_c for the wake cavity length.

2.2 Windfield Change Methodology

For the second part of the calculation, the changes in measured wind speed and direction were estimated using the modified potential flow model incorporated in MIDAS-AT as the urban model. The discussion in Reference 1 Section 7-4.1 indicates that potential flow should yield valid results well away from the separation streamlines, and, as the previous calculation shows, this condition is met at the location of the meteorological tower.

A Microsoft Excel Spreadsheet was used to develop a model of each structure as a stack of circular cylinders. Each circle was digitized into 64 circumferential locations, and the points were converted into geographic coordinates and written to a vertex (.vrt) file, with a corresponding entry into a comma-separated value (.csv) file describing the layer. These files were processed by the RaiseTerrain program, which added them to a bare earth layer constructed from Digital Terrain Elevation Data. The output from this process is a pair of grid files, one with the terrain height without structures, and the other with the terrain height including structures. The grid elements are 10 m squares, and the elevation of each grid element is given as an integer height in meters.

The MIDAS-AT model (Reference 2) was modified to output the calculated wind vector at the 10 m and 60 m elevations above grade at the location of the meteorological tower. The code was then run for the sixteen primary directions at D stability and F stability, and the wind speed vectors at the meteorological tower location recorded at the 10 m and 60 m levels. This was done with and without the plant structures. The results were compared to determine the impact of the plant structures on measurements at the meteorological tower.

3. Input Data

The locations of structures at the site were taken from a series of drawings supplied by UniStar. The general plant layout is shown in Figure 2. By comparison of the coordinates shown on the drawings with other topographic information, it was possible to determine that the coordinate system of the drawings was Pennsylvania State Plane North using the North American Datum of 1927. The plan coordinates of the cooling towers and the corners of the turbine building, control structure, reactor building, radwaste building, and diesel generator building were measured on Reference 3. The height and diameter of the control tower at various levels was measured on Reference 4. The heights of the turbine building, control structure, and reactor building were taken from Reference 5, the height of the radwaste building from Reference 6, and the height of the diesel generator building from Reference 7. The measured coordinates are shown in Table 1. The coordinates were transformed to the Uniform Transverse Mercator grid for the North American Datum of 1983 using the Corpscon 6.0.1 program (Reference 8). These coordinates, also shown in Table 1, were used to develop the grid for the MIDAS program. The structure heights above ground are shown in Table 2. The diameter of the cooling tower at selected heights above the ground is shown in Table 3.

