Naval Station Newport Wind Resource Assessment

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites, and The Naval Facilities Engineering Service Center

Robi Robichaud, Jason Fields, and
Joseph Owen Roberts

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6A20-52801
February 2012

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Prepared under Task No. WFD5.1000

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Executive Summary

The U.S. Environmental Protection Agency (EPA) launched the RE-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites initiative in September 2008. EPA and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are collaborating on a number of projects to evaluate the feasibility of siting renewable energy (RE) technologies on these potentially contaminated sites. This report focuses on the wind resource assessment campaign at Naval Station (NAVSTA) Newport in Newport, Rhode Island.

Wind data was collected from 60-meter meteorological (met) towers at Coddington Point (Site #9202) and at Tank Farm #4 (Site #9203). The data collected provided an effective dataset for comparative analysis of wind speed, turbulence intensity, and energy production at the two sites. Table ES-1 shows the summary results of annual wind speeds, energy production for a generic 1.5 MW wind turbine, and capacity factor.

Table ES-1. Comparison of Annual Energy Characteristics of Coddington Point and Tank Farm #4

Site	Hub Height Wind Speed (m/s)	Time at Zero Output (%)	Time at Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Coddington Point	6.79	6.1	7.5	438.9	3,844,637	29.3
Tank Farm #4	6.39	14.3	4.0	353.4	3,095,995	23.6
Advantage of Coddington Point	**6.3%**	**-57.4%**	**87.2%**	**24.2%**	**24.2%**	**24.2%**

Due to the differences in the wind resource and the site constraints imposed by Federal Aviation Administration (FAA) height restrictions, the assessment focused on the energy production potential of the FAA-approved sites and height limits.

Table ES-2 provides the estimated annual energy production (AEP) figures of the project scenarios targeting approximately 9 MW of wind capacity. Net AEP is estimated in the range of 23.7–30.0 GWh/yr, which represents 22%–29% of the annual electricity consumption at NAVSTA Newport (approximately 105 GWh/yr). The net capacity factors range from 30.0%–36.4%.

Table ES-2. Annual Energy Production Figures for Approximately 9 MW of Wind at NAVSTA Newport

Characteristics	Unit	~9 MW Scenario						
WTG* Manufacturer		Siemens	GE	Vestas	Vestas	Nordex	REPower	Alstom
WTG Model	#	2.3 MW	XLE 100	V100	V112	N100	MM100	ECO 110
WTG Capacity	MW	2.3	1.6	1.8	3.0	2.5	1.8	3.0
WTG Hub Height	m	80	80	80	80	80	80	80
WTG Rotor Diameter	m	101	100	100	112	100	100	110
Array Size	#	4	6	5	3	4	5	3
Site Capacity	MW	9.20	9.60	9.00	9.00	10.00	9.00	9.00
Ideal Yield	GWh/yr	31.27	37.33	34.70	30.19	32.08	35.11	28.19
Gross AEP Central Estimate	GWh/yr	30.79	35.65	33.50	29.56	31.57	33.89	27.59
Net AEP Central Estimate	GWh/yr	25.74	30.05	28.35	25.36	26.44	28.73	23.67
Net Capacity Factor	%	31.93	35.73	35.95	32.17	30.18	36.44	30.02

*WTG = Wind Turbine Generator; AEP = Annual Energy Production

Overall, the wind resource at the selected sites at NAVSTA Newport is sufficient for a wind turbine project. There are a number of other factors to consider before turbine selection is undertaken, including cost, availability, constructability, and transportability. There are also a number of other factors still to be explored as the parameters of this project become more clearly defined, including financing, National Environmental Protection Act (NEPA), constructability, subsoil/foundations, impact on neighbors, and transportation planning and logistics.

There are a number of proposed tasks to continue to move this project forward, including:

- NAVSTA Newport to complete the NEPA evaluation already underway
- NREL/DNV to complete an electrical interconnection study
- Complete the economic feasibility study
- Complete the transportation and logistics study
- Complete the visual and sound impact study
- Develop a public information plan.

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1 Introduction

In 2008, the U.S. Environmental Protection Agency (EPA) launched the RE-Powering America's Land initiative to encourage the development of renewable energy (RE) on potentially contaminated land and mine sites. As part of this effort, EPA is collaborating with the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate RE options at Naval Station (NAVSTA) Newport in Newport, Rhode Island.

EPA has been involved with NAVSTA Newport as there are multiple contaminated areas that pose a threat to human health and the environment. The base was designated a superfund site on the National Priorities List in 1989. NAVSTA Newport is committed to working toward reducing the base's dependency on fossil fuels, decreasing its carbon footprint, and implementing RE projects where feasible. EPA Region 1 and NAVSTA Newport have engaged NREL to investigate the RE options for the base.

The Naval Facilities Engineering Service Center (NFESC) partnered with NREL in February 2009 to investigate the potential for wind energy generation at a number of Naval and Marine bases on the East Coast. NAVSTA Newport was one of several bases chosen for a detailed, site-specific wind resource investigation. NAVSTA Newport, in conjunction with NREL and NFESC, has been actively engaged in assessing the wind resource through several ongoing efforts.

This report focuses on the wind resource assessment, the estimated energy production of wind turbines, and a survey of potential wind turbine options based upon the site-specific wind resource.

2 Location

NAVSTA Newport, established during the Civil War era, encompasses 1,399 acres extending 9–10 km (6–7 miles) along the western shore of Aquidneck Island in the towns of Portsmouth, Rhode Island, and Middletown, Rhode Island, and the city of Newport, Rhode Island. The base footprint also includes the northern third of Gould Island in the town of Jamestown, Rhode Island. The base is located in the southern part of the state near where Narragansett Bay adjoins the Atlantic Ocean. Figure 1 shows NAVSTA Newport relative to the Narragansett Bay and the State of Rhode Island.

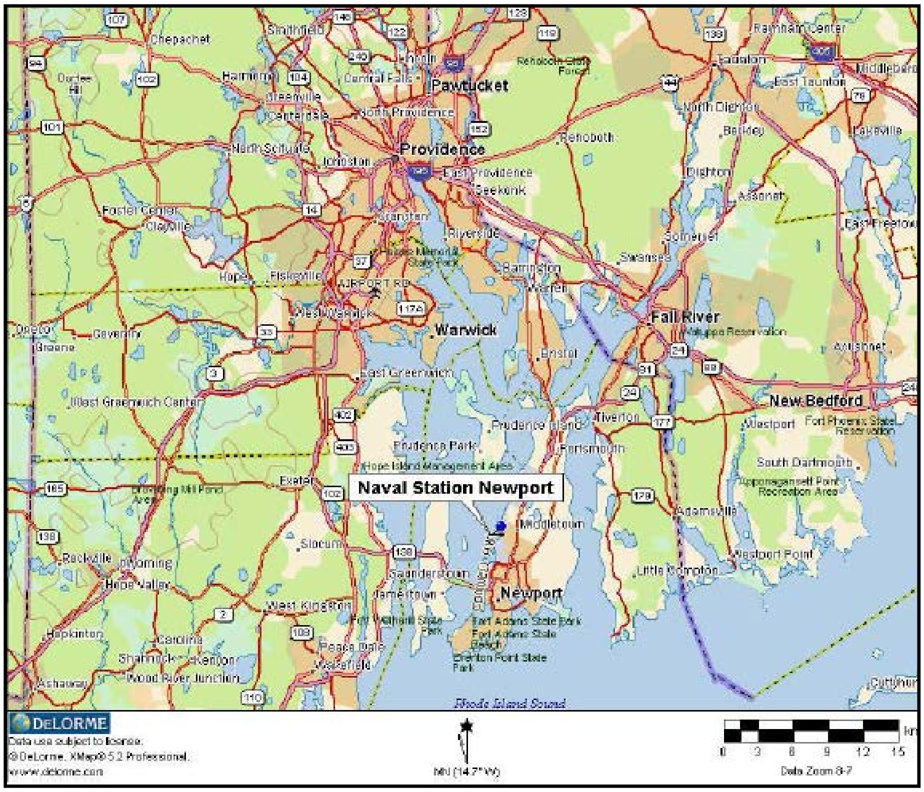

Figure 1. Location of NAVSTA Newport, Rhode Island[1]

The main part of the base is along Narragansett Bay just north of the City of Newport. Other parts of the base include former liquid holding tanks, named Tank Farm #1–#5, that are near or on the bay going northward to Tank Farm #1, which is 9–10 km (6–7 miles) from the main base. See Figure 2.

[1] DNV Global Energy Concepts. "Preliminary Survey of Potential Wind Development of Naval Station Newport." CSRP0029-A. Seattle, WA: DNV, April 2010; p. 2.

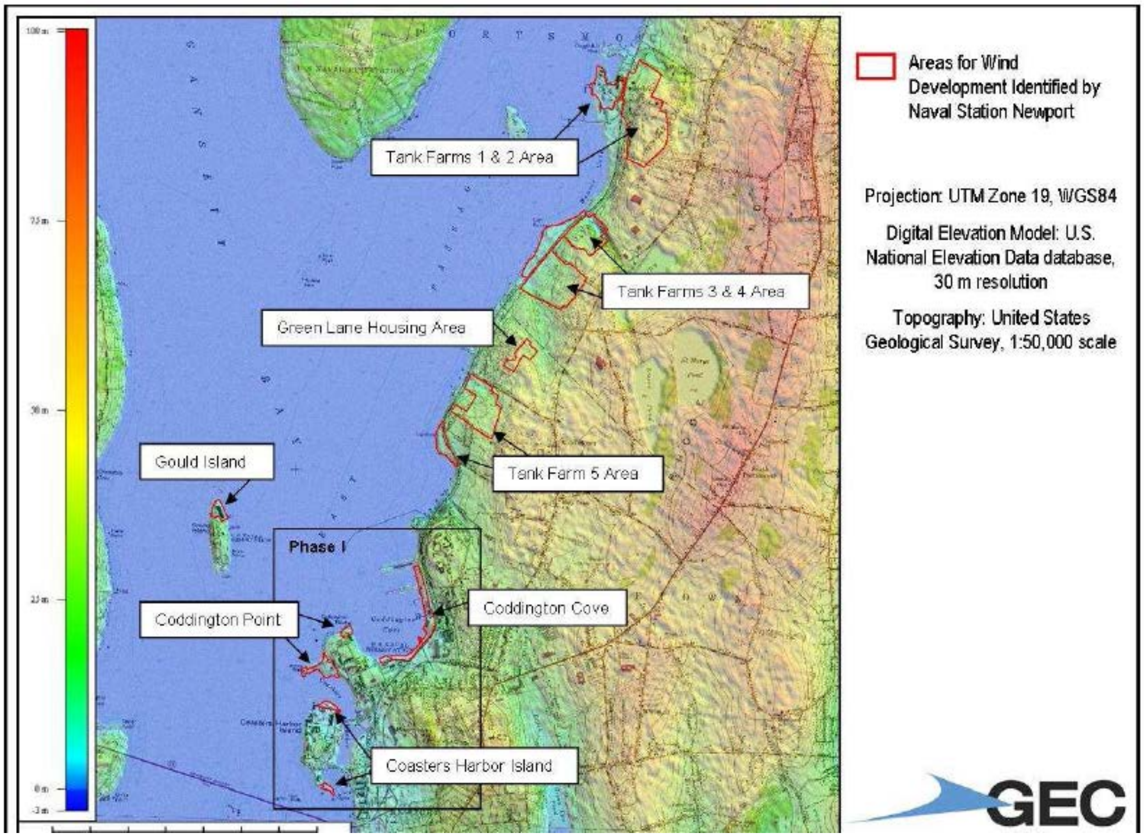

Figure 2. Topographical map of NAVSTA Newport showing possible wind development sites.[2]

Note: McAlister Point Landfill is included in the label for Tank Farm #5.

[2] DNV Global Energy Concepts. "Preliminary Survey of Potential Wind Development of Naval Station Newport." CSRP0029-A. Seattle, WA: DNV, April 2010; p. 3.

3 Wind Resource Assessment Campaign

The assessment characterized the wind resource for the entire base to identify the most promising sites. Primary wind characteristics of interest include:

- Wind speed at or close to proposed wind turbine sites
- Vertical wind shear factor (VWSF) to determine wind speeds at hub height
- Wind speed frequency distribution (aka probability distribution function)
- Turbulence intensity (TI) to determine turbine site suitability based upon standard International Electrotechnical Commission (IEC) classifications.

3.1 Wind Resource Assessment Activities at NAVSTA Newport

The wind assessment campaign has been actively engaged in assessing the wind resource through several ongoing efforts and equipment, as follows:

- Coddington Point, Site #9202—60 m meteorological (met) tower installed and operational since July 29, 2009
- MiniSODAR unit installed and operational at Coddington Point since February 22, 2010
- Tank Farm #4, Site #9203—60 m met tower installed and operational since March 19, 2010.

The original wind assessment campaign called for two fixed met tower stations at or near the northern and southern ends of the base that would be installed for at least one year. However, the base, which extends roughly 6–7 miles north to south along a jagged coastline, has a topography that is not easily characterized. It includes hills rising quickly from the shore and areas that are densely populated with one- to four-story buildings. Different locations within the base will have different wind regimes due to topography and surface roughness. Wind regimes within the base vary according to topography, surface roughness, season, and time of day.

An Atmospheric Systems Corporation (ASC) mini sonic detection and ranging (miniSODAR) unit was added to enhance the analysis with measurements at heights up to twice as high as what met towers can readily provide. Met towers are stationary and not easily moved, whereas a miniSODAR has the advantage of being portable so that it can be used to characterize multiple sites.

4 Site Characterization

The main base terrain varies from generally flat to small hills in the 3–30 m (10–130 ft) range. The highest point on or adjacent to the main base is Miantonomi Hill (approximately 50 m or 165 ft) in Memorial Park. This hill can impede wind flow coming from the east or southeast and flowing toward Coddington Point or Coasters Harbor Island. The proposed locations for wind turbines are flat or are adjacent to smaller hills in the 3–10 m (10–35 ft) range.

The main base is populated with one- to four-story buildings. Taller buildings can cause turbulence even for utility-scale wind turbines when they are less than 400 m (approximately 1,300 ft) upwind. The one- to two-story buildings have minimal impact on utility-scale turbines. For wind turbines located on Coasters Harbor Island, Coddington Point, or along Coddington Cove, the buildings are expected to be the primary source of turbulence when winds are coming from the northwest or southwest.

The vegetation throughout the base is primarily deciduous with larger trees further inland and more grassy areas and smaller trees or bushes closer to the bay. The vegetation near the proposed turbine sites is not expected to represent a significant source of turbulence.

The sites with the highest wind speeds and lowest turbulence will be those along the western shores of Coasters Harbor Island and Coddington Point bordering the Narragansett Bay. These sites will have access to both the predominant northwestern winds and secondary southwestern winds across the smooth surface of the bay that. Figure 3 shows the fetch across the water to the northwest and southwest.

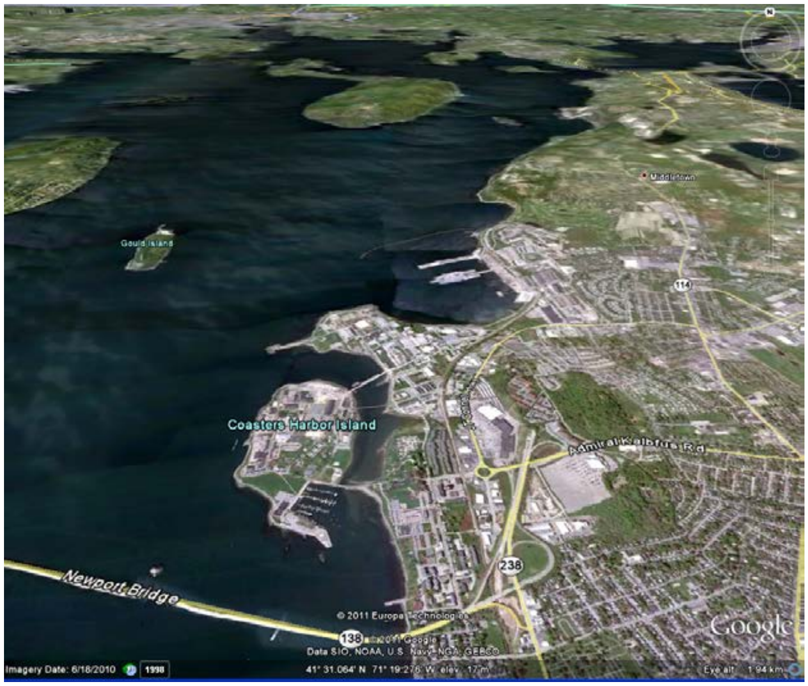

Figure 3. Image of the NAVSTA Newport base with view to the north

Source: Google Earth

Tank farms #2–#5 vary in elevation and topography, generally moving to higher ground from approximately 25 m (80 ft) at Tank Farm #5 to approximately 55 m (180 ft) at Tank Farm #2. Tank Farm #1 is close to sea level. Tank Farm #5 is characterized by large mounds of debris surrounded by forest. Tank Farm #3 and #4 have more open space on higher hills with forest in most directions. Tank Farm #2 is on top of a hill and is relatively open space with smaller, interspersed trees among grassy fields.

Figure 3 illustrates the sites at NAVSTA Newport originally considered for wind development. Tank Farms #1 and #2 are no longer available for consideration for wind development, and Gould Island and McAllister Point are not currently being considered.

5 Wind in Rhode Island

Wind maps provide a graphical estimation of the wind resource in an area but do not incorporate sufficient information to reliably estimate annual electricity generation at any specific point. Areas of varying vegetation (e.g., tall trees versus grassland or cropland), complex topographical features (e.g., ridges versus valleys or canyons versus mountains), and varying surface roughness (e.g., city skyscrapers versus flat or rolling farmland) are characterized by highly variable wind resources that are very site specific. Sites in close proximity to each other, but with the above variations, can represent different wind power densities. Wind maps are valuable for understanding, where strong winds merit further investigation with on-site wind monitoring stations. Wind maps are not, however, typically used to site large wind farms, because maps lack the micro-siting detail required to minimize the energy estimation uncertainty to the level required by financiers. On-site wind data collected for a period of 1–3 years is the industry norm to estimate wind turbine performance accurately. This study used recently collected on-site wind data for its analysis and energy production estimates.

The wind map for Rhode Island, shown in Figure 4, provides a context for the data analysis that follows. The wind map indicates NAVSTA Newport is in a region with an expected mean annual wind speed between 6.0–6.5 m/s (13.4–14.5 mph) at 80 m (262 ft). Some variation in wind speeds is expected depending upon access to wind across the bay and the proximity of hills, ravines, and buildings, for example.

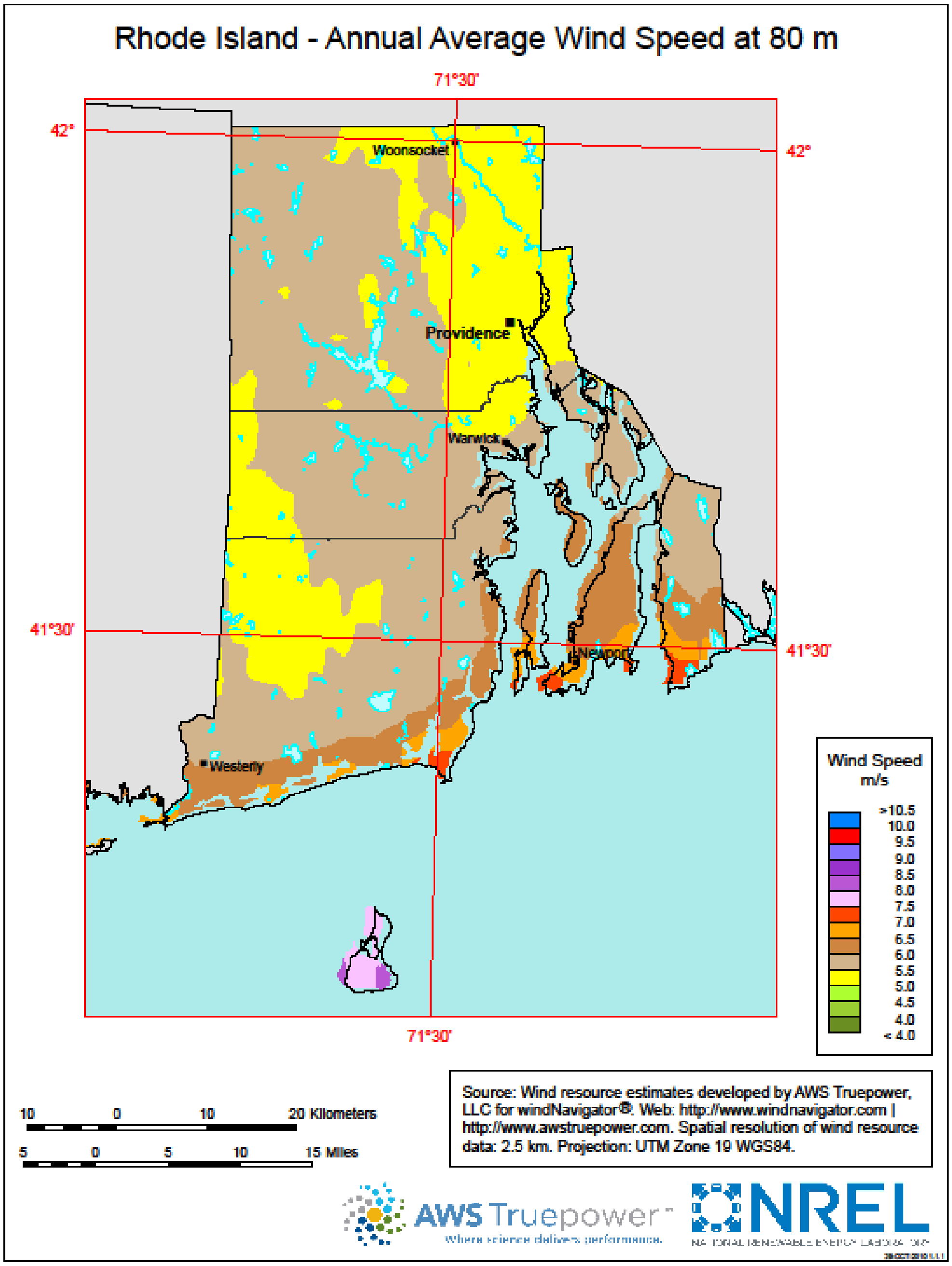

Figure 4. Rhode Island wind speed map at 80 m[3]

[3] Wind Powering America, DOE. "Rhode Island Wind Map and Resource Potential," Wind Powering America website, http://www.windpoweringamerica.gov/images/windmaps/ri_80m.jpg. Accessed July 26, 2011.

6 Instrumentation and Equipment

6.1 Meteorological Towers

Met towers are temporary structures installed at or as close as possible to potential wind turbine sites to reduce the uncertainty of wind turbine energy production estimates. The towers may be 40–100 m (130–330 ft) tall, though 60–80 m (200–260 ft) is the most common for utility-scale wind turbine investigations. The met towers are usually configured with multiple anemometers, to measure the wind speed near the top of the tower and at 10–15 m (33–50 ft) intervals to a minimum height of 20–30 m (65–100 ft) above the ground. The met tower will also typically have two to three wind vanes to measure the wind direction at several heights.

At NAVSTA Newport, the met tower instrumentation consisted of an NRG 60 m XHD Tall Tower, six anemometers, two wind vanes, temperature sensor, barometric pressure sensor, and a data logger. The met towers were erected at Coddington Point (Site #9202) and at Tank Farm #4 (Site #9203). The met tower at Coddington Point was erected in July 2009 and was operational as of July 29, 2009. Table 1 summarizes details of the sensor configuration at Coddington Point. The information was taken from the Coddington Point commissioning report.[4] Sensor and tower details are in Appendix A.

Table 1. Sensors, Heights, and Orientations at Coddington Point

Sensors:		Type	Vendor Name	Model number	Serial number	Slope	Offset	Sensor mounting height				Boom length				Boom Direction
Ch.	1	anemometer	NRG	#40C Anemometer	179500112601	0.765	0.35	190.29	ft	58	m	95.0	in	241.3	cm	274
Ch.	2	anemometer	NRG	#40C Anemometer	179500112602	0.765	0.35	190.29	ft	58	m	95.0	in	241.3	cm	187
Ch.	3	anemometer	NRG	#40C Anemometer	179500112603	0.765	0.35	155.84	ft	47.5	m	95.0	in	241.3	cm	275
Ch.	7	vane	NRG	#200P Vane	--	0.351	0	160.76	ft	49	m	95.0	in	241.3	cm	3
Ch.	8	vane	NRG	#200P Vane	--	0.351	0	85.30	ft	26	m	95.0	in	241.3	cm	1
Ch.	9	thermometer	NRG	#110S Temperature	--	0.136	-86.38	9.84	ft	3	m	--	in	--	cm	--
Ch.	13	anemometer	NRG	#40C Anemometer	179500112607	0.765	0.35	131.23	ft	40	m	95.0	in	241.3	cm	270
Ch.	14	anemometer	NRG	#40C Anemometer	179500112608	0.765	0.35	131.23	ft	40	m	95.0	in	241.3	cm	188
Ch.	15	anemometer	NRG	#40C Anemometer	179500112618	0.765	0.35	78.74	ft	24	m	95.0	in	241.3	cm	270

The met tower at Tank Farm #4 was erected in March 2010 and was operational as of March 19, 2010. Table 2 summarizes details of the sensor configuration at Tank Farm #4. The information was taken from the Tank Farm #4 commissioning report.[5]

Table 2. Sensors, Heights, and Orientations at Tank Farm #4

Sensors:		Type	Vendor Name	Model number	Serial number	Slope	Offset	Sensor mounting height				Boom length				Boom Direction
Ch.	1	anemometer	NRG	#40C Anemometer	179500115275	0.765	0.35	190.29	ft	58	m	95.0	in	241.3	cm	270
Ch.	2	anemometer	NRG	#40C Anemometer	179500115276	0.765	0.35	190.29	ft	58	m	95.0	in	241.3	cm	180
Ch.	3	anemometer	NRG	#40C Anemometer	179500115277	0.765	0.35	164.04	ft	50	m	95.0	in	241.3	cm	270
Ch.	7	vane	NRG	#200P Vane		0.351	0	155.84	ft	47.5	m	95.0	in	241.3	cm	0
Ch.	8	vane	NRG	#200P Vane		0.351	0	85.30	ft	26	m	95.0	in	241.3	cm	0
Ch.	9	thermometer	NRG	#110S Temperature		0.136	-86.383	9.84	ft	3	m		in		cm	
Ch.	11	voltmeter	NRG	iPack Voltmeter		0.021	0	0.00	ft	0	m		in		cm	
Ch.	13	anemometer	NRG	#40C Anemometer	179500115283	0.765	0.35	131.23	ft	40	m	95.0	in	241.3	cm	270
Ch.	14	anemometer	NRG	#40C Anemometer	179500115287	0.765	0.35	131.23	ft	40	m	95.0	in	241.3	cm	180
Ch.	15	anemometer	NRG	#40C Anemometer	179500116030	0.765	0.35	82.02	ft	25	m	95.0	in	241.3	cm	270

[4] DNV Commissioning Report for Site #9202, July 28, 2009.
[5] DNV Commissioning Report for Site #9203, March 18, 2010.

The two 60 m met towers were sited at Coddington Point and Tank Farm #4 as shown in Figure 5.

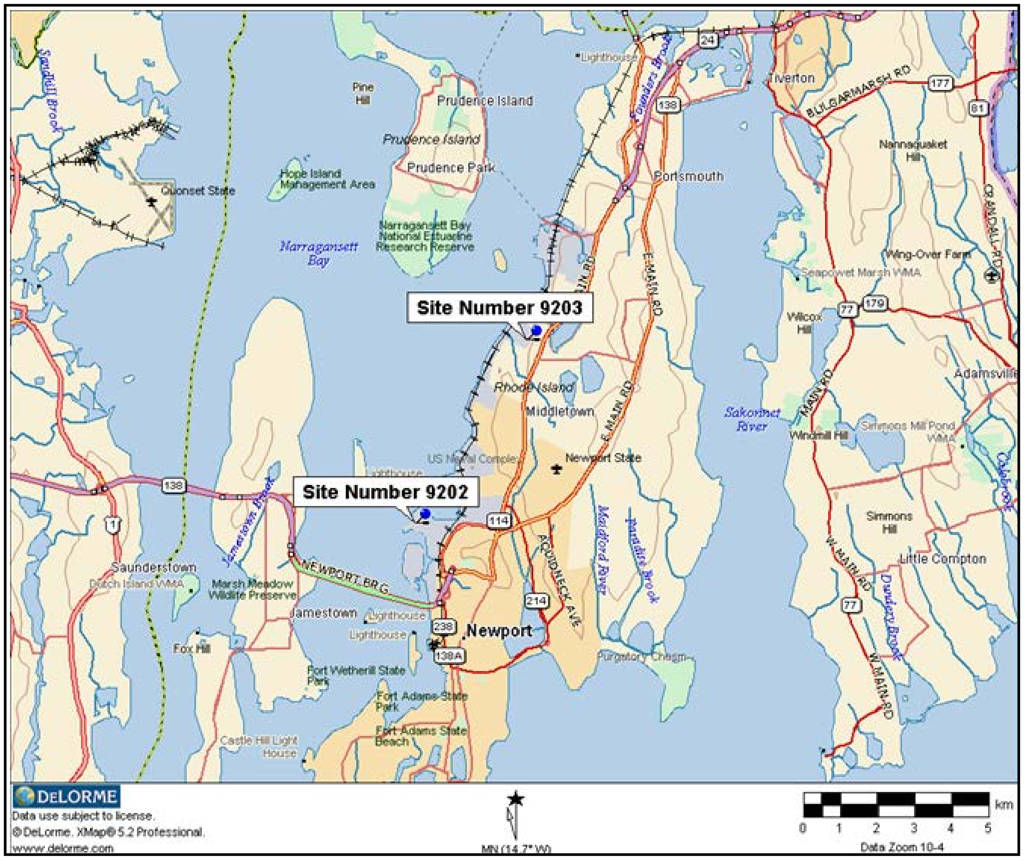

Figure 5. Map of NAVSTA Newport with met tower locations[6]

[6] Wind Resource Data Summary Naval Station Newport, Rhode Island, Data Summary and Transmittal for August 2010, DNV Renewables (USA) Inc.

6.2 Site Summary

Table 3 summarizes the dataset properties, environmental conditions, and wind power and wind shear coefficients for the two met tower sites.

Table 3. Site Summaries of the Met Tower Sites

Coddington Point - #9202		Tank Farm #4 - #9203	
Variable	**Value**	**Variable**	**Value**
Latitude	N 41.5194	Latitude	N 41.56358
Longitude	W 71.3273	Longitude	W 71.29185
Elevation	5 m	Elevation	29 m
Start date	7/29/2009	Start date	3/19/2010
End date	4/1/2011	End date	4/29/2011
Duration	20 months	Duration	13.3 months
Length of time step	10 minutes	Length of time step	10 minutes
Calm threshold	3 m/s	Calm threshold	3 m/s
Mean temperature	10.8 °C	Mean temperature	11.0 °C
Mean pressure	101.2 kPa	Mean pressure	100.9 kPa
Mean air density	1.243 kg/m³	Mean air density	1.239 kg/m³
Air density ratio	1.015	Air density ratio	1.012
Power density at 50 m	290 W/m²	Power density at 50 m	232 W/m²
Wind power class	2	Wind power class	2
Power law exponent	0.119	Power law exponent	0.356
Surface roughness	0.0084 m	Surface roughness	2.53 m
Roughness class	0.75	Roughness class	4.68

6.3 SODAR Systems

Sonic detection and ranging (SODAR) systems are a relatively new remote sensing technology now being utilized to conduct or augment wind resource measurement and characterization. They can be used to measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere at elevations up to several hundreds of meters. SODAR systems operate by emitting an acoustic pulse that travels up into the air and is reflected by moisture or particulates moving in the air. The Doppler (frequency) shift of the return signal is then analyzed to calculate the speed, direction, and turbulent character of the air mass above the SODAR. A profile of the lower atmosphere as a function of height is obtained by analyzing the return signal at different intervals that follow the transmission of each pulse. A miniSODAR system can effectively characterize the wind up to 100–150 m (330–500 ft) above ground level, which is appropriate for wind turbine applications.

6.4 MiniSODAR

The miniSODAR system deployed at NAVSTA Newport was a series 4000 Wind Explorer unit manufactured by ASC and designed to record wind speed and direction from 40–120 m (130–390 ft).

The miniSODAR unit was first deployed at Coddington Point (labeled Bishop's Rock) from February 2010 through early August 2010 for initial calibration alongside the 60 m met tower at Coddington Point; it was then moved periodically, as shown in Table 4.

Table 4. Log of MiniSODAR Locations, February 2010–August 2011

Location	Latitude*	Longitude*	Direction	Mag Dec	Start Date	End Date
	N	W	deg	deg	d-m-y	d-m-y
Coddington Point Bishop Rock	41° 31.046'	71° 19.626'	170°	-12°	25-Feb-10	5-Aug-10
Coddington Point Bldg 1112	41° 31.376'	71° 19.416'	260°	-12°	5-Aug-10	30-Nov-10
West of Bldg 6CC Derecktor's Shipyard	41° 31.419'	71° 18.661'	270°	-12°	1-Dec-10	3-May-11
Coastal Harbor Island Helipad	41° 30.241'	71° 19.560'	230°	-12°	3-May-11	8-Jul-11
Katy Field OFFTA Site	41° 30.853'	71° 19.615'	180°	-12°	8-Jul-11	18-Aug-11

* Lattitude and longitude are in WGS84 datum

The wind speed varies significantly at locations close to the ground throughout the NAVSTA Newport area. At some point above the ground (approximately 300 m or 1,000 ft, for instance) the wind speed will not depend on the location within the base. The height above ground level where all potential turbine locations can be expected to yield similar energy production estimates are not known. By utilizing SODAR, it can be determined if this height is within the typical tower heights within the market. The objective for the periodic repositioning of the miniSODAR was to characterize the wind speed, turbulence, wind direction, and VWSF at each potential site to determine the best sites for wind energy production at NAVSTA Newport.

7 Data Recovery and Validation

The data logger sampled the sensors every 2 seconds and recorded the 10-minute average value for each sensor. The collected data was transmitted via cell phone modem to DNV who performed data validation to each monthly dataset through March 31, 2010, for Coddington Point and through April 29, 2011, for site Tank Farm #4. Table 5 and Table 6 show the data recovery rates for each met tower.

Table 5. Dataset Recovery Rates for Coddington Point, April 1, 2010, to March 31, 2011

Coddington Point - #9202 Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)	Mean	Min	Max	Std. Dev
58m 270deg WS	m/s	58 m	52,560	48,810	92.87	6.56	0.35	23.98	3.3
58m 270deg SD	m/s	58 m	52,560	48,810	92.87	0.685	0	4.72	0.371
58m 270deg Max	m/s	58 m	52,560	48,810	92.87	8.33	0.35	30.57	4.09
58m 188deg WS	m/s	58 m	52,560	38,849	73.91	6.3	0.35	21.34	3.06
58m 188deg SD	m/s	58 m	52,560	38,849	73.91	0.695	0	4.52	0.361
58m 188deg Max	m/s	58 m	52,560	38,849	73.91	8.09	0.35	26.36	3.81
50m 270deg WS	m/s	50 m	52,560	50,053	95.23	6.35	0.35	23.23	3.24
50m 270deg SD	m/s	50 m	52,560	50,053	95.23	0.689	0	4.72	0.367
50m 270deg Max	m/s	50 m	52,560	50,053	95.23	8.13	0.35	29.8	4.02
40m 270deg WS	m/s	40 m	52,560	50,288	95.68	6.21	0.35	22.95	3.19
40m 270deg SD	m/s	40 m	52,560	50,288	95.68	0.691	0	4.52	0.374
40m 270deg Max	m/s	40 m	52,560	50,288	95.68	8.01	0.35	31.33	3.99
40m 188deg WS	m/s	40 m	52,560	45,086	85.78	6.14	0.35	21.82	3.11
40m 188deg SD	m/s	40 m	52,560	45,086	85.78	0.71	0	4.52	0.374
40m 188deg Max	m/s	40 m	52,560	45,086	85.78	8	0.35	28.66	3.91
24m 270deg WS	m/s	24 m	52,560	50,152	95.42	5.9	0.35	22.33	3.1
24m 270deg SD	m/s	24 m	52,560	50,152	95.42	0.7	0	4.52	0.386
24m 270deg Max	m/s	24 m	52,560	50,152	95.42	7.73	0.35	28.27	3.93
49m Direction	°	49 m	52,560	52,227	99.37	275.7	0	360	99.1
49m Direction SD	°	49 m	52,560	52,227	99.37	7.3	0	117	5.4
25m Direction	°	25 m	52,560	52,252	99.41	275.4	0	360	99.7
25m Direction SD	°	25 m	52,560	52,252	99.41	8.8	0	112	6.1
Temperature Avg	°C		52,560	52,560	100	11.7	-15.9	36.6	9.29

Note: WS = wind speed; SD = standard deviation; MAX = maximum wind recorded; DIR = direction; Avg = average

Table 6. Dataset Recovery Rates for Tank Farm #4, April 1, 2010, to March 31, 2011

Tank Farm #4 - #9203									
Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)	Mean	Min	Max	Std. Dev
58m 270deg WS	m/s	58 m	52,560	50,721	96.5	6.11	0.4	22.4	3.1
58m 270deg SD	m/s	58 m	52,560	50,721	96.5	0.833	0	4.9	0.44
58m 270deg Max	m/s	58 m	52,560	50,721	96.5	8.18	0.4	29.9	4.02
58m 180deg WS	m/s	58 m	52,560	48,023	91.37	6.07	0.4	22.2	3.08
58m 180deg SD	m/s	58 m	52,560	48,023	91.37	0.838	0	5.1	0.441
58m 180deg Max	m/s	58 m	52,560	48,023	91.37	8.15	0.4	29.2	4.02
50m 270deg WS	m/s	50 m	52,560	52,439	99.77	5.81	0.4	21.7	3.01
50m 270deg SD	m/s	50 m	52,560	52,439	99.77	0.861	0	4.9	0.45
50m 270deg Max	m/s	50 m	52,560	52,439	99.77	7.94	0.4	31.1	3.96
40m 270deg WS	m/s	40 m	52,560	50,812	96.67	5.4	0.4	20.6	2.87
40m 270deg SD	m/s	40 m	52,560	50,812	96.67	0.914	0	4.9	0.474
40m 270deg Max	m/s	40 m	52,560	50,812	96.67	7.66	0.4	29.3	3.9
40m 180deg WS	m/s	40 m	52,560	48,038	91.4	5.43	0.4	20.2	2.82
40m 180deg SD	m/s	40 m	52,560	48,038	91.4	0.908	0	4.9	0.473
40m 180deg Max	m/s	40 m	52,560	48,038	91.4	7.68	0.4	28.8	3.86
25m 270deg WS	m/s	25 m	52,560	51,028	97.09	4.45	0.4	16.9	2.45
25m 270deg SD	m/s	25 m	52,560	51,028	97.09	0.974	0	4.3	0.491
25m 270deg Max	m/s	25 m	52,560	51,028	97.09	6.9	0.4	26.2	3.63
47.4m Direction	°	47.5 m	52,560	52,441	99.77	272.2	0	359	99.2
47.5m Direction SD	°	47.5 m	52,560	52,441	99.77	13	0	127	6.5
26m Direction	°	26 m	52,560	52,444	99.78	279.1	0	359	100.5
26m Direction SD	°	26 m	52,560	52,444	99.78	10.1	0	117	6
Temperature Avg	°C		52,560	52,560	100	11.24	-17.1	37.2	9.81

Note: WS = wind speed; SD = standard deviation; MAX = maximum wind recorded

7.1 Data Analysis

The wind data from Coddington Point and Tank Farm #4 validated by DNV was used for all of the met tower analyses. For the purposes of comparing the wind resources at Coddington Point and Tank Farm #4, the analysis in this section will examine a 12-month period where the met towers have concurrent data, April 1, 2010, to March 31, 2011.