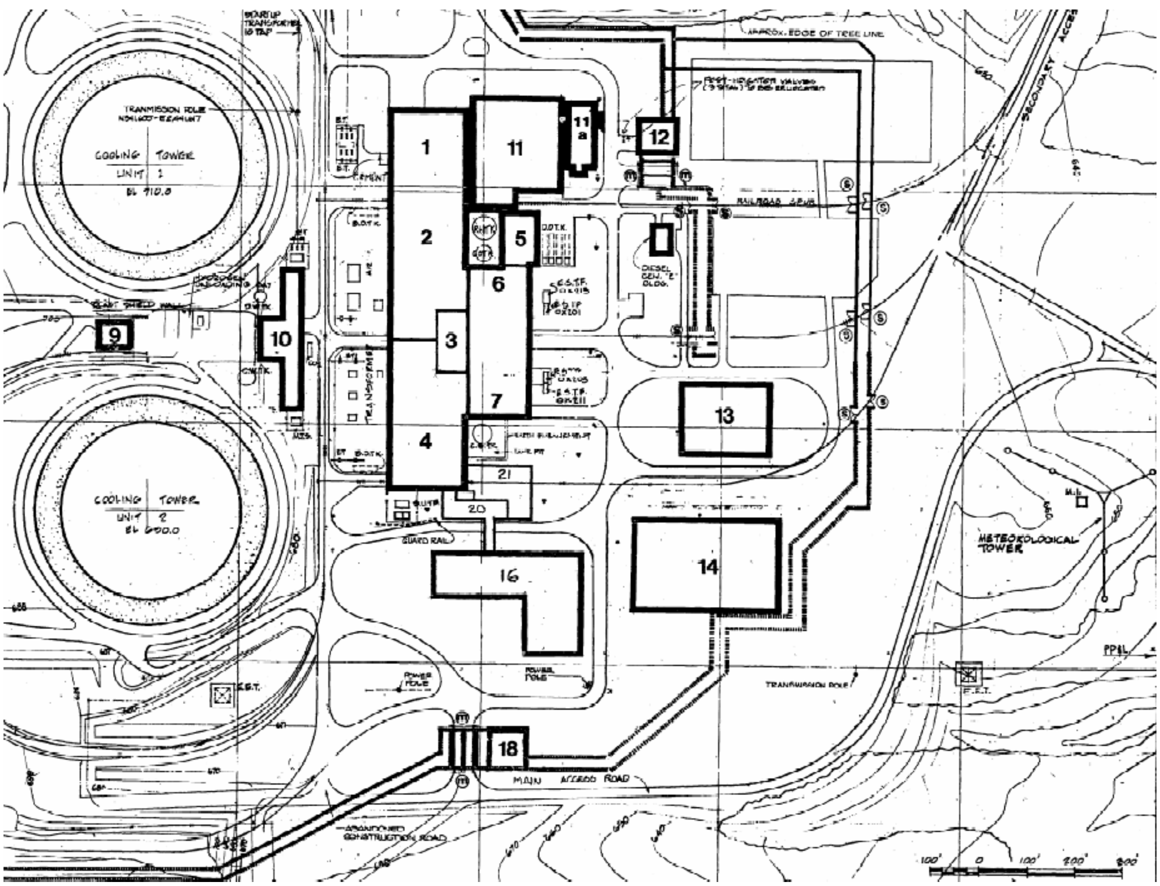

Figure 2. Plan View of Significant Plant Structures and the Meteorological Tower

Structure Name and Point	PA North SP NAD 1927		UTM Zone 18 NAD 1983	
	Northing, ft	Easting, ft	Northing, ft	Easting, ft
Meteorological Tower	340900.7	2443290.3	14926149.2	1325904.8
Unit 1 Cooling Tower Center	341542.5	2441305.4	14926853.3	1323941.7
Unit 2 Cooling Tower Center	340807.5	2441305.4	14926118.9	1323918.4
Turbine Building NW Corner	341486.3	2441802.0	14926781.5	1324436.2
Turbine Building NE Corner	341486.3	2441969.8	14926776.2	1324603.8
Turbine Building SE Corner	340859.6	2441969.8	14926149.9	1324584.0
Turbine Building SW Corner	340859.6	2441802.0	14926155.2	1324416.3
Radwaste Building NW Corner	341664.4	2441802.0	14926959.4	1324441.8
Radwaste Building NE Corner	341664.4	2441969.8	14926954.1	1324609.5
Radwaste Building SE Corner	341486.3	2441969.8	14926776.2	1324603.8
Radwaste Building SW Corner	341486.3	2441802.0	14926781.5	1324436.2
Control Structure NW Corner	341243.2	2441909.4	14926535.1	1324535.8
Control Structure NE Corner	341243.2	2441969.8	14926533.2	1324596.1
Control Structure SE Corner	341106.2	2441969.8	14926396.3	1324591.8
Control Structure SW Corner	341106.2	2441909.4	14926398.2	1324531.5
Reactor Building NW Corner	341335.6	2441969.8	14926625.6	1324599.1
Reactor Building NE Corner	341335.6	2442100.7	14926621.4	1324729.8
Reactor Building SE Corner	341013.7	2442100.7	14926299.8	1324719.7
Reactor Building SW Corner	341013.7	2441969.8	14926303.9	1324588.9
Diesel Generator Building NW Corner	341448.6	2442033.6	14926736.5	1324666.4
Diesel Generator Building NE Corner	341448.6	2442120.8	14926733.7	1324753.5
Diesel Generator Building SE Corner	341335.6	2442120.8	14926620.8	1324750.0
Diesel Generator Building SW Corner	341335.6	2442033.6	14926623.6	1324662.8

Table 1. Locations of plant structures in both coordinate systems

Building Name	Height Above Grade, ft
Turbine Building	113.71
Radwaste Building	39.00
Control Structure	150.50
Reactor Building	201.58
Diesel Generator Building	65.50

Table 2. Heights of plant structures above grade

Height, ft	Diameter, ft
0.00	420.00
45.75	396.00
136.50	346.50
226.50	312.00
303.00	291.75
363.75	285.00
433.50	285.00
523.50	298.50
540.00	315.00

Table 3. Diameter of Cooling Tower at Selected Heights

The conversion of the input data to the terrain data grid used by MIDAS-AT is shown in

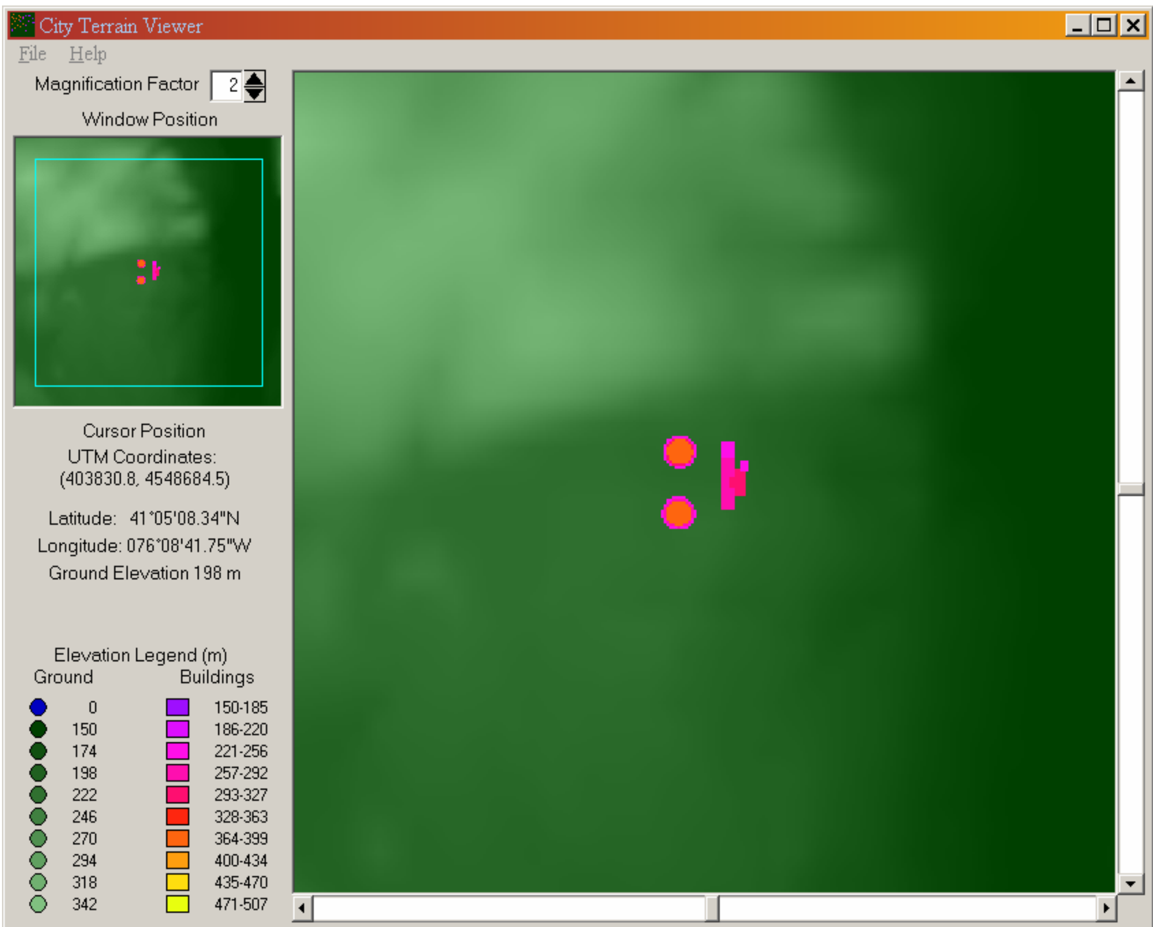

Figure 3. Terrain Near the Plant Showing Plant Structures as Modeled in MIDAS-AT

4. Results

4.1 Results of Wake Analysis

The results of the wake analysis for the major structures is shown in Table 4. The largest effect is about 17% for the reactor building. For the reasons noted in the methodology section, the actual effect would be expected to be much smaller than the wake defect.

Structure	Wake Cavity Length, ft (x_r or x_c)	Meteorological Tower Distance, ft	Maximum Wake Defect
Unit 1 Cooling Tower	848.7	2085.6	9.65%
Unit 2 Cooling Tower	848.7	1986.6	10.96%
Reactor Building	684.0	1348.3	17.13%
Turbine Building	642.6	1512.6	10.80%

Table 4. Maximum Wake Defect for Susquehanna Structures at the Meteorological Tower

4.2 Results of the MIDAS-AT Analysis

The results of the MIDAS-AT analysis are shown in Figure 4, which shows the ratio of the measured speeds at the meteorological tower with and without the plant structures; and in Figure 5, which shows the difference in the measured wind directions at the meteorological tower with and without the plant structures. A statistical summary of the results is shown in Table 5.

The wind speed deviations for F Stability at both heights range follow a nearly sinusoidal pattern from 2% lower to 1% higher, and average about 0.5% lower. The maximum effect occurs with wind from either the East or West. The effects at D Stability are only about a third as large, but follow a similar pattern. The direction differences range within about a degree either side of zero in a sinusoidal pattern offset about 45° in direction from the wind speed pattern. Again, the deviations for D Stability are only about a third as large as for F Stability.