Wind speed data were collected at 58, 50, 40, and 24 m (190, 164, 131, and 79 ft) with redundant wind speed sensors at 58 and 40 m (196 and 131 ft). The wind speed sensors were mounted on boom arms facing south (180°–190°) or west (270°–275°) to minimize met tower shading effects.

Two anemometers at Coddington Point, 58m 188 deg wind speed and 40 m 188 deg wind speed, were significantly affected by met tower shading and these data points have been flagged and removed from the datasets.

The analyses that follow group, average and sort the data utilizing a variety of methods to help illustrate important trends and other statistical data relevant to the characterization of the wind resource.

8 Wind Resource Assessment Summary

8.1 Wind Resource Characterization

Uneven heating of the earth's surface creates wind energy. Variation in heating and factors such as surface orientation or slope (azimuth), absorptivity (albedo), and atmospheric transmissivity also affect the wind resource. In addition, the wind resource can be accelerated, decelerated, or made turbulent by factors such as terrain, bodies of water, buildings, and vegetative cover.

Wind is air with kinetic energy that can be converted into usable energy by means of a wind turbine. Wind is a distributed resource that can generate electricity cost effectively and competitively in many regions.

8.2 Measuring Power in the Wind

Wind speeds vary by season, time of day, and according to weather events.

The wind speed determines the amount of power it contains. The power available is given by:

$$P = \tfrac{1}{2} * A * \rho * V^3$$

where

P = power of the wind [W]

A = windswept area of the rotor (blades) [m^2] = $\pi D^2/4 = \pi r^2$

ρ = density of the air [kg/m^3] (at sea level at 15°C)

V = velocity of the wind [m/s]

As shown, wind power is proportional to velocity cubed (V^3). This is important to understand because as wind velocity is doubled, the available power is increased by a factor of eight ($2^3 = 8$). Consequently, what may appear to be a small increase in average speed yields a significant increase in available energy. Typically, developers looking to capture energy from higher velocity winds select taller wind turbine towers. Accordingly, the wind industry has been steadily moving toward taller towers, and the industry norm has increased from 30 m to 100 m over the last 15–20 years.

8.3 NAVSTA Newport Wind Speed Variability

The wind varies widely throughout the day and night and by season as illustrated in the graph of two months of data collected at 58 m at Coddington Point in Figure 6. As shown, there are a number of 10-minute periods that have wind speeds less than 1 m/s (~2 mph). Likewise, there are many periods that have wind speeds in excess of 10 m/s (~22 mph). This sort of variability is typical, but further statistical analysis will illuminate important trends and patterns.

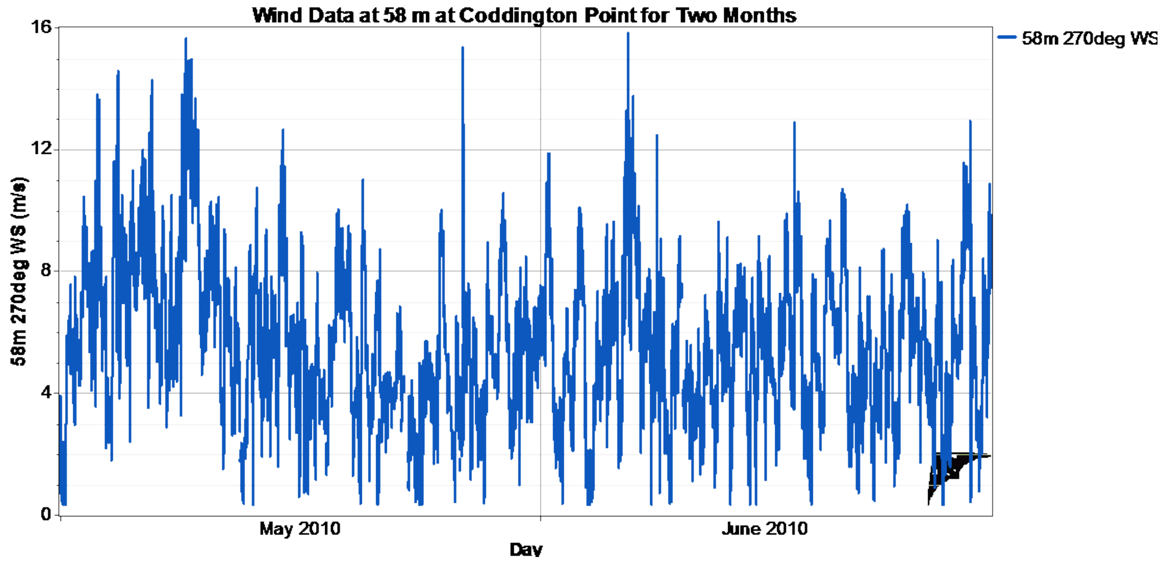

Figure 6. Wind data at 58 m at Coddington Point, May–June 2010

8.4 NAVSTA Newport Monthly Box Plot Statistics

A box plot indicating the monthly maximum wind speed, the daily high, the monthly mean, the daily low, and monthly minimum wind speed measured at each site are shown in Figure 7 and Figure 8. These graphics illustrate the seasonal trends of the local wind resource. An average will look smoother than Figure 6, but the stochastic nature and dynamic variability of the wind should not be overlooked.

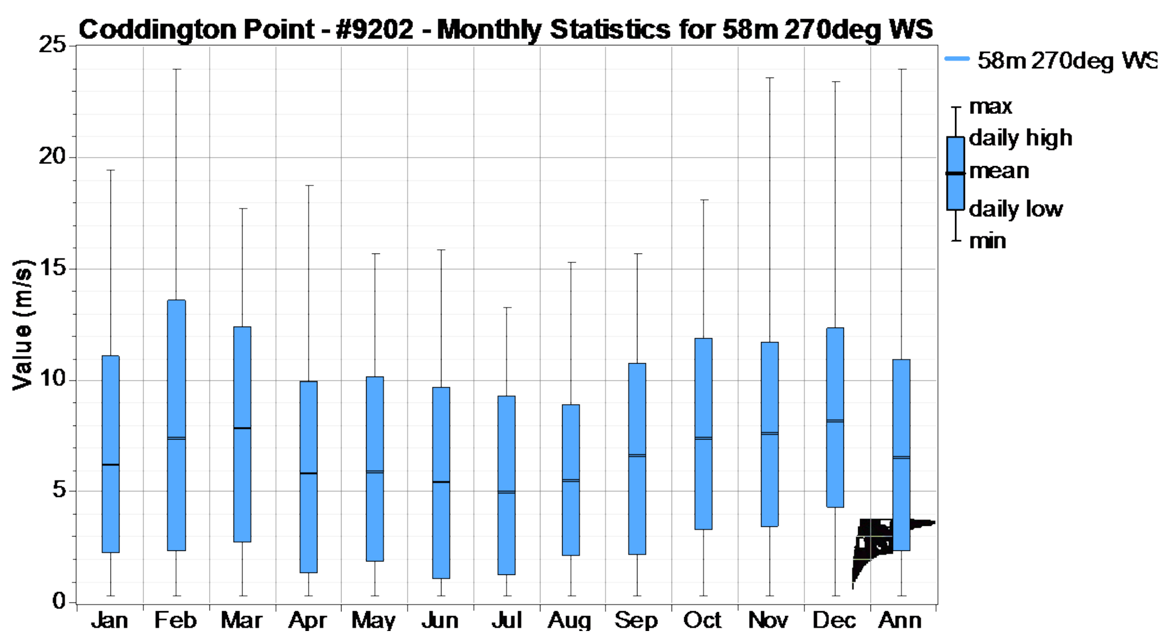

Figure 7. Boxplot of Coddington Point, April 1, 2010, to March 31, 2011

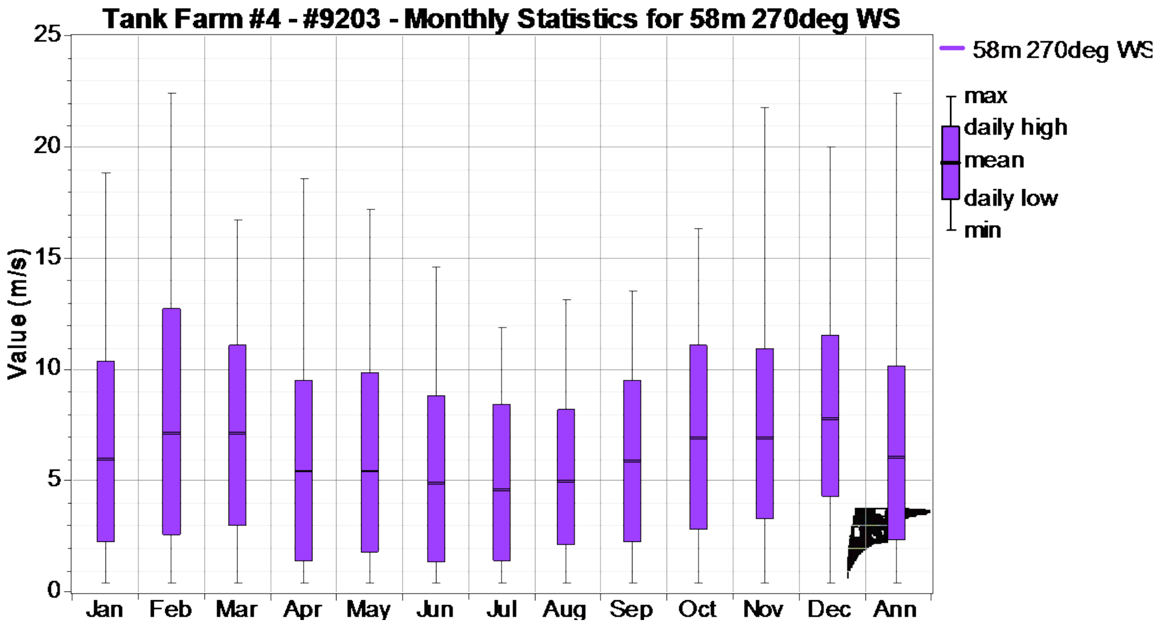

Figure 8. Boxplot of Tank Farm #4, April 1, 2010, to March 31, 2011

8.5 NAVSTA Newport Seasonal Wind Profile

Figure 9 shows the wind speeds at each anemometer height as they are plotted against time to depict the seasonal trends. As can be seen in the Coddington Point graph, the fall and winter seasons were the windiest periods. Wind speeds typically increase with increased height above the ground. The collected data follows that pattern. The variation in wind speed from 24 to 58 m (79 to 190 ft) is relatively small, generally less than 1 m/s (2.2 mph). This is an indication of low VWSF. The anemometers at 180° at both 40 m and 58 m showed significant effects of tower shading and were not included in the subsequent analyses.

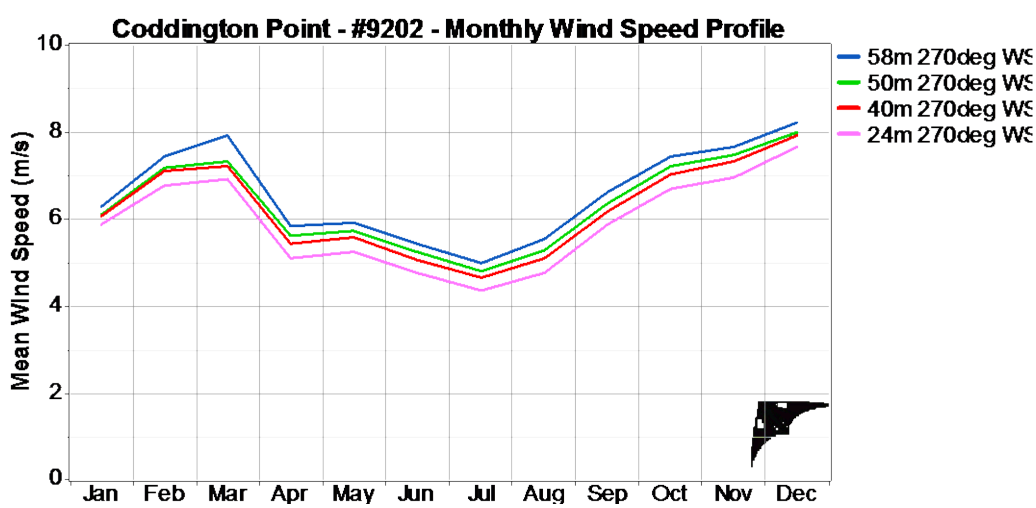

Figure 9. Seasonal wind speed profile at Coddington Point, April 1, 2010, to March 31, 2011

The data from Tank Farm #4 shows the same general seasonal trends as Coddington Point, as shown in Figure 10, though the wind speeds are generally lower at the 58 m level. Of importance is how much lower the wind speeds are at 24 m at Tank Farm #4 than at Coddington Point and the much higher resultant vertical wind shear factor (VWSF). The wind speed at 24 m at Tank Farm #4 was much lower due to the impact of the undulating terrain and trees near the met tower. At Coddington Point, most of the wind is coming off the water, so there is little to impede the flow of the wind.

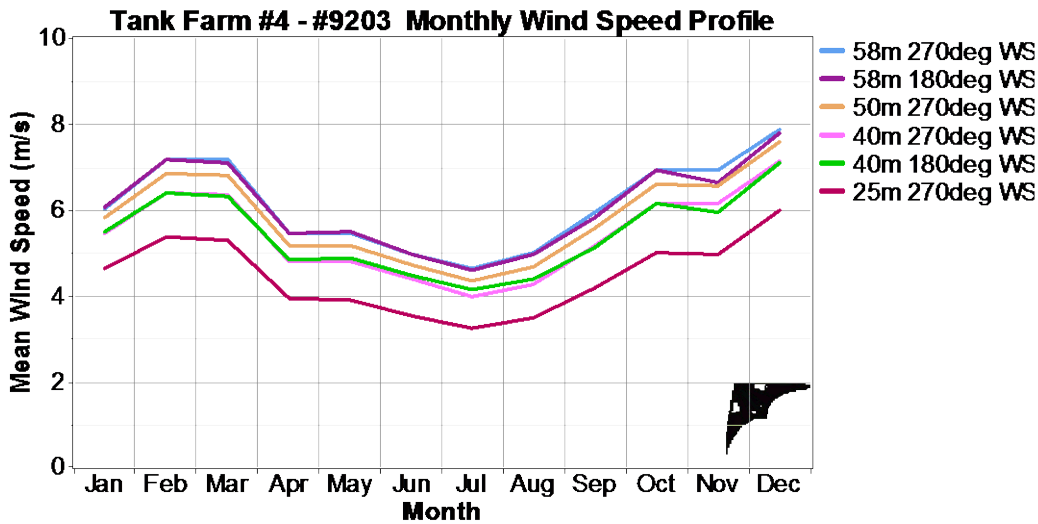

Figure 10. Seasonal wind speed profile at Tank Farm #4, April 1, 2010, to March 31, 2011

8.6 NAVSTA Newport Diurnal Wind Profile

Figure 11 and Figure 12 illustrate how the wind speed varies during the course of the day. As shown, the wind speeds increase during late morning and continue increasing until mid-afternoon. Nighttime is generally the period of lower winds.

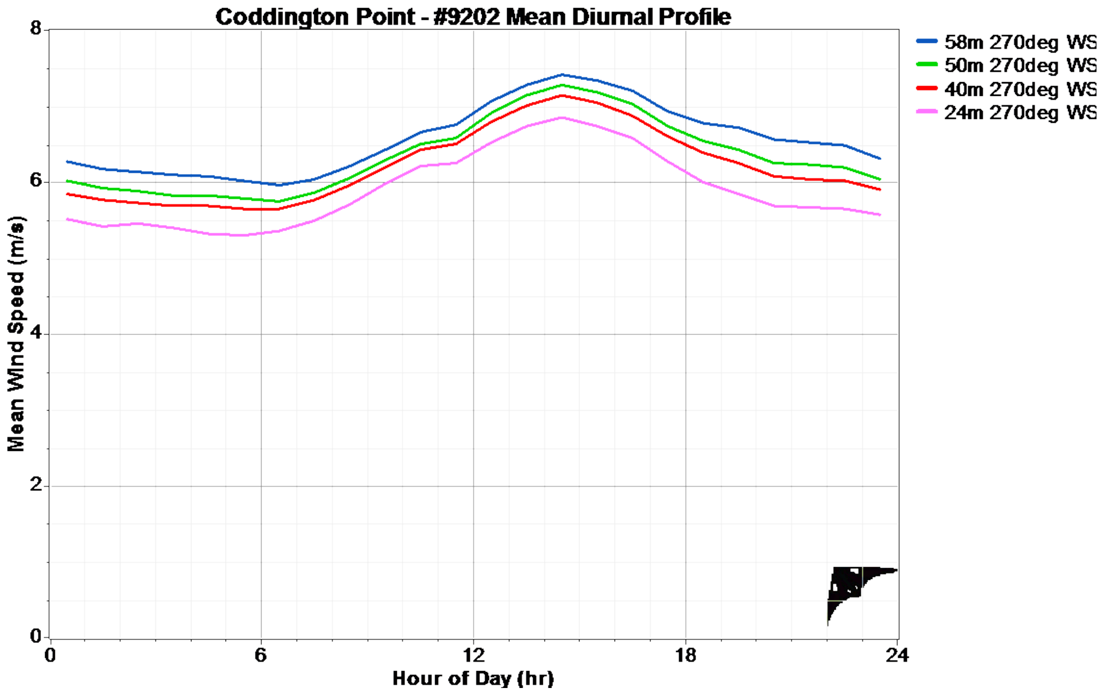

Figure 11. Diurnal profile of the wind speed at Coddington Point, April 1, 2010, to March 31, 2011

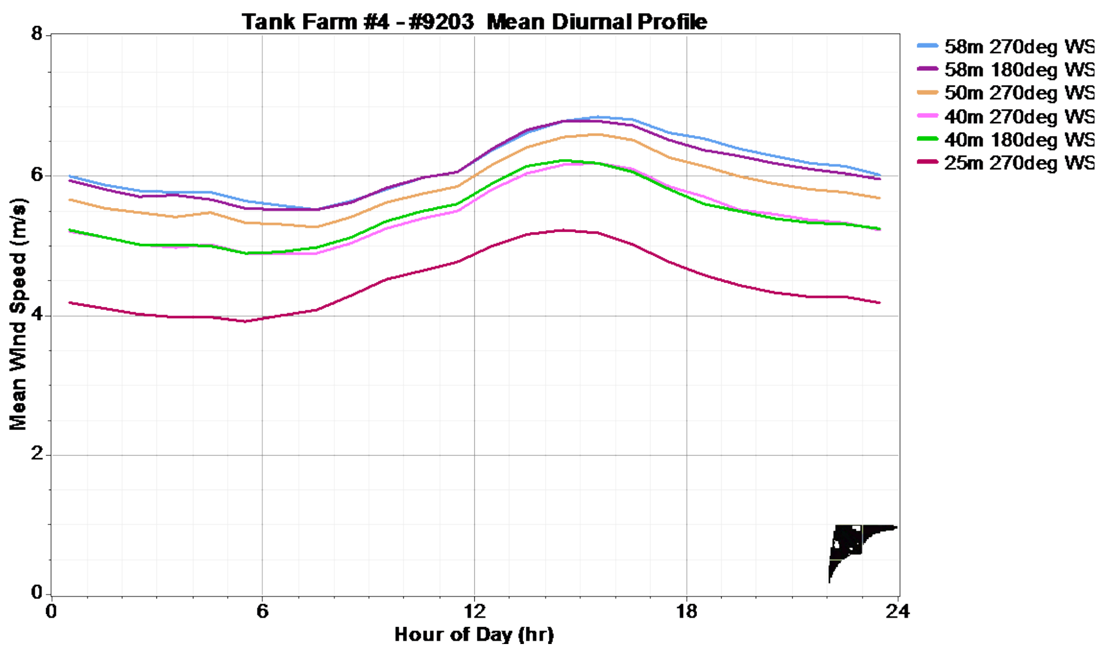

Figure 12. Diurnal profile of the wind speed at Tank Farm #4, April 1, 2010, to March 31, 2011

The diurnal trend may have some utility cost saving implications due to the demand charges by NAVSTA Newport's utility, National Grid. There is much uncertainty as to when exactly the wind will blow, at what speeds it will blow, and how the wind will correspond to periods of maximum loads for NAVSTA Newport. There is potential for some demand charge savings on a monthly basis, though the amount will vary widely.