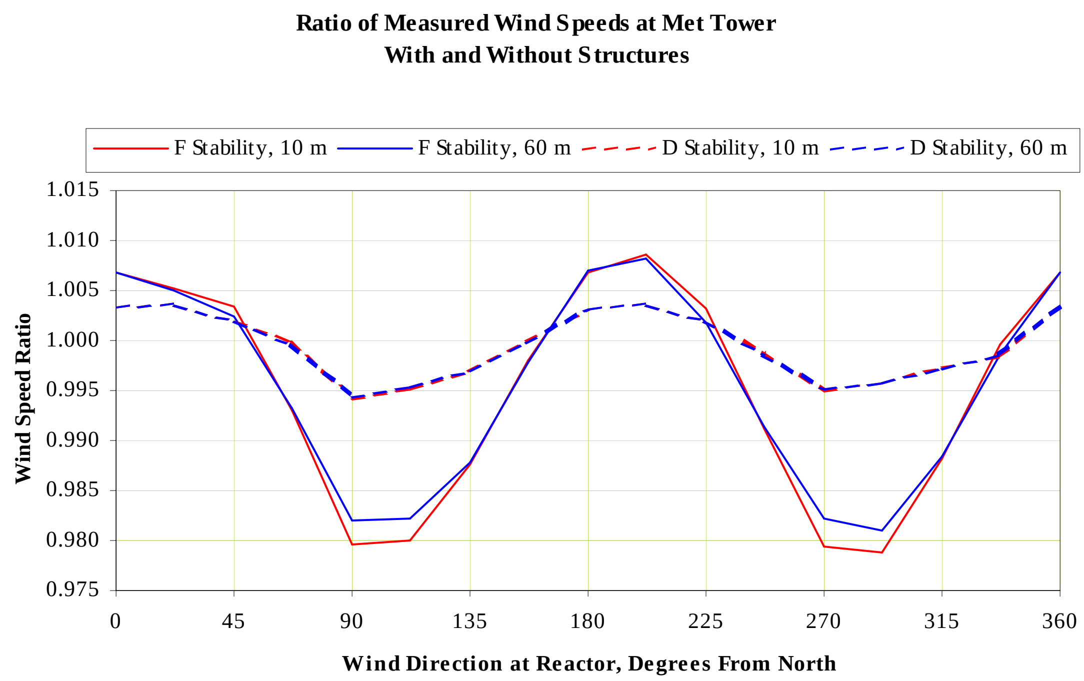

Figure 4. Ratio of Measured Speeds With and Without Plant Structures

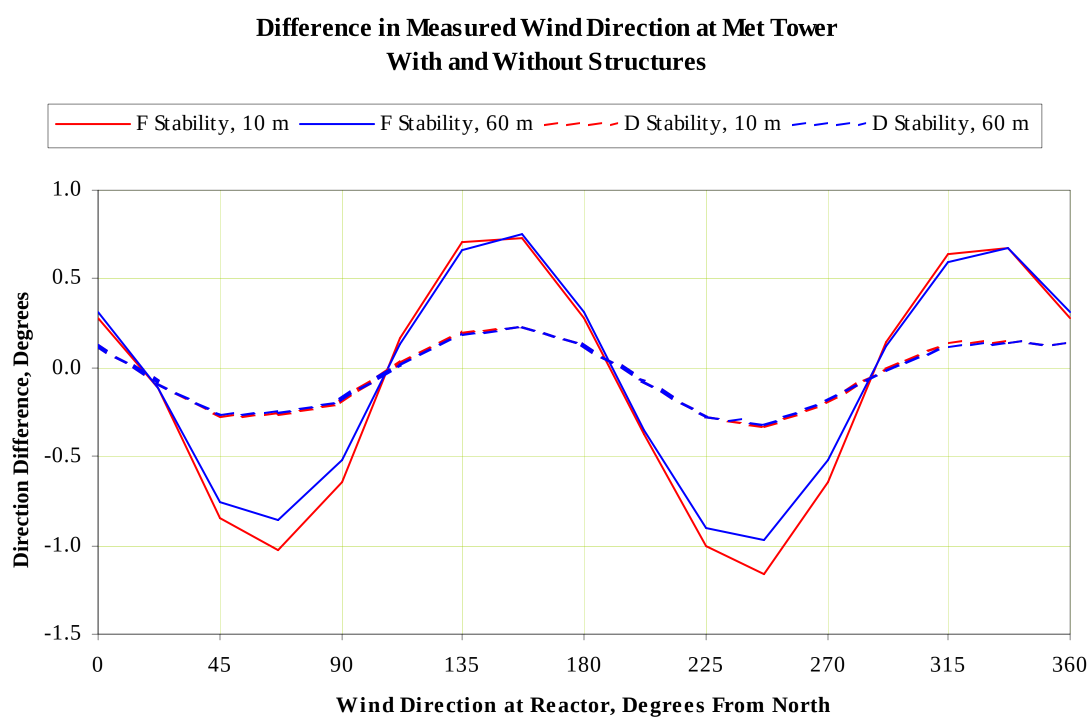

Figure 5. Difference Between Measured Wind Directions With and Without Plant Structures

Stability Class	Measurement Height, m	Wind Speed Ratio		Direction Difference, °	
		Mean	σ	Mean	σ
F	**10**	0.9944	0.0110	-0.14	0.68
	60	0.9948	0.0099	-0.09	0.61
D	**10**	0.9994	0.0034	-0.04	0.19
	60	0.9994	0.0033	-0.04	0.19

Table 5. Statistical Summary of MIDAS-AT Results

Because the wake defect is an upper estimate of the effect, and the potential flow model in MIDAS-AT should give a good approximation of the flow at several wake cavity lengths, the impact of plant structures on the measured wind speed should be minimal, and the effect on the measured wind direction nearly non-existent.