Figures 13 and 14 show the diurnal trends for each month of the year. As seen at Coddington Point, April through September has wind typically peaking in mid-afternoon. There is a similar trend at Tank Farm #4, but the variation is very pronounced at 25–60 m.

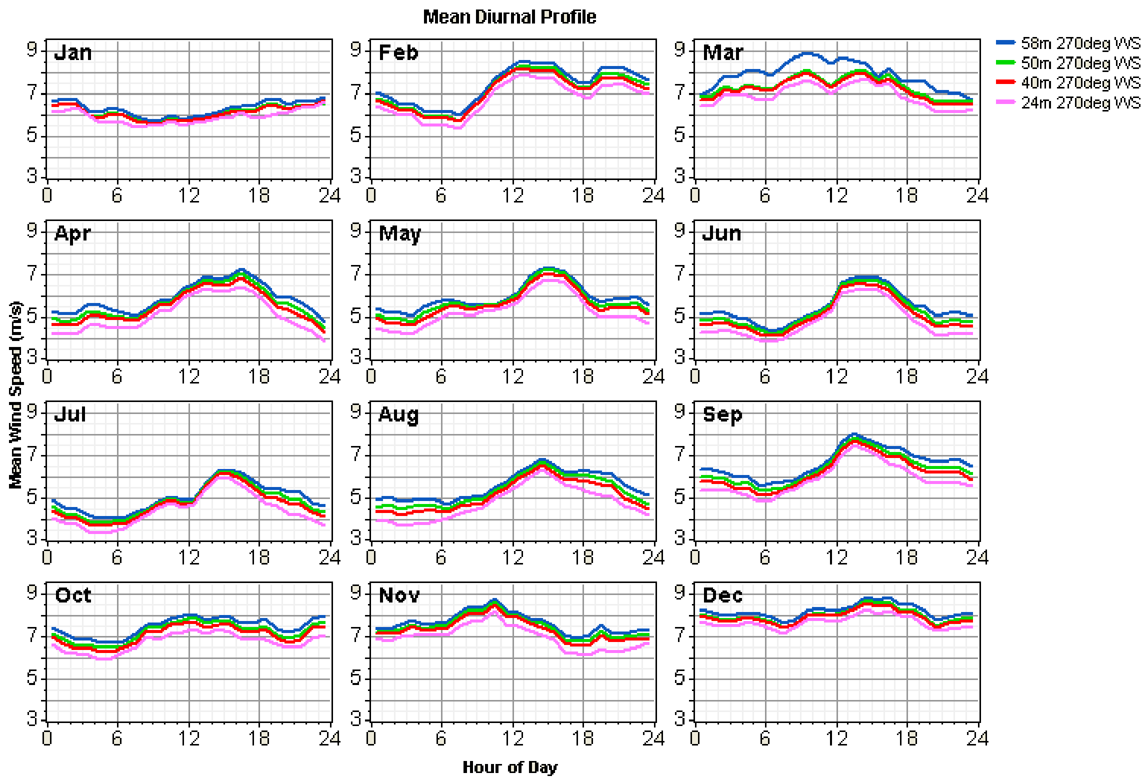

Figure 13. Monthly diurnal profile of the wind speed at Coddington Point, April 1, 2010, to March 31, 2011

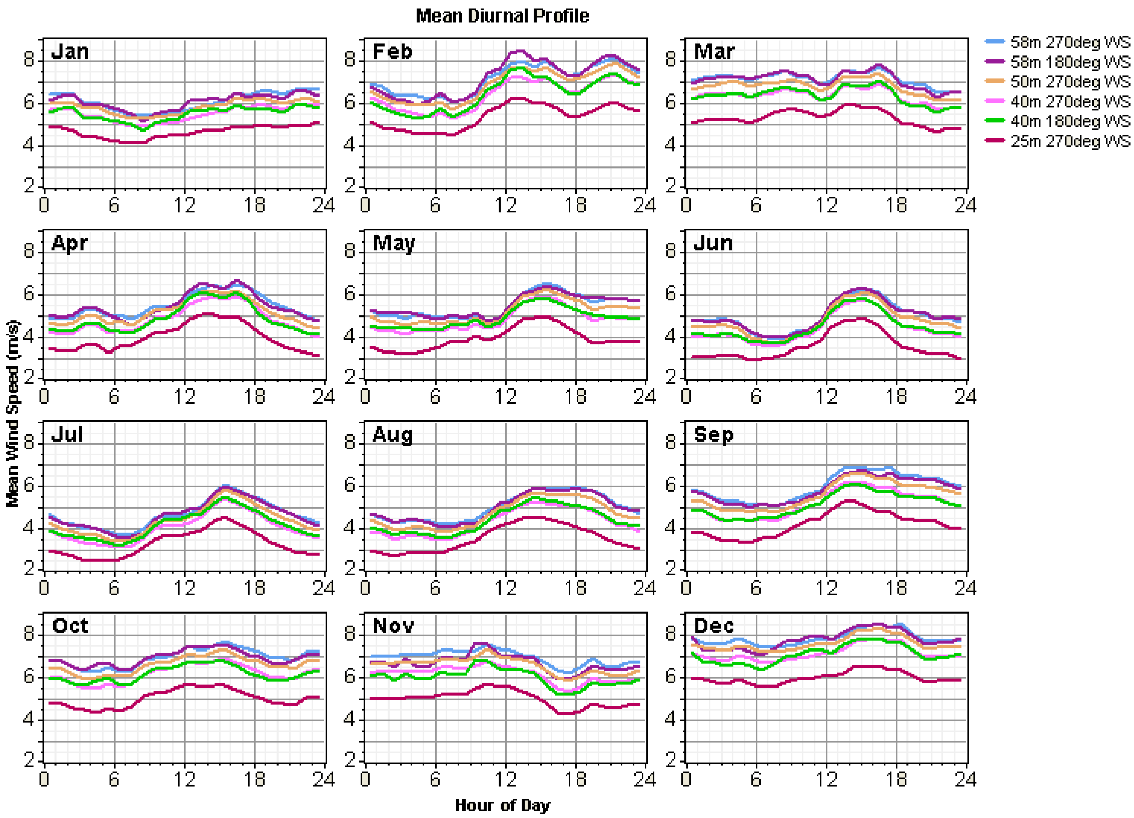

Figure 2. Monthly diurnal profile of the wind speed at Tank Farm #4, April 1, 2010, to March 31, 2011

8.7 NAVSTA Newport Wind Direction Data

Wind direction informs decisions about turbine siting to maximize exposure to the best winds and minimize exposure to turbulent winds. In this analysis of direction, the compass was divided into 16 sectors, each 22.5° in size.

8.7.1 NAVSTA Newport Wind Frequency

Figure 15 shows the frequency the wind blows from each direction for Coddington Point and Tank Farm #4. At Coddington Point, the wind was “calm” or blowing at less than 3 m/s (7.67 mph) 15% of the time, compared to Tank Farm #4 where it was calm 18% of the time.

At Coddington Point, the wind blows most frequently (24% of the time) in the south through southwest arc (169°–214°). Second-most frequent (22%) is the northwest arc (281°–326°). At Tank Farm #4, the wind blows most frequently (26%) in the south through southwest arc (169°–214°). Second-most frequent (22%) is the northwest arc (281°–326°).

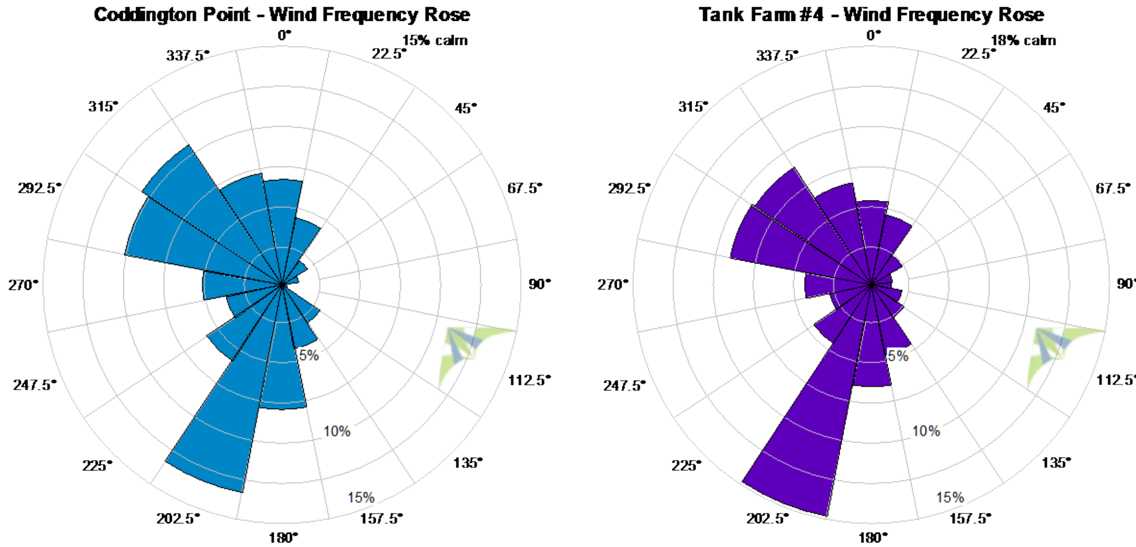

Figure 35. Wind frequency rose at Coddington Point and Tank Farm #4 at 58 m, April 1, 2010, to March 31, 2011

8.7.2 NAVSTA Newport Total Wind Energy

The two total wind energy roses in Figure 16 summarize the direction the most energetic winds come from. The most energetic winds are those from the west through north arc flowing across the bay. The bay has very low surface roughness as water is smooth compared to land surfaces. At Coddington Point, though the wind most frequently comes from the south-southwest arc, the strongest winds with the most energy are from the northwest arc. The winds from the northwest (259°–326°) account for 43% of the wind energy, while those from the southwest (146°–214°) account for 23% of the wind energy. At Tank Farm #4, comparing the same sectors, the northwest provides 46% of the wind energy compared to 20% for the south-southwest sector.

In siting wind turbines at NAVSTA Newport, attention should be paid to ensuring a clear fetch to the northwest and southwest of each wind turbine to the greatest degree possible as these winds will be the most energetic. Surface obstructions (trees or buildings) in these directions should be avoided as they will increase the turbulence intensity the turbines will experience.

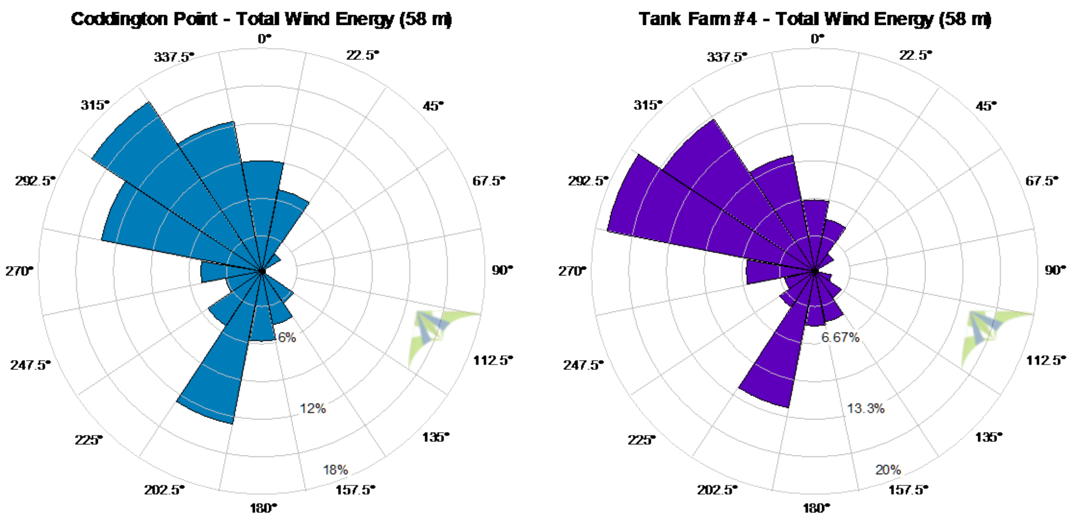

Figure 16. Total wind energy rose at Coddington Point and Tank Farm #4 at 58 m, April 1, 2010, to March 31, 2011

The monthly wind total wind energy rose at Coddington Point in Figure 17 point to both the northwest-through-north arc as strong in the winter (December through February) as a source of wind energy and the southwest sector being of prime importance during the summer (June through August). Overall, this data points to the advantage of finding sites with good fetch across the water in the northwest and southwest directions.

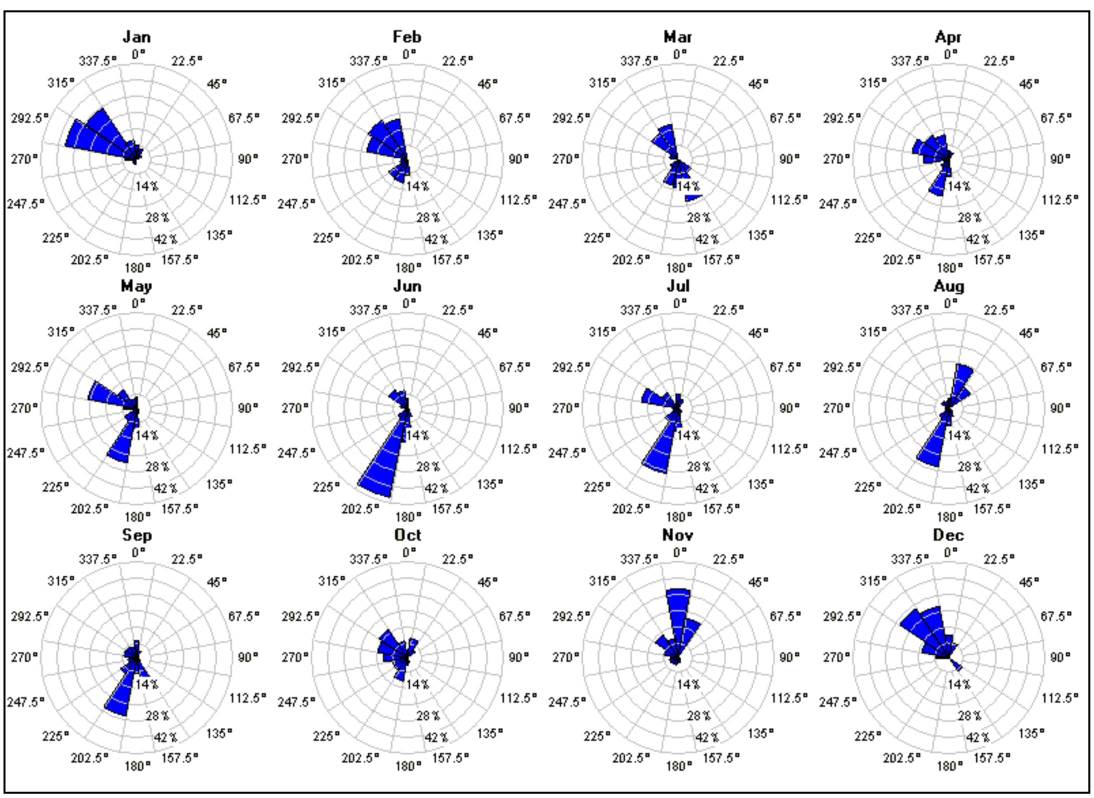

Figure 17. Total wind energy rose at Coddington Point by month at 58 m, April 1, 2010, to March 31, 2011

The same seasonal directional patterns can be seen, in Figure 18, at Tank Farm #4 as at Coddington Point with the northwest-through-north arc being strong in winter (December through February) as a source of wind energy and the southwest sector being of prime importance during the summer (June through August).

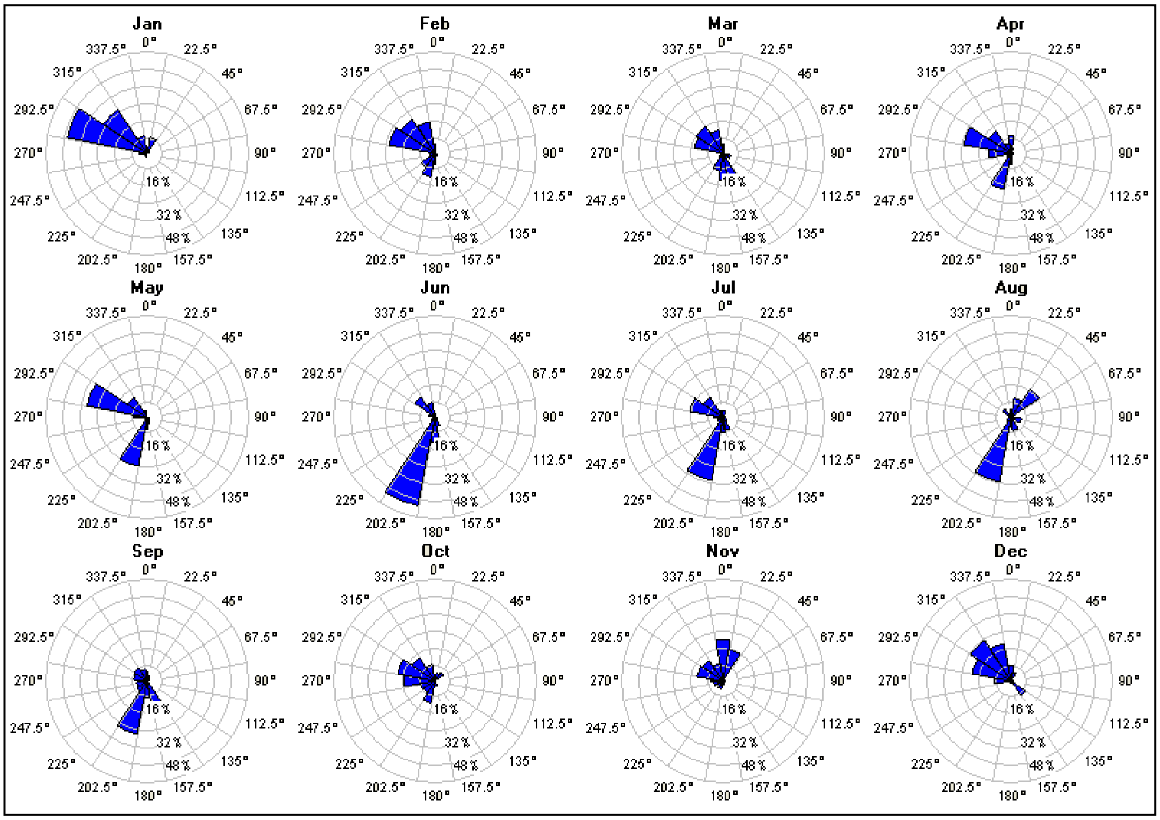

Figure 48. Total wind energy rose at Tank Farm #4 by month at 58 m, April 1, 2010, to March 31, 2011

8.8 NAVSTA Newport Wind Frequency (Probability) Distribution

Figure 19 illustrates a Weibull distribution of the frequency (percent of time) that the wind at 58 m is at a given speed. There are two commonly used factors to describe the distribution function, the Weibull *c* and Weibull *k* factors. The Weibull *c* is the scale factor for the distribution related to the annual mean wind speed. The Weibull *k* value is a unitless measure indicating the shape of the distribution of the wind speeds about the mean with values ranging from 1.0–3.0.

In Figure 19, the best fit Weibull distribution parameters for the measured data at Coddington Point are $k = 2.07$ and $c = 7.39$ m/s. The distribution shows that the most frequent winds, or mode of the dataset, are between 5–7 m/s as measured by the wind sensor at 58 m.

Figure 20 shows the same distribution for Tank Farm #4. The best fit Weibull distribution parameters for the measured data are $k = 2.06$ and $c = 6.89$ m/s.

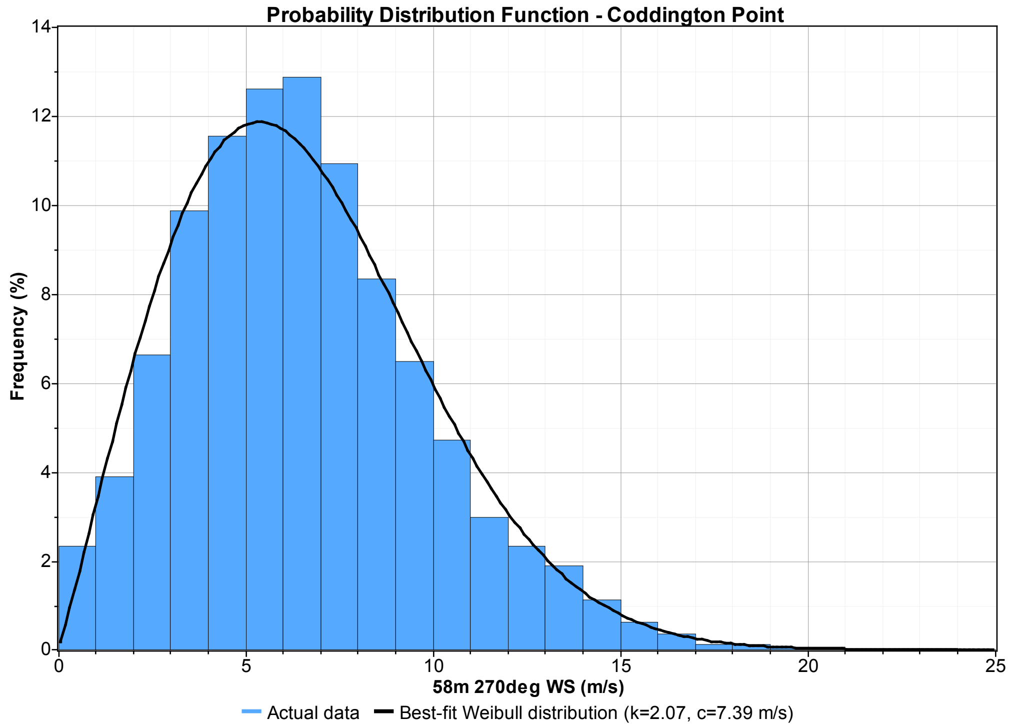

Figure 19. Wind frequency distribution for Coddington Point at 58 m, April 1, 2010, to March 31, 2011

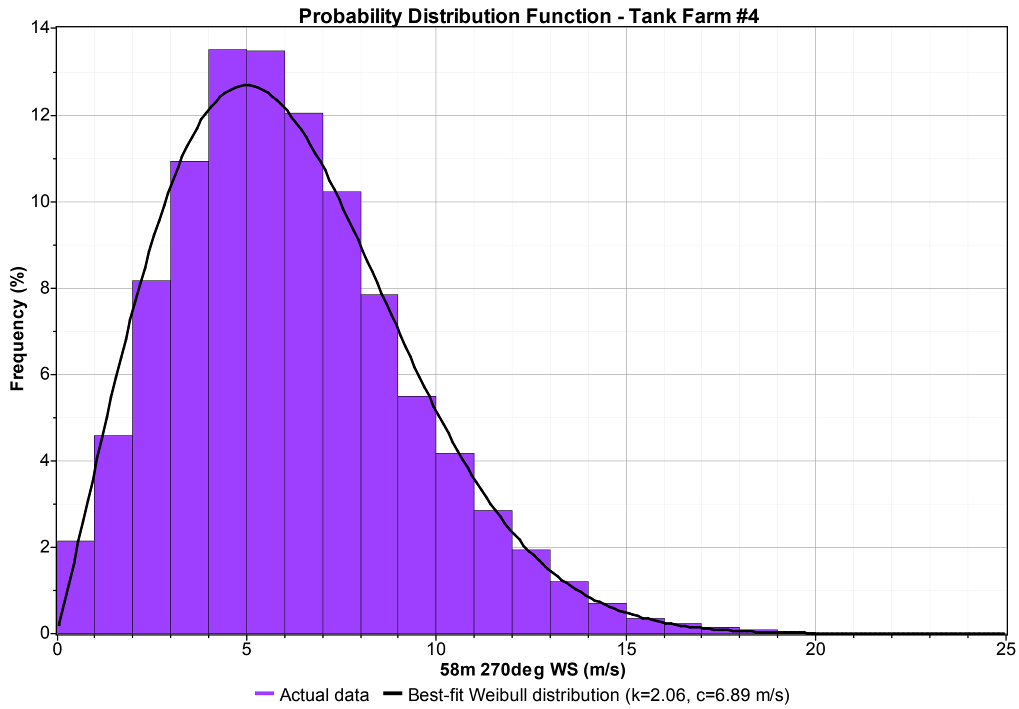

Figure 20. Wind frequency distribution for Tank Farm #4 at 58 m, April 1, 2010, to March 31, 2011

8.9 Vertical Wind Shear

VWSF is the change in wind speed with increasing height above ground. Typically, wind speeds increase with height. This variation of wind speed with elevation is called the vertical profile of the wind speed, or VWSF. In wind turbine engineering, the determination of VWSF is an important design parameter since: (1) it directly determines the productivity of a wind turbine on a tower of certain height, and (2) it can represent the level of cyclic mechanical loading on the wind turbine system.

Analysts typically use one of two mathematical relations to characterize the measured wind shear profile:

- Power Law profile
- Logarithmic Law profile.

8.9.1 Power Law

The Power Law equation is:

$$V = V_{ref} \left[\frac{Z}{Z_{ref}} \right]^{u}$$

V = wind speed at height of interest (e.g., hub height)

V_{ref} = wind speed measured at height Z_{ref}

Z = height of interest (e.g., hub height)

Z_{ref} = height of measured data

α = wind shear exponent

The wind shear exponent, α, or VWSF, defines how the wind speed changes with height. When the actual wind shear value is not known, a typical value used for estimation is 0.14 (aka 1/7 Power Law). When wind speed data are available at multiple heights, the wind shear factor can be calculated using the Power Law equation.

The VWSFs from several heights with known wind speeds are used to estimate both the VWSF and wind speed at other heights of interest (e.g., turbine hub height). Depending on the type of terrain and surface roughness features, the VWSF may vary from 0.0 to 0.4.

8.9.2 Logarithmic Law

The Logarithmic Law uses a parameter known as the *surface roughness length* (measured in meters) in predicting the wind shear profile. Surface roughness length describes the conditions of the ground and its expected impact on wind flows and ranges, according to Table 7.

Table 7. Surface Roughness Lengths and Descriptions[7]

Terrain Description	Surface Roughness Length, z_0 (m)
Very smooth, ice and mud	0.00001
Calm open sea	0.0002
Blown sea	0.0005
Snow surface	0.003
Lawn grass	0.008
Rough pasture	0.01
Fallow field	0.03
Crops	0.05
Few trees	0.1
Many trees, hedges, few buildings	0.25
Forest and woodlands	0.5
Suburbs	1.5
Centers of cities with tall buildings	3.0

The Best Fit Power Law Exponent was calculated with the data collected at Coddington Point and Tank Farm #4. Table 8 and Table 9 show the calculated wind shear values at each site in the "Best-Fit Power Law Exponent" column. Though the wind shear exponent is very high in the two sectors from 56°–101°, combined they represent just 0.4% of the year so the impact is minimal.

[7] Ray, M.L.; Rogers, A.L.; McGowan, J.G.; (2002). *Analysis of Wind Shear Models and Trends in Different Terrains.* http://www.ceere.org/rerl/publications/published/2006/AWEA%202006%20Wind%20Shear.pdf. Accessed July 2011.

Also shown in Table 8 is the application of surface roughness lengths. The surface roughness parameter is “solved for” from the existing wind speed data at various heights. The resultant characterization may not always match the actual surface conditions, but it serves as a descriptor of the vertical wind shear profile. The surface roughness lengths have been calculated for Coddington Point and Tank Farm #4 and are shown in “Surface Roughness” column at the far right in Table 8 and Table 9. As shown, there is a marked difference in the surface roughness characteristics between the two sites. Most of the wind coming into the met tower at Coddington point is over water, grass, parking lots, or roads. There are some taller buildings to the east that are the cause of the high surface roughness lengths shown in the two sectors from 56°–101°. These sectors represent wind data from 0.4% of the year so the overall impact is minimal.

Table 8. Power Law Exponent and Surface Roughness Length for Coddington Point, April 1, 2010, to March 31, 2011

Direction Sector	Time Steps	Mean Wind Speed				Best-Fit Power Law Exponent	Surface Roughness
		58m 270° WS	50m 270° WS	40m 270° WS	24m 270° WS		
°	#	m/s	m/s	m/s	m/s	unitless	m
348.75° - 11.25°	3,926	6.507	6.405	6.340	6.091	0.073	0.000038
11.25° - 33.75°	2,533	6.786	6.534	6.322	5.506	0.235	0.504055
33.75° - 56.25°	1,048	5.631	5.362	5.184	4.534	0.24	0.554952
56.25° - 78.75°	136	3.117	2.850	2.692	2.105	0.433	3.560614
78.75° - 101.25°	36	1.284	0.928	0.877	0.829	0.392	3.525177
101.25° - 123.75°	324	4.938	4.637	4.413	3.926	0.25	0.676891
123.75° - 146.25°	1,742	5.876	5.644	5.443	5.055	0.164	0.085183
146.25° - 168.75°	2,428	6.181	5.908	5.750	5.417	0.14	0.029994
168.75° - 191.25°	4,581	5.598	5.333	5.151	4.880	0.145	0.039881
191.25° - 213.75°	7,234	6.738	6.533	6.292	5.887	0.15	0.047117
213.75° - 236.25°	3,473	6.143	5.889	5.709	5.342	0.151	0.049494
236.25° - 258.75°	2,339	5.739	5.465	5.322	4.979	0.15	0.049262
258.75° - 281.25°	2,983	6.356	6.103	5.999	5.693	0.115	0.006509
281.25° - 303.75°	5,066	7.474	7.241	7.148	6.885	0.085	0.000316
303.75° - 326.25°	5,651	7.550	7.321	7.269	7.028	0.073	0.000044
326.25° - 348.75°	4,213	7.121	6.977	6.933	6.707	0.063	0.000005
Overall Annual Figure		**6.605**	**6.383**	**6.245**	**5.904**	**0.121**	**0.009460**

The surface roughness lengths at Tank Farm #4, as seen in Table 9 below, are much higher in all directions due to the hills, trees, and vegetation nearby.

Table 9. Power Law Exponent and Surface Roughness Length for Tank Farm #4, April 1, 2010, to March 31, 2011

Direction Sector	Time Steps	Mean Wind Speed						Best-Fit Power Law Exponent	Surface Rough-ness
		58m 270° WS	58m 180° WS	50m 270° WS	40m 270° WS	40m 180° WS	24m 270° WS		
°	#	m/s	m/s	m/s	m/s	m/s	m/s	unitless	m
348.75° - 11.25°	80	4.611	4.119	4.422	4.019	3.589	3.354	0.343	2.024659
11.25° - 33.75°	2,643	5.663	5.542	5.386	4.863	4.816	3.949	0.426	3.497828
33.75° - 56.25°	1,721	5.067	5.056	4.770	4.322	4.351	3.520	0.434	3.665493
56.25° - 78.75°	730	4.093	4.121	3.807	3.384	3.445	2.616	0.537	5.674358
78.75° - 101.25°	0								
101.25° - 123.75°	958	5.521	5.525	5.215	4.655	4.763	3.779	0.455	4.070293
123.75° - 146.25°	1,663	5.523	5.452	5.240	4.699	4.729	3.770	0.455	4.049013
146.25° - 168.75°	2,778	5.819	5.699	5.493	4.932	4.918	3.708	0.534	5.542946
168.75° - 191.25°	4,114	5.198	5.130	4.952	4.507	4.482	3.533	0.461	4.128535
191.25° - 213.75°	8,538	6.175	6.159	5.951	5.525	5.518	4.621	0.349	2.076652
213.75° - 236.25°	3,038	5.410	5.453	5.147	4.663	4.749	3.866	0.406	3.140462
236.25° - 258.75°	2,157	5.226	5.262	4.933	4.413	4.531	3.435	0.507	5.043667
258.75° - 281.25°	2,944	6.241	6.272	5.957	5.483	5.559	4.412	0.419	3.322762
281.25° - 303.75°	5,573	7.547	7.556	7.335	6.940	6.993	5.702	0.34	1.884309
303.75° - 326.25°	5,346	7.246	7.224	7.096	6.739	6.744	5.752	0.28	1.010974
326.25° - 348.75°	3,687	6.792	6.713	6.641	6.219	6.197	5.274	0.305	1.352402
Overall Annual Figure		**6.172**	**6.144**	**5.935**	**5.487**	**5.506**	**4.502**	**0.379**	**2.590000**

Figure 21 shows graphs comparing the measured data to the Power Law approach to vertical wind shear versus the Logarithmic Law approach. Both methods track closely with the measured data and each other at Coddington Point. There is a wider spread between these methods at lower and higher wind speeds at Tank Farm #4. The Power Law was used for energy calculations as it is tied more closely to statistical calculations rather than surface roughness approximations.

As shown, at a height of 100 m above the ground, the impact of surface roughness is negated and the wind speeds are all assumed to be 10 m/s. With low surface roughness (designated by z_0 = 0.00001 m), the wind speed decreases minimally, moving closer to the ground such that even as low as 5 m above the ground, the wind speed is 8 m/s; that is, it has only decreased 20% despite a 95% reduction in height above the ground. With high surface roughness associated with cities and high buildings (designated by z_0 = 3 m), the wind speed decreases by 20% with only a 50% reduction in height above the ground, and the wind speed is reduced by 50% at approximately 18 m above the ground or a reduction in height of 82%. These phenomena impact the energy production estimates for Coddington Point and Tank Farm #4.

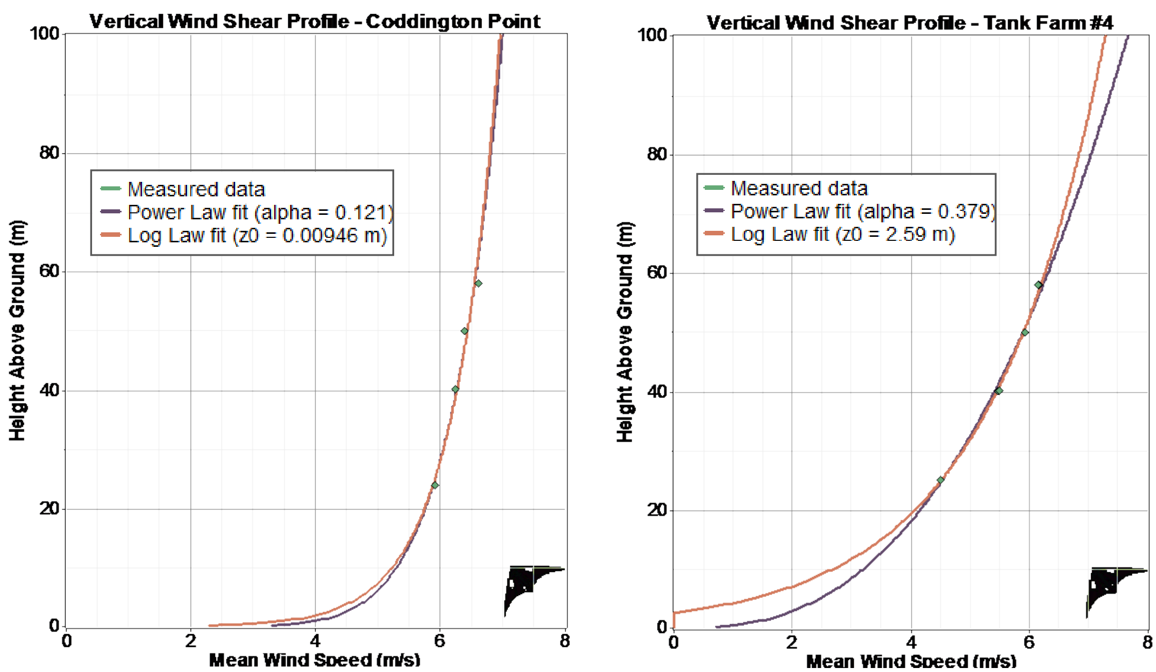

Figure 21. Vertical wind shear profile at Coddington Point and Tank Farm #4 at 58 m, April 1, 2010, to March 31, 2011

The daily wind shear at Coddington Point as it varies by month is shown in Figure 22. The months with the higher wind shears generally have lower wind speeds, especially during nighttime hours.

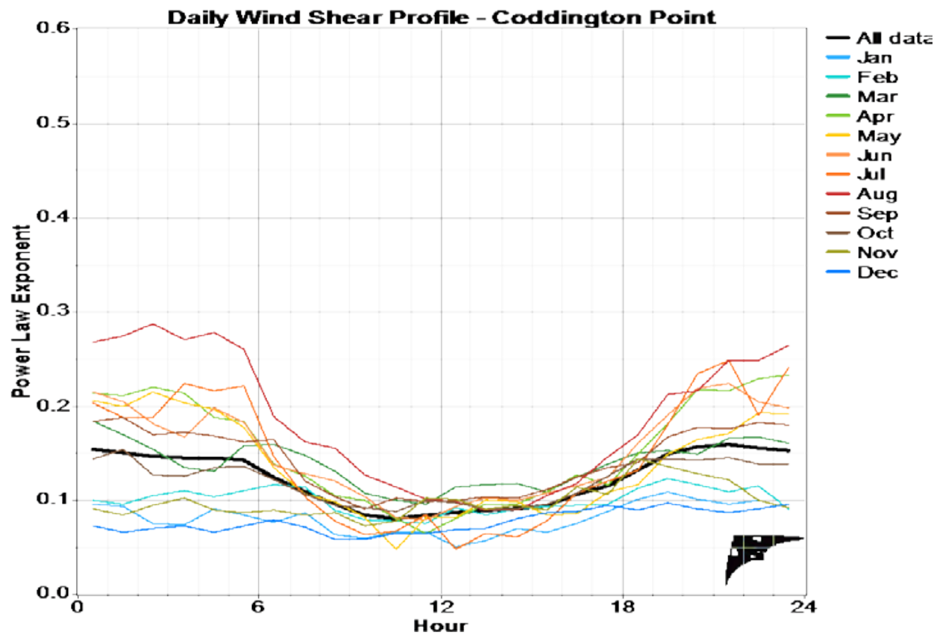

Figure 22. Daily wind shear profile by month at Coddington Point, April 1, 2010, to March 31, 2011

At Tank Farm #4, the patterns are similar, though the overall values are much higher.

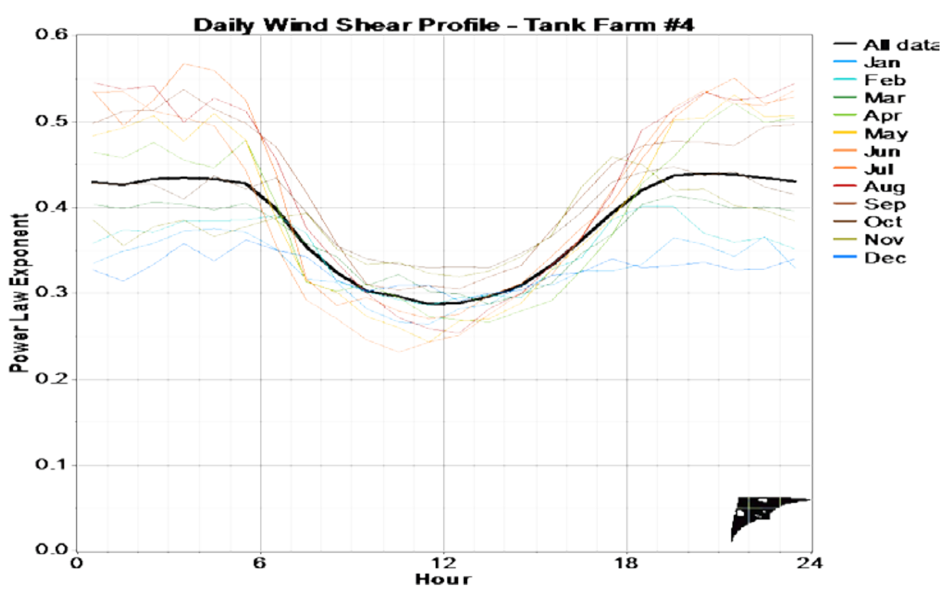

Figure 23. Daily wind shear profile by month at Tank Farm #4, April 1, 2010, to March 31, 2011

8.10 Turbulence Intensity

Turbulence intensity (TI) is the standard deviation of the wind speed within a time step divided by the mean wind speed over that same time step. TI is a measure of the gustiness of the wind. High turbulence is associated with increased wind turbine system wear and increased operation and maintenance (O&M) costs. At lower wind speeds, the calculated turbulence intensity is higher, as seen in Figure 24. However, the higher turbulence at low wind speeds is not a concern because of the low power available at those low wind speeds. Turbulence at higher winds speeds is of greater interest and concern to wind turbine manufacturers.

Turbulence analysis determines the suitable types of turbine designs for a wind energy project. Because wind turbines must withstand a variety of wind conditions, design standards have been developed by the International Electrotechnical Commission (IEC). The IEC 61400-1:2005[8] has two components—one for wind speed and one for turbulence—and can be seen in Table 10. The standard designates four different classes of wind turbines, I through IV, which are designed for varying degrees of wind resource, with Class I being very high mean wind speed and Class IV being low mean wind speed.

The standard also designates a wind turbulence classification, A through C, that describes the amount of turbulence a turbine must be designed to withstand, with A being the highest turbulence and C being the lowest. In recent years, wind turbine manufacturers have introduced designs for sites with lower wind speeds and low turbulence known as low wind speed turbines. These turbines have larger rotors, for a given generator size, and are thus capable of producing significantly more annual energy at a low wind speed site than the Class I or II or Class A or B turbines of similar generator size.

There are several types of TI of interest. The representative TI, for a set of 10-minute time steps, is equal to the 90th percentile of the TI values. Assuming a normal distribution of these values, it represents the mean value plus 1.28 standard deviations. The mean TI is the mean value of all of the TI data at a particular wind speed.

Table 10 displays design wind speed and mean turbulence intensity ratings for the different wind turbine design classes.

[8] International Electrotechnical Commission (IEC). "International Standard IEC 61400-1 Third Edition." Geneva, Switzerland: IEC, 2005.

Table 10. IEC Wind Turbine Classes, Ratings, and Characteristics of Turbulence Intensity[9]

WTG* Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind	IEC IV Low Wind
V_{ave} average wind speed at hub-height (m/s)	10	8.5	7.5	6
V_{50} extreme 50-year gust (m/s)	70	59.5	52.5	42
Mean turbulence intensity at 15 m/s - turbulence Class A	14% - 16%			
Mean turbulenceiIntensity at 15 m/s - turbulence Class B	12% - 14%			
Mean turbulence intensity at 15 m/s - turbulence Class C	0 - 12%			

* Wind Turbine Generator

Figure 24 shows the representative and mean TI as a function of wind speed at 58 m at Coddington Point.

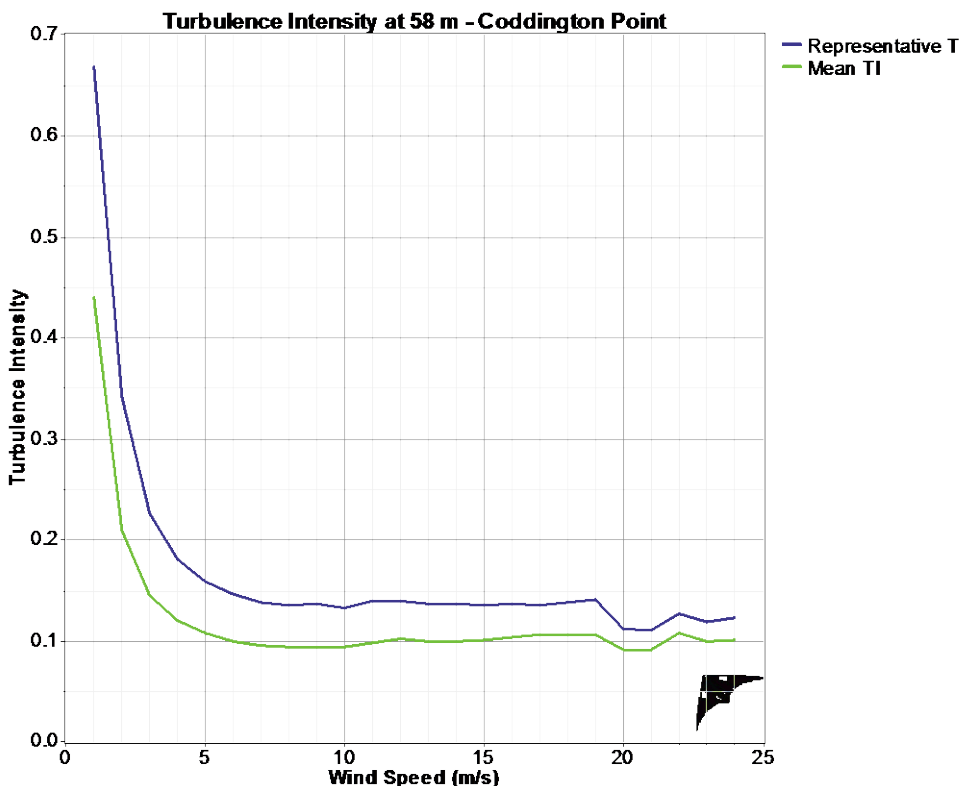

Figure 24. Representative and mean turbulence intensities for Coddington Point, April 1, 2010, to March 31, 2011

[9] IEC/TC88, 61400-1 ed. 3, Wind turbines - Part 1: Design Requirements, International Electrotechnical Commission (IEC), 2005.

Figure 25 shows the IEC turbulence ratings relative to the representative TI. A point of primary interest is the mean TI at 15 m/s, which is 0.101 (10.1%). This indicates low turbulence and that a Class C wind turbine is possible.

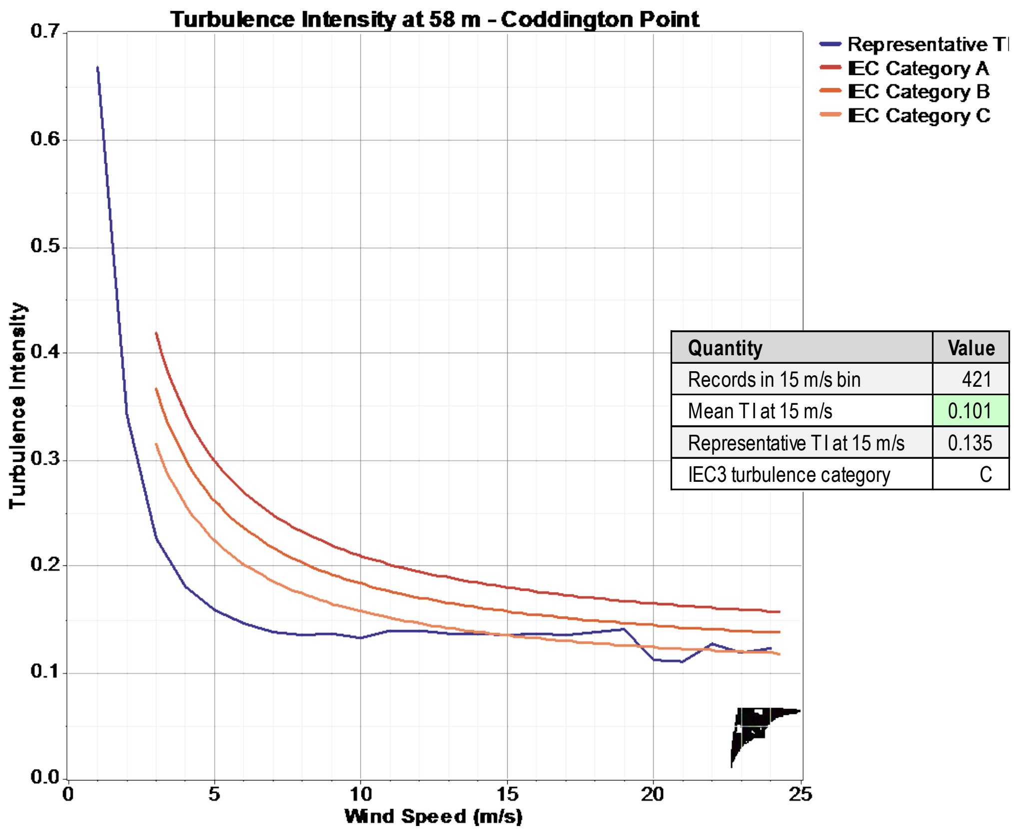

Figure 25. Turbulence intensity for Coddington Point at 58 m, April 1, 2010, to March 31, 2011

The same traits are graphed in Figure 26 for Tank Farm #4. The difference in the turbulence between these two sites can be seen readily in the Representative TI (blue line) in each graph. The impact of the turbulence findings is that a Class B wind turbine is most suitable for Tank Farm #4, which will result in lower annual energy production from a given manufacturer's turbines (Class B versus Class C).

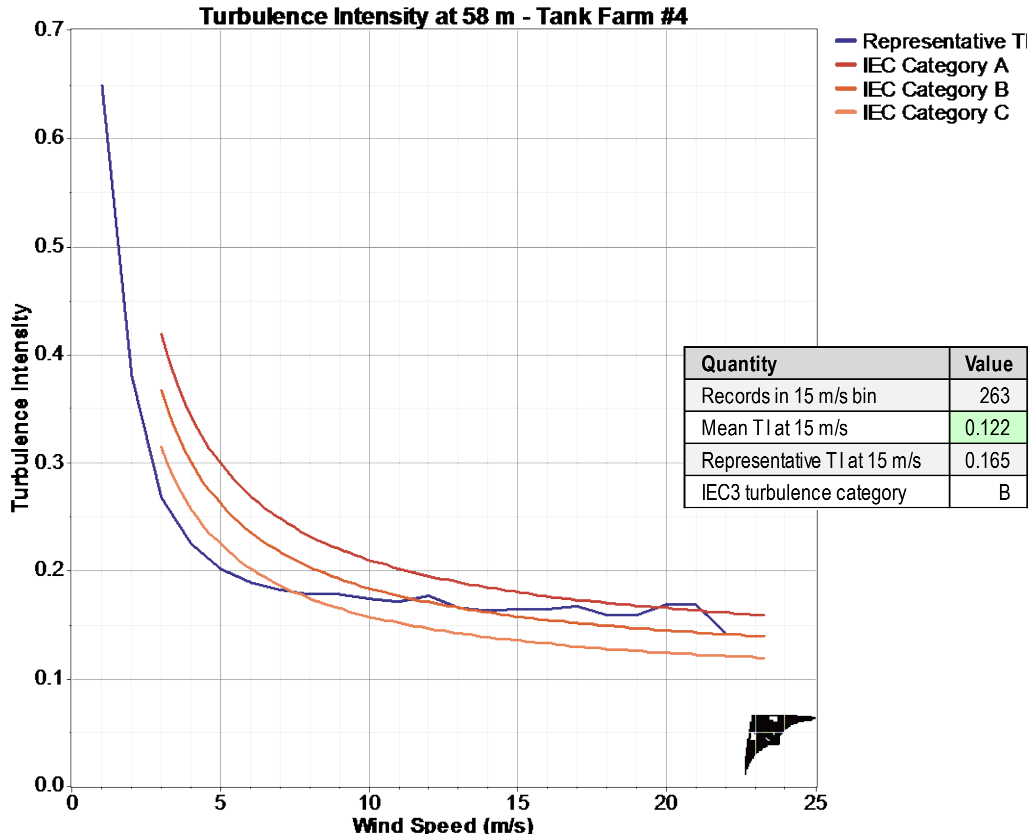

Figure 26. Turbulence intensity for Tank Farm #4 at 58 m, April 1, 2010, to March 31, 2011

Additional visual displays of the turbulence data and analyses can be seen in Appendix B.

8.11 Energy Production Potential of Coddington Point and Tank Farm #4

Using a full year of concurrent wind data collected at both Coddington Point and Tank Farm #4, along with the turbulence factors determined by analysis and the turbine height restrictions based on Federal Aviation Administration (FAA) permits, a comparative analysis of the energy production potential at these two sites was conducted to determine the viability of each site.

The maximum permitted height for each site is shown in Table 11. Based on the turbulence analysis in the previous section, a representative Class C wind turbine (low turbulence) was identified as appropriate for Coddington Point, and a similar Class B turbine was identified as appropriate for Tank Farm #4. A low wind speed turbine on an 80 m (263 ft) tower is in compliance with the FAA-permitted height at Coddington Point. A rotor designed for mid-range wind speeds and turbulence installed on a 64.7 m (212 ft) tower is in compliance with the FAA-permitted height at Tank Farm #4.

Table 11. FAA-Permitted Heights and Turbine Dimensions

Potential Turbine Site	Turbine Model #	FAA Height Limit m	Hub Height m	Blade Length m	Total Height m	FAA Height Limit ft	Hub Height ft	Blade Length ft	Total Height ft
Coddington Point	GE 1.5 xle	139.9	80.0	41.3	121.3	459	262.5	135.3	397.8
Tank Farm # 4 A	GE 1.5 sle	103.3	64.7	38.5	103.2	339	212.3	126.3	338.6
Tank Farm # 4 B	GE 1.5 sle	88.4	61.4	38.5	99.9	290	201.4	126.3	327.8

Table 12 and Table 13 show the results of the turbine energy outputs. An overall loss factor of 13.4% at each site was included in these calculations. The turbine at Coddington Point has been modeled to produce 748,000 kWh more per year than at Tank Farm #4, resulting in approximately $82,000 cost savings per year, or over $1.6 million over the 20-year expected life of the turbines. Given this differential, the energy production analysis for the base will focus on those sites with minimal FAA height restrictions.

Table 12. Coddington Point Energy Production with Low Wind Speed Class C Turbine

Coddington Point	**GE 1.5 xle**		**80 m tower**			
Month	**Hub Height Wind Speed (m/s)**	**Time at Zero Output (%)**	**Time at Rated Output (%)**	**Mean Net Power Output (kW)**	**Mean Net Energy Output (kWh/yr)**	**Net Capacity Factor (%)**
Jan	6.38	11.1	6.3	419.0	311,716	27.9
Feb	7.58	5.9	14.7	536.5	360,557	35.8
Mar	7.90	3.4	14.7	592.4	440,718	39.5
Apr	6.08	6.9	2.3	347.8	250,448	23.2
May	6.16	5.3	3.0	354.8	263,970	23.7
Jun	5.67	6.0	0.7	280.1	201,674	18.7
Jul	5.18	9.5	0.3	225.8	167,992	15.1
Aug	5.86	7.3	3.5	307.6	228,832	20.5
Sep	6.85	4.8	3.5	451.6	325,128	30.1
Oct	7.66	4.2	8.9	567.8	422,457	37.9
Nov	7.82	4.2	14.0	582.2	419,158	38.8
Dec	8.38	4.8	17.7	602.2	448,010	40.1
Overall	**6.79**	**6.1**	**7.5**	**438.9**	**3,844,637**	**29.3**

Table 13. Tank Farm #4 Energy Production with Medium Wind Speed Class B Turbine

Tank Farm #4		GE 1.5 s le		64.7m tower		
Month	**Hub Height Wind Speed (m/s)**	**Time at Zero Output (%)**	**Time at Rated Output (%)**	**Mean Net Power Output (kW)**	**Mean Net Energy Output (kWh/yr)**	**Net Capacity Factor (%)**
Jan	6.31	17.0	4.8	373.2	277,671	24.9
Feb	7.45	8.7	11.8	471.8	317,069	31.5
Mar	7.42	7.9	7.4	498.2	370,635	33.2
Apr	5.68	17.5	2.0	260.5	187,532	17.4
May	5.72	17.1	2.2	254.9	189,628	17.0
Jun	5.20	18.7	0.1	181.8	130,864	12.1
Jul	4.82	21.8	0.0	145.7	108,432	9.7
Aug	5.22	20.5	0.1	196.0	145,828	13.1
Sep	6.22	13.8	0.4	317.9	228,895	21.2
Oct	7.27	9.4	5.3	467.7	347,957	31.2
Nov	7.22	10.4	3.8	477.4	343,731	31.8
Dec	8.22	8.3	10.5	603.8	449,223	40.3
Overall	**6.39**	**14.3**	**4.0**	**353.4**	**3,095,995**	**23.6**

9 MiniSODAR Data

The miniSODAR was first deployed at Coddington Point at the South Pritchard Field site in February 2009 and was then moved to other locations at NAVSTA Newport, as shown in Table 4 in Section 6.4. The objective was to provide wind speed data throughout the span of the rotor to effectively compare the wind resource at potential turbine sites with varying surface roughness features. Analysis to date of the wind speed data from the miniSODAR does not correlate well with the data collected from the met towers, increasing the uncertainty of using the miniSODAR data for energy production estimates across the base.

10 Long-Term Data Adjustment

It is important to determine if the data monitoring period is representative of the long-term wind resource at the site. Different methodologies are used to estimate the long-term wind resource at the site where the short-term met tower study was conducted. A standard industry approach with a number of variations is measure-correlate-predict (MCP), where a short-term dataset is correlated to a long-term wind dataset from a nearby monitoring station (reference site). The correlation relationship is then applied to the measured data at the site of interest to project the expected long-term wind resource. An industry-standard MCP method, the ratio of the mean of monthly means, was used in this analysis.

The purpose of this estimate is to provide a normalized, realistic estimate of the long-term wind resource and the resultant wind turbine energy production. Though wind turbine production at any site will vary year-to-year, the goal is to have the long-term energy production estimate minimize the uncertainty of the relatively short period of collected data.

10.1 Long-Term Datasets

The Federal Aviation Administration (FAA) and National Weather Service (NWS) own and operate automated surface observing systems (ASOS) for the purposes of aviation and weather observation. These datasets generally represent the most consistent weather observation data as the FAA and NWS are tasked with building an historical long-term surface weather observation record. Other long-term weather observation datasets include military airfield observations, ocean buoy observations, and other forms of surface observations.

10.1.1 Wind Speed Sensor Change

Over the past decade, the NWS has replaced cup-type anemometers at ASOS stations with sonic anemometers to improve data capture rates, data recovery, and measurement reliability. These two wind speed measurement sensors, however, do not uniformly record the same wind speeds. Industry analysis of this issue has resulted in widespread acceptance of using a correction factor of 3% to increase the wind speed readings of the sonic anemometers relative to either cup or propeller anemometers.[10]

Four long-term reference stations are within an 8.5-mile radius of the Coddington Point met tower. The monthly data recovery rates for these stations were examined for site suitability. Two of the sites did not have records that overlapped the met tower observation period and thus were automatically excluded. Site #725074, Quonset State Airport in Rhode Island, had an average data recovery rate of 39.3% over the met tower observation period, which is insufficient to provide adequate confidence in long-term wind adjustments. Thus, Site #725079, Newport State Airport, was used for the MCP analysis. Figure 27 shows the data recovery rates from 1998 to 2011.

[10] ams.confex.com/ams/pdfpapers/69268.pdf. Accessed August 2011.

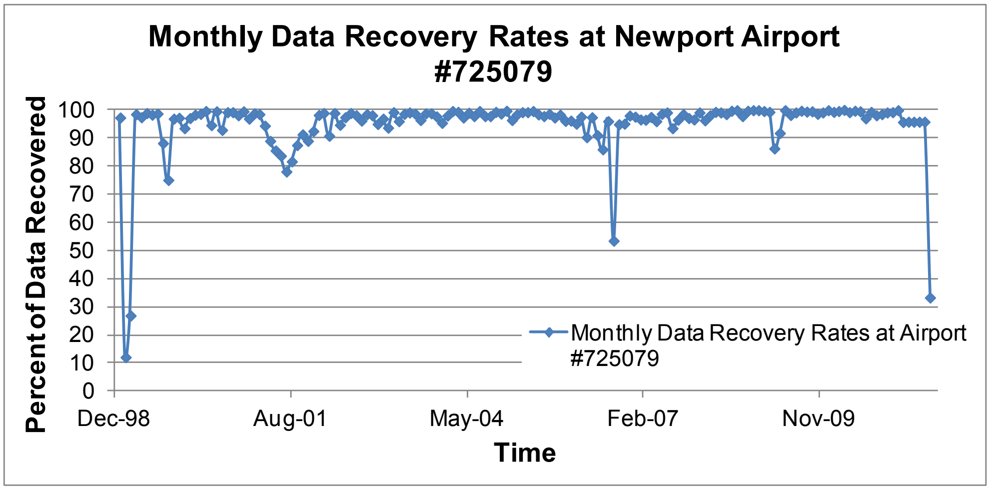

Figure 27. Monthly data recovery rates at Newport Airport, December 1998–March 2011

10.1.2 Newport Airport Data

Newport Airport (ASOS) is approximately 2.5 miles from the Coddington Point met tower location and had a monthly average data recovery rate over 98% for the period of 1998 to 2011. The anemometer is mounted at 10 m above ground level (AGL). Several months had significant periods of missing data due to instrumentation changes or other issues. Data from months where data recovery rates were below 85% were not used in the MCP process. However, those monthly averages were replaced with the average of all of the same months from all other available years with sufficient data recovery rates so as not to skew the yearly averages.

As mentioned earlier, ASOS stations have undergone a fleet-wide upgrade to sonic anemometers in recent years. At Newport Airport, the change in anemometry occurred on September 26, 2006.[11] Data collected on or after that date have been adjusted upward by 3% according to standard industry practice. The revised long-term annual mean wind speeds can be seen in Figure 28.

[11] Lewis, R.; Dover, J.; Field and Operational Tests of a Sonic Anemometer for the Automated Surface Observing System. http://www.nws.noaa.gov/asos/pdfs/IFW_stat.pdf. Accessed August 2011.

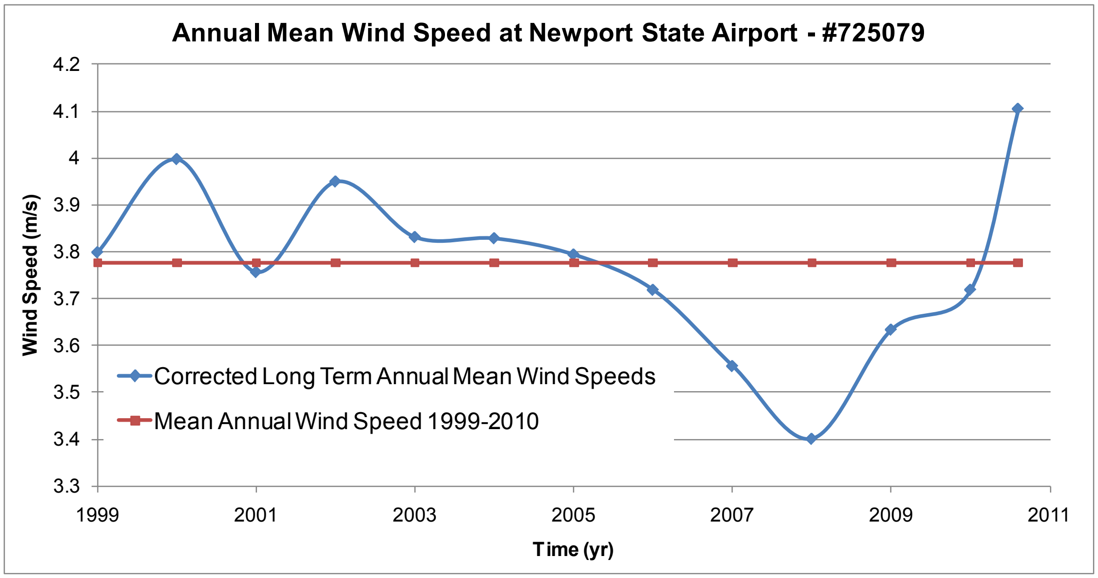

Figure 28. Corrected long-term annual mean wind speeds and overall mean annual wind speed at Newport Airport, January 1, 1999, to March 31, 2011

Note: 2011 includes data through March 31, 2011

In the graph in Figure 29, the collected data from Coddington Point is displayed relative to the collected data during the same timeframe at Newport Airport. Also shown is the long-term monthly means at Newport Airport during each of the months the Coddington Point met tower was collecting data. Visually, the sites represent similar winds based on the similarity in their patterns over time, though it should be noted that the Newport Airport met tower is at 10 m versus 25, 40, and 60 m at Coddington Point; thus, the magnitude of the winds are much lower at Newport Airport than at Coddington Point.

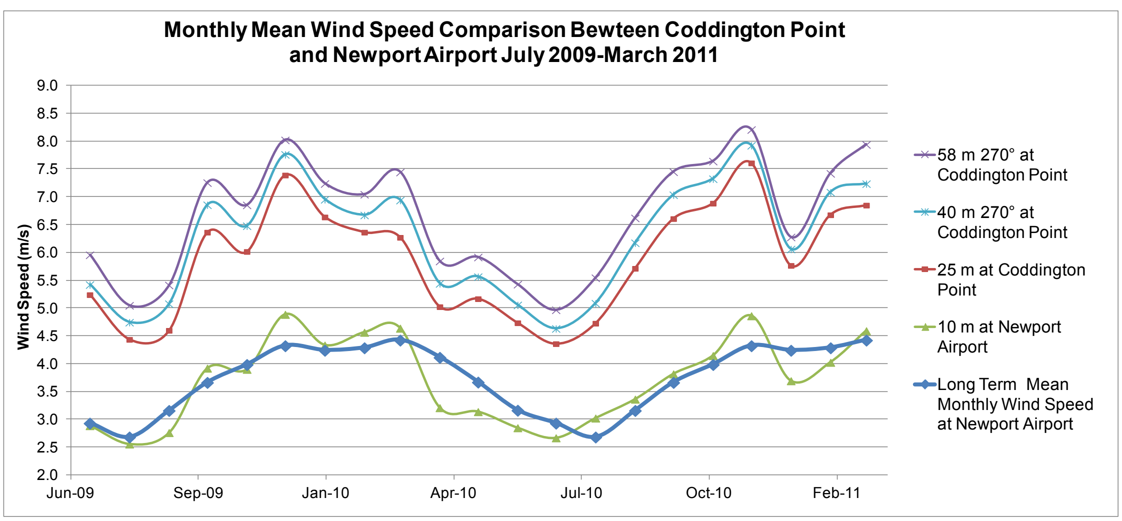

Figure 29. Collected data at Coddington Point versus collected and long-term data at Newport Airport

10.1.3 Measure-Correlate-Predict

With the long-term data at Newport Airport adjusted for the wind sensor change out, the data was examined to determine if the period of collection (at Coddington Point and Newport Airport) represents a normal, higher-than-normal, or lower-than-normal wind year. The MCP method employed to analyze the data used the *ratio of the mean of monthly means* approach. This method involves using the ratio of the monthly means of the long-term data to the monthly means during the period of collection to determine a monthly adjustment factor to be applied to the measured data at Coddington Point, so it will represent long-term data trends and characteristics.

In Table 14, the "Ratio of Monthly Means" column is the ratio of the long-term monthly means at Newport Airport to the monthly means during the data collection period at Newport Airport. That ratio is multiplied by the monthly means during the data collection period from Coddington Point at 40 m and 58 m. The results in the two columns at the far right represent the expected long-term mean monthly wind speed at 40 m and 58 m at Coddington Point. These adjusted wind speeds are used in the wind flow modeling and energy production estimates in Section 11.

Table 14. Newport Airport and Coddington Point Data Adjusted to Long-Term Trends

Station	Newport Airport		Ratio of Monthly Means	Coddington Point		Coddington Point Adjusted WS	
Height	WS @ 10 m	WS @ 10 m		WS @ 40 m	WS @ 58 m	WS @ 40 m	WS @ 58 m
Period	7/09 - 3/11	1/99 - 3/11		7/09 - 3/11	7/09 - 3/11	Long-Term Mean	Long-Term Mean
Unit	m/s	m/s		m/s	m/s	m/s	m/s
Jul-09	2.89	2.93	1.02	5.42	5.96	5.51	6.05
Aug-09	2.56	2.68	1.05	4.75	5.05	4.98	5.30
Sep-09	2.76	3.16	1.14	5.08	5.42	5.81	6.19
Oct-09	3.92	3.66	0.93	6.86	7.26	6.41	6.78
Nov-09	3.90	3.99	1.02	6.48	6.86	6.62	7.01
Dec-09	4.89	4.32	0.88	7.76	8.02	6.87	7.10
Jan-10	4.34	4.24	0.98	6.96	7.24	6.81	7.08
Feb-10	4.57	4.29	0.94	6.67	7.05	6.27	6.62
Mar-10	4.64	4.43	0.95	6.94	7.45	6.62	7.10
Apr-10	3.21	4.12	1.28	5.44	5.85	6.98	7.49
May-10	3.14	3.67	1.17	5.57	5.92	6.51	6.92
Jun-10	2.85	3.16	1.11	5.06	5.43	5.62	6.03
Jul-10	2.67	2.93	1.10	4.63	4.97	5.09	5.46
Aug-10	3.02	2.68	0.89	5.09	5.55	4.52	4.92
Sep-10	3.36	3.16	0.94	6.17	6.62	5.80	6.22
Oct-10	3.82	3.66	0.96	7.04	7.45	6.75	7.15
Nov-10	4.15	3.99	0.96	7.33	7.64	7.04	7.35
Dec-10	4.86	4.32	0.89	7.93	8.21	7.05	7.30
Jan-11	3.70	4.24	1.15	6.06	6.28	6.96	7.21
Feb-11	4.03	4.29	1.06	7.08	7.42	7.54	7.90
Mar-11	4.59	4.43	0.96	7.24	7.94	6.97	7.65

Figure 30 illustrates graphically the adjustment to the Coddington Point data through the MCP analysis. With this adjustment, the data is now representative of the local long-term wind trends.

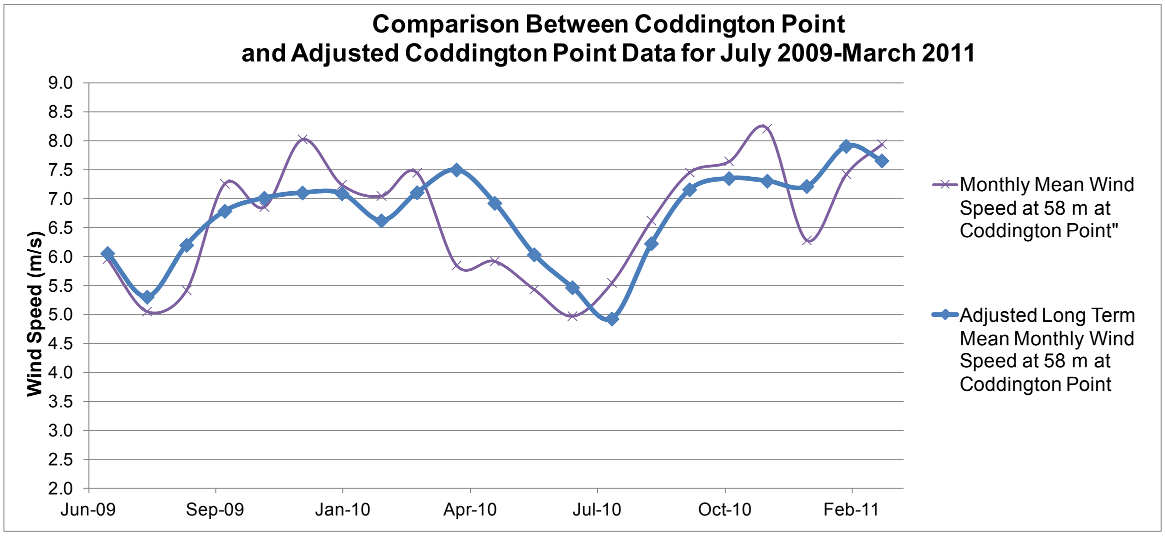

Figure 30. Comparison of Coddington Point data with the MCP adjusted wind data, July 1, 2009, to March 31, 2011

11 Energy Production Estimates

This section discusses the potential energy generation from wind turbines at NAVSTA Newport. Several layout scenarios and turbine types were evaluated using a common wind flow model and wake model approach. The approximately 9 MW project scenarios result in a spread of approximately 24–30 GWh/yr of energy production and capacity factors of 30%–36%. A full economic analysis is recommended, but this is generally considered a moderate to good production potential when held in the context of local energy costs.

Analysis was conducted for a larger build out by assuming the siting of utility-scale turbines at every viable site. The results of these analyses can be found in Appendix D.

11.1 Wind Turbines Modeled

A broad range of utility-scale wind turbine models were selected to represent potential project scenarios at NAVSTA Newport. These turbines were selected based upon IEC turbine type as well as general availability and access to the power curves. These turbines generally represent low wind and moderate wind classifications. The range of turbines is generally intended to showcase the available turbines with large nameplate capacities (1.6 MW or greater) as well as the new generation of low wind machines, which couple an enlarged rotor with a standard generator. All power curves were for sea level air density at 1.225 kg/m^3. The turbine models are shown in Table 15.

Table 15. Wind Turbine Specifications Used in Modeling

Turbine Manufacturer, Size, and Model	Nameplate Capacity MW	Turbine Class #	Hub Height m	Rotor Span m	Max Height m	Max Height ft	9 MW Scenario # turbines
Siemens 2.3 MW 101	2.3	III	80	101	130.5	428	4
GE 1.6 XLE-100	1.6	III	80	100	130	427	6
RePower MM100	1.8	III	80	100	130	427	5
Vestas V100 1.8 MW	1.8	III	80	100	130	427	5
Alstom ECO 110 3.0 MW	3	IIa	75	110	130	427	3
Nordex N100	2.5	III	80	100	130	427	4
Vestas V112 3.0 MW	3	III	84	112	140	459	3

11.2 Site Layout

Overall, 16 available sites were evaluated for turbine installation given the available FAA determination of no hazard (DNH) filings. Many sites were eliminated from this review because their DNH height restriction was well below the level of all utility-scale turbines under review for this project. NREL recommends working with the FAA and local air space managers to further investigate the viability of height restriction easing should NAVSTA Newport feel the remaining available sites are insufficient. Table 16 includes a list of all FAA DNH sites along with their respective total heights.

Table 16. FAA-Approved Heights at Each Site

Site Name	Lat (NAD 83)				Long(NAD 83)							
	Deg	Min	Sec	Zone	Deg	Min	Sec	Zone	FAA - AGL*	FAA - AMSL**	Site Elevation - ASL***	Max Turbine Height
	°	'	"	dir	°	'	"	dir	m	m	m	m
Coddington Point Bishop Rock	41	31	3.56	N	71	19	49.86	W	139.9	143.0	3.0	139.9
Building 6/ Derecktor Shipyard	41	31	29.47	N	71	18	41.00	W	102.1	106.7	4.6	102.1
Coddington Point Bldg 1112	41	31	22.73	N	71	19	24.95	W	139.9	152.1	12.2	139.9
Bldg 1285 CP	41	31	11.38	N	71	18	58.14	W	105.2	106.7	1.5	105.2
Katy Field	41	30	50.00	N	71	19	40.47	W	139.9	144.5	4.6	139.9
NUWC	41	32	12.55	N	71	18	26.74	W	89.6	106.7	17.1	89.6
Pritchard Field North	41	31	9.17	N	71	19	38.30	W	139.9	144.5	4.6	139.9
Pritchard Field South	41	31	3.04	N	71	19	37.11	W	139.9	143.0	3.0	139.9
Coastal Harbor Island Helipad	41	30	14.28	N	71	19	33.91	W	139.9	144.5	4.6	139.9
Tank Farm 3	41	34	11.98	N	71	17	16.06	W	88.4	115.5	27.1	88.4
Tank Farm 3 A	41	34	16.60	N	71	17	18.38	W	93.6	115.5	21.9	93.6
Tank Farm 4 A	41	33	53.14	N	71	17	40.62	W	103.3	115.5	12.2	103.3
Tank Farm 4 B	41	33	53.60	N	71	17	25.48	W	88.4	115.5	27.1	88.4
Tank Farm 5	41	33	8.05	N	71	18	17.24	W	90.2	103.3	13.1	90.2
Tank Farm 5 C	41	32	52.79	N	71	18	12.49	W	64.3	93.0	28.7	64.3
W36 CP	41	30	42.04	N	71	19	20.66	W	139.9	146.0	6.1	139.9

*FAA AGL is the FAA Above Ground limit

**FAA AMSL is the FAA Above Mean Sea Level limit

***Above Sea Level

Table 17 shows the viable FAA sites based upon turbine maximum tip height. These figures assumed the standard tower for each turbine—typically 80 m (262 ft). The selected turbines represent a reasonable sampling of IEC Class II and III wind turbines with IEC Turbulence Class C rating. Overall, there are seven sites that can accommodate these turbines. The turbine selection here by no means represents an endorsement of a particular wind turbine over another suitability-rated turbine. There are a number of other factors to consider in the turbine selection process, including cost, availability, constructability, transportability, warranty, the types of other proximal wind turbines, and O&M.

Table 17. Total Wind Turbine Heights Compared to FAA-Approved Heights

Site Name	Maximum Turbine Height	Siemens 2.3 MW 101	GE 1.6 XLE	RePower MM100	Vestas V100 1.8 MW	Alstom ECO 110	Nordex N100	Vestas V112 3.0 MW
	m	m	m	m	m	m	m	m
Coddington Point Bishop Rock	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Building 6/ Derecktor Shipyard	102.1	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Coddington Point Bldg 1112	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Bldg 1285 CP	105.2	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Katy Field	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
NUWC	89.6	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Pritchard Field North	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Pritchard Field South	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Coastal Harbor Island Helipad	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 3	88.4	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 3 A	93.6	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 4 A	103.3	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 4 B	88.4	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 5	90.2	130.5	130.1	130.1	130.1	130.1	130.1	139.9
Tank Farm 5 C	64.3	130.5	130.1	130.1	130.1	130.1	130.1	139.9
W36 CP	139.9	130.5	130.1	130.1	130.1	130.1	130.1	139.9

Color Key: Green is a viable FAA Site, Red is not a viable FAA site, Orange may be in violation of FAA DNH

Table 18 outlines the preferred sites and turbines for the various project scenarios for an installed nameplate capacity of 9 MW at NAVSTA Newport.

Table 18. Recommended Turbine Per Project Size Parameter of 9 MW

Index	Site	Easting [m]	Northing [m]	Applicable Turbine Models	Total Project Size
Preferred 3 Turbine Setup					
Index	**Site**	**Easting [m]**	**Northing [m]**	**Applicable Turbine Models**	**Total Project Size**
1	Coddington Point Bishop Rock	305533.93	4598846.67	Vestas V112 3.0MW	9 MW
2	Coddington Point Bldg 1112	306127.02	4599422.36	Alstom ECO 110	9 MW
3	Katy Field	305740.56	4598422.58		
Preferred 4 Turbine Setup					
Index	**Site**	**Easting [m]**	**Northing [m]**	**Applicable Turbine Models**	**Total Project Size**
1	Coddington Point Bishop Rock	305533.93	4598846.67		
2	Coddington Point Bldg 1112	306127.02	4599422.36	Nordex N100 2.5 MW	10 MW
3	Pritchard Field North	305807.48	4599012.45	Siemens 2.3 MW	9.2 MW
4	Katy Field	305740.56	4598422.58		
Preferred 5 Turbine Setup					
Index	**Site**	**Easting [m]**	**Northing [m]**	**Applicable Turbine Models**	**Total Project Size**
1	Coddington Point Bishop Rock	305533.93	4598846.67		
2	Coddington Point Bldg 1112	306127.02	4599422.36	Vestas V100 1.8 MW	9 MW
3	Pritchard Field North	305807.48	4599012.45	RePower MM100 1.8MW	9 MW
4	Katy Field	305740.56	4598422.58		
5	Building 6/ Dereckter Shipyard	307152.42	4599602.88		
Preferred 6 Turbine Setup					
Index	**Site**	**Easting [m]**	**Northing [m]**	**Applicable Turbine Models**	**Total Project Size**
1	Coddington Point Bishop Rock	305533.93	4598846.67		
2	Coddington Point Bldg 1112	306127.02	4599422.36		
3	Pritchard Field North	305807.48	4599012.45	GE 1.6 XLE-100	9.6 MW
4	Katy Field	305740.56	4598422.58		
5	Building 6/ Derektor Shipyard	307152.42	4599602.88		
6	Building 1283/ Navy Lodge	306740.20	4599055.59		
7 Turbine Setup (All)					
Index	**Site**	**Easting [m]**	**Northing [m]**	**Applicable Turbine Models**	**Total Project Size**
1	Coddington Point Bishop Rock	305533.93	4598846.67		
2	Coddington Point Bldg 1112	306127.02	4599422.36		
3	Pritchard Field North	305807.48	4599012.45		
4	Katy Field	305740.56	4598422.58	All Turbines	9-10 MW
5	Building 6/ Derektor Shipyard	307152.42	4599602.88		
6	Building 1283/ Navy Lodge	306740.20	4599055.59		
7	Pritchard Field South	305830.20	4598822.64		

Note: Green shading represents viable turbine(s) at the selected sites

11.3 Energy Production Loss Factors

All energy projects will incur some type of energy loss due to real-world conditions differing from the idealized case. The resulting decrease in efficiency is often accounted for by a series of estimated and calculated loss factors. The loss factors for the NAVTSA project include:

- **Array efficiency:** This loss parameter is associated with the wakes created by the turbines. This results in a decrease in wind speed and increase in turbulence as the wind moves through the wind farm array. This is a value calculated by the OpenWind[12] wind farm design model.

[12] OpenWind, AWSTruepower, http://www.awsopenwind.org/. Accessed August 4, 2011.

- **Topographic efficiency:** This parameter relates to the increase or decrease in wind resource across the project due to topographic influences. This can be a positive or negative value and is dependent on the location of the meteorological measurements along with the model used to predict flow across the site. See Section 11.4 for further discussion of the modeling approach used.
- **Turbine availability:** This term accounts for the expected downtime a wind turbine will experience during its annual operation. This includes routine maintenance, faults, and any component failures. Turbine availability or uptime is typically covered in the manufacturer's warranty terms with a value of 95% or greater.
- **Electrical:** Electrical losses occur in the process of collecting and transmitting the project energy across the site. As the power moves through the transformers and collection system, a certain percentage will be lost as heat. This value is typically estimated at 2%.
- **Hysteresis:** This is the term for when a turbine shuts down to protect itself from ambient climate events that are outside of the design envelope. This typically involves a high wind event that forces the turbine to shut down for a predetermined amount of time. The NAVSTA site did not show any evidence of regular high wind events and therefore is not expected to incur losses from hysteresis.
- **Environmental:** Environmental losses occur because of ambient conditions that may affect blade aerodynamics or turbine operation. This includes icing, blade soiling, insect accumulation, and extreme cold or hot events. This is expected to happen at NAVSTA and is anticipated to be on the order of 1%.
- **Operational:** All operational energy requirements such as power for the control system, heating system, and other parasitic loads.
- **Power curve variation:** The power curve may deviate from the manufacturer-stated designation due to yaw system misalignment, incorrect programming, or ambient weather events such as high turbulence or variations in atmospheric stability. This was not believed to be an issue for NAVSTA.
- **Sector management:** Sector management can be required if the wind rose has multiple directions that affect the turbine layout.
- **Substation downtime:** The collection substation on the NAVSTA Newport side of the utility interconnection will likely require some downtime for routine maintenance. This is estimated at 0.5% for NAVSTA.
- **Utility downtime:** Utility transmission and distribution uptime or availability is generally very high. However, there are certain areas of the country or seasons of the year with more risk. The NAVSTA site is assumed to experience energy loss of 0.5% due to the utility electrical system being unavailable for power transmission.

Table 19 lists the range of efficiencies used to determine wind turbine energy production. The bottom row provides an estimate of the net productive efficiency of each turbine in the 9 MW scenarios.

Table 19. Site Production Annual Loss Factors for the 9 MW Scenario

		Turbine Manufacturer /Model						
Characteristic	**Unit**	**Siemens 2.3 MW 101**	**GE 1.6 XLE**	**RePower MM100**	**Vestas V100 1.8 MW**	**Alstom ECO 110**	**Nordex N100**	**Vestas V112 3.0 MW**
Maximum Blade Tip Height	ft	428	427	427	427	427	427	459
*Array Efficiency	%	94.47	95.25	95.67	96.94	94.59	95.82	96.91
*Topographic Efficiency	%	97.90	96.76	97.27	97.23	97.88	97.25	97.12
Turbine Availability	%	95.00	95.00	95.00	95.00	95.00	95.00	95.00
Plant Electrical Efficiency	%	98.00	98.00	98.00	98.00	98.00	98.00	98.00
Hysteresis	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Environmental	%	99.00	99.00	99.00	99.00	99.00	99.00	99.00
Operational	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Power Curve Variation	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sector Management	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Substation Maintenance	%	99.50	99.50	99.50	99.50	99.50	99.50	99.50
Utility Downtime	%	99.00	99.00	99.00	99.00	99.00	99.00	99.00
Total Losses	%	**16.02**	**16.33**	**15.51**	**14.42**	**15.93**	**15.39**	**14.55**
Net Production	**%**	**83.98**	**83.67**	**84.49**	**85.58**	**84.07**	**84.61**	**85.45**

*Calculated Loss factor

11.4 Site Climatology

NREL evaluated the available sites by creating a wind flow model of the project area. This project area is composed of the viable turbine sites per Section 11.2. The wind flow model was created using the Wind Atlas Analysis and Application Program[13] (WAsP) from Risø Technical University of Denmark. WAsP is a linearized formulation of the Reynolds Averaged Navier Stokes (RANS) equations. WAsP can account for moderate changes in terrain and surface roughness when used in conjunction with measured met data. WAsP provides a map of wind speed up and slow down relative to the measurement location known as a wind resource grid. In this way, estimates of the general performance of potential turbine sites across the project area are derived. This analysis employed terrain information from the National Elevation Dataset[14] (NED), along with aerial imagery from the National Agriculture Imagery Program[15] (NAIP). The WAsP model was run with a horizontal grid resolution of 25 m and an elevation of 80 m above ground level. Figure 31 shows the 80 m hub height mean wind speed map for all direction sectors.

[13] WAsP – Wind Atlas Analysis and Application Program. Software – WasP Version 10.01.0100. http://www.wasp.dk/index_old.htm. Accessed August 2, 2011.
[14] National Elevation Dataset, U.S. Geological Survey. http://ned.usgs.gov/. Accessed August 2, 2011.
[15] National Agriculture Imagery Program, Farm Service Agency, U.S. Department of Agriculture, http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai. Accessed August 2, 2011.

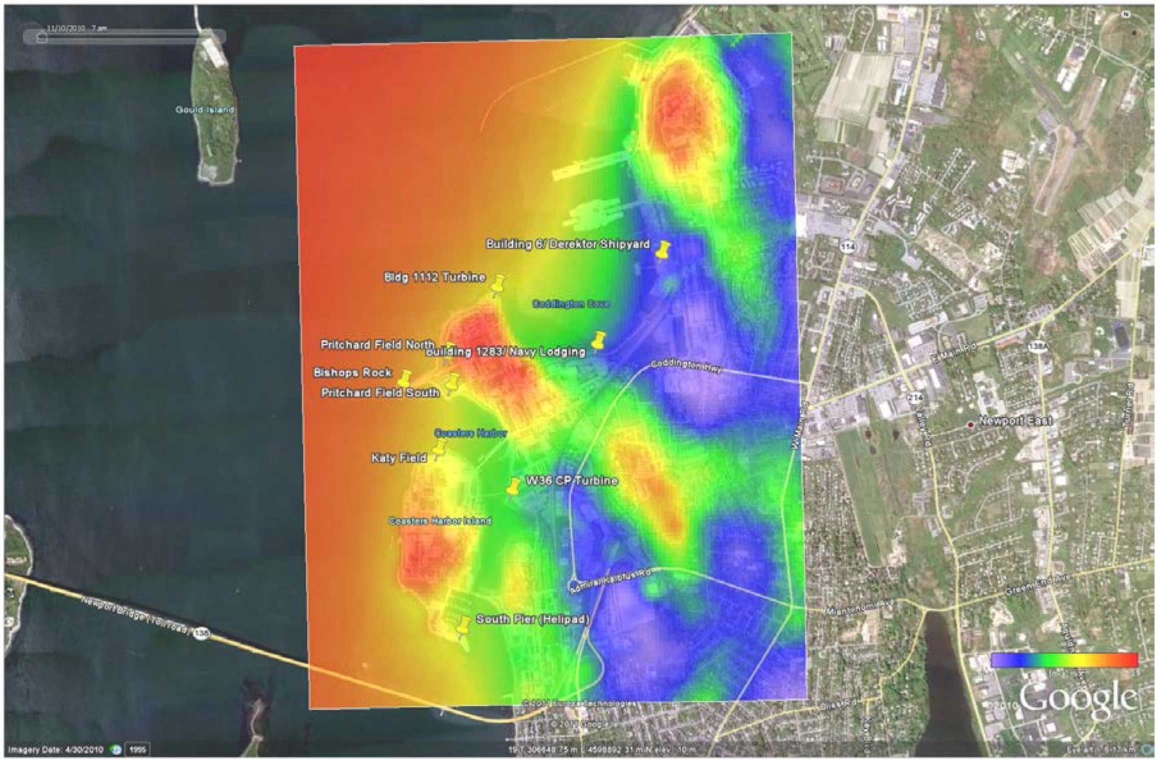

Figure 31. Wind speed map of NAVSTA Newport based on data collected on site

11.5 Wake Modeling and Energy Production

The open source wind farm design tool, OpenWind,[16] was used to estimate the wake losses and energy production from multiple turbine layout scenarios. OpenWind uses the combination of terrain, wind data, turbine power, and thrust curves to calculate wake losses and energy production on an annual per turbine basis. For this analysis, the two-dimensional eddy viscosity wake model calculation, along with a wind resource grid and frequency distribution information from WAsP was used to estimate wake effects.

For comparative purposes, two project scenarios were evaluated as part of this analysis. Scenario 1 assumes the installation of a utility-scale turbine at each of the seven sites with adequate FAA height clearance. Scenario 2 represents a 9 MW nameplate capacity wind project with selected turbines at selected sites. These scenarios are explained in more detail in Section 11.2. Table 20 shows the energy production for all turbine models side-by-side for Scenario 1. It indicates that the larger turbines will produce more power at a smaller number of sites because of their larger nameplate capacity but will not necessarily be as efficient at converting low winds into energy as the smaller machines.

Also shown in the table are gross and net annual energy production (AEP) estimates. Net AEP is estimated in the range of 33.9–53.8 Wh/yr, which represents 29%–45% of the

[16] OpenWind Version 00.09.00.0900, AWS TrueWind, http://www.awsopenwind.org/.

annual electricity consumption at NAVSTA Newport (approximately 105 GWh/yr).[17] The net capacity factors range from 27.2%–34.8%.

Table 20. Annual Energy Production Figures for One Wind Turbine at Each of the Seven Sites at NAVSTA Newport

Characteristics	Unit	7 Turbines - All Sites Scenario						
WTG* Manufacturer		Siemens	GE	Vestas	Vestas	Nordex	REPower	Alstom
WTG Model	#	2.3 MW	XLE 100	V100	V112	N100	MM100	ECO 110
WTG Capacity	MW	2.3	1.6	1.8	3.0	2.5	1.8	3.0
WTG Hub Height	m	80	80	80	80	80	80	80
WTG Rotor Diameter	m	101	100	100	112	100	100	110
Array Size	#	7	7	7	7	7	7	7
Site Capacity	MW	16.10	11.20	12.60	21.00	17.50	12.60	21.00
Ideal Yield	GWh/yr	54.73	43.55	48.58	70.43	56.14	49.16	65.78
Gross AEP Central Estimate	GWh/yr	52.29	41.73	46.59	67.32	53.60	47.14	62.76
Net AEP Central Estimate	GWh/yr	42.02	33.91	37.83	53.79	43.15	38.39	50.07
Net Capacity Factor	%	29.79	34.56	34.28	29.24	28.15	34.78	27.22

*WTG = Wind Turbine Generator; AEP = Annual Energy Production

Table 21 shows the energy production for all turbine models side-by-side for Scenario 2. It shows the estimated AEP figures of the project scenarios targeting approximately 9 MW of wind capacity. This table highlights the potential real-world scenarios and the resulting energy production.

Net AEP is estimated to be in the 23.7–30.0 GWh/yr range, which represents 22%–29% of the annual electricity consumption at NAVSTA Newport (approximately 105 GWh/yr).[18] The net capacity factors range from 30.0%–36.4%.

Table 21. Annual Energy Production Figures for Approximately 9 MW of Wind at NAVSTA Newport

Characteristics	Unit	~9 MW Scenario						
WTG* Manufacturer		Siemens	GE	Vestas	Vestas	Nordex	REPower	Alstom
WTG Model	#	2.3 MW	XLE 100	V100	V112	N100	MM100	ECO 110
WTG Capacity	MW	2.3	1.6	1.8	3.0	2.5	1.8	3.0
WTG Hub Height	m	80	80	80	80	80	80	80
WTG Rotor Diameter	m	101	100	100	112	100	100	110
Array Size	#	4	6	5	3	4	5	3
Site Capacity	MW	9.20	9.60	9.00	9.00	10.00	9.00	9.00
Ideal Yield	GWh/yr	31.27	37.33	34.70	30.19	32.08	35.11	28.19
Gross AEP Central Estimate	GWh/yr	30.79	35.65	33.50	29.56	31.57	33.89	27.59
Net AEP Central Estimate	GWh/yr	25.74	30.05	28.35	25.36	26.44	28.73	23.67
Net Capacity Factor	%	31.93	35.73	35.95	32.17	30.18	36.44	30.02

*WTG = Wind Turbine Generator; AEP = Annual Energy Production

[17] FY 2009 data from Reichert, J. Email. NAVSTA Newport, Newport, RI, 14 February 2011.
[18] FY 2009 data from Reichert, J. Email. NAVSTA Newport, Newport, RI, 14 February 2011.

12 Conclusions and Recommendations

12.1 Conclusions

The wind resource assessment campaign has resulted in a much better understanding of the wind resource available at NAVSTA Newport.

The wind data collected at the Coddington Point and Tank Farm #4 met towers provided an effective dataset for comparative analysis. Due to the differences in the wind resource and the FAA-imposed height restrictions, the assessment focused on the energy production potential of the FAA-approved 80 m sites on or near Coddington Point and Coasters Harbor Island.

Table 22 provides the estimated AEP figures of the project scenarios targeting approximately 9 MW of wind capacity. Net AEP is estimated to be in the 23.7–30.0 GWh/yr range, which represents 22%–29% of the annual electricity consumption at NAVSTA Newport (approximately 105 GWh/yr). The net capacity factors range from 30.0%–36.4%.

Table 22. Annual Energy Production Figures for Approximately 9 MW of Wind at NAVSTA Newport

Characteristics	Unit	~9 MW Scenario						
WTG* Manufacturer		Siemens	GE	Vestas	Vestas	Nordex	REPower	Alstom
WTG Model	#	2.3 MW	XLE 100	V100	V112	N100	MM100	ECO 110
WTG Capacity	MW	2.3	1.6	1.8	3.0	2.5	1.8	3.0
WTG Hub Height	m	80	80	80	80	80	80	80
WTG Rotor Diameter	m	101	100	100	112	100	100	110
Array Size	#	4	6	5	3	4	5	3
Site Capacity	MW	9.20	9.60	9.00	9.00	10.00	9.00	9.00
Ideal Yield	GWh/yr	31.27	37.33	34.70	30.19	32.08	35.11	28.19
Gross AEP Central Estimate	GWh/yr	30.79	35.65	33.50	29.56	31.57	33.89	27.59
Net AEP Central Estimate	GWh/yr	25.74	30.05	28.35	25.36	26.44	28.73	23.67
Net Capacity Factor	%	31.93	35.73	35.95	32.17	30.18	36.44	30.02

*WTG = Wind Turbine Generator; AEP