4.3 Influence of Local Meteorology

The predominant wind direction on the primary meteorological tower at Susquehanna has been very persistent over the last 25 years of data collection at the site. At the 10 m level the prevailing wind direction has been from the east-northeast (about 14% of the time) at the 10 m level and from the north-northeast (about 16% of the time) at the 60 m level. The secondary peak has been from the southwest at both levels on the tower. The cooling towers and other plant structures are located from the west to the northwest of the primary meteorological tower. Winds from these three sectors occur less than 10% of the time at the 10 m level and about 12% of the time at the 60 m level during an average year. When “stable” atmospheric stability conditions are taken into consideration in conjunction with the wind direction passing through the cooling towers and other plant structure these conditions occur about 0.1% of the time at the 10 m level and about 0.4% of the time at the 60 m level. Figure 6 and Figure 7 show wind roses from the 10 and 60 m levels for a recent (2005-2007) three-year period that is representative of the long-term data at the site. Therefore the prevailing meteorology at the site will help to minimize any affects that the cooling towers and other plant structures have on the primary meteorological tower.

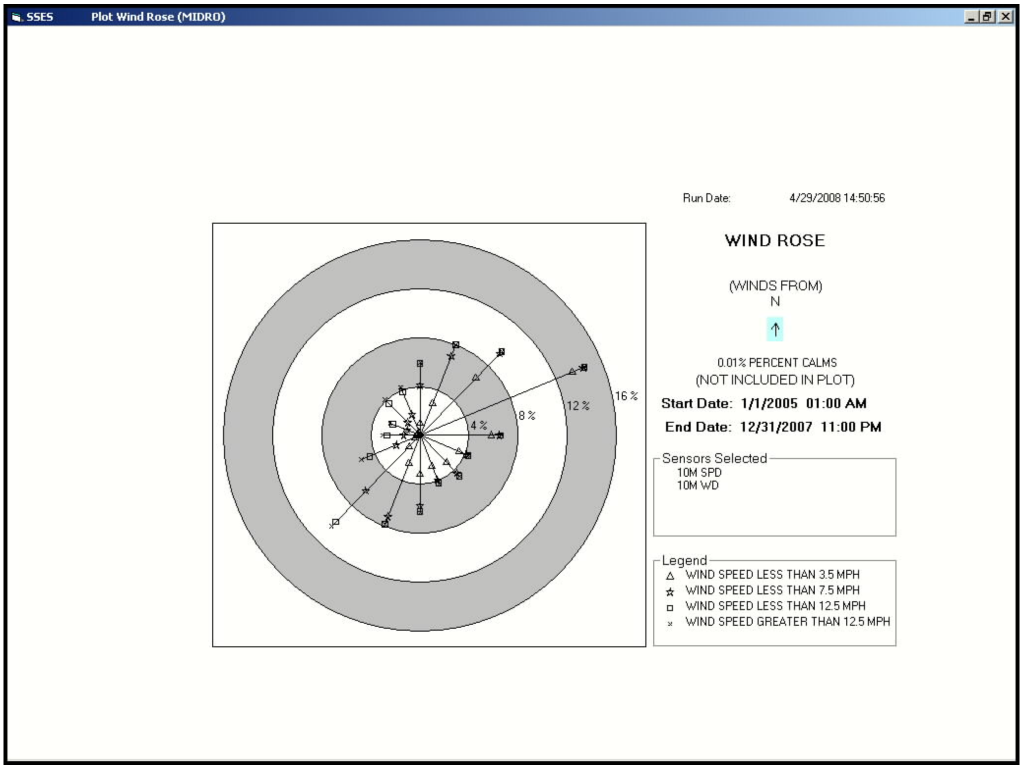

Figure 6. Wind Rose at 10 m

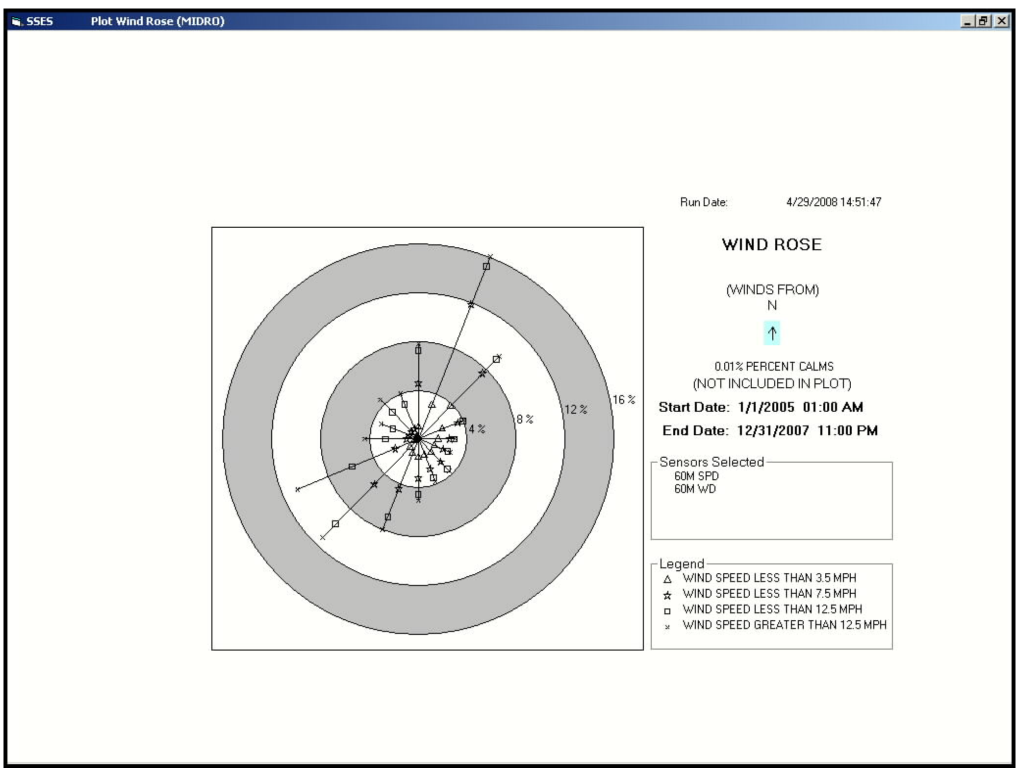

Figure 7. Wind Rose at 60 m

5. References

1. Randerson, Darryl, Editor, Atomic Energy and Power Production, DOE/TIC-27601.

2. MIDAS Technical Description, Attachment A, ABSG Consulting, Inc., 22 November 2002.

3. PP&L Drawing E105004, Revision 13, General Arrangement, Fence and Patrol Road, September 25, 2006.

4. PP&L Drawing CT-220-30, General Notes, Location Plan and Elevation.

5. PP&L Drawing E105005, Sheet 1, Revision 9, General Cross-Section 'A', August 2, 1994.

6. PP&L Drawing E106336, Revision 21, Equipment Location Radwaste Bldg Sections A-A and B-B, October 28, 1987.

7. PP&L Drawing E106335, Revision 5, Equipment Location Units 1 and 2 Diesel Generator Building Plan of EL. 710'9" & 723'0" Sects A-A and B-B, April 7, 1988.

8. http://crunch.tec.army.mil/software/corpscon/corpscon.html, Corps of Engineers Coordinate Conversion 6.0.1, January 3, 2008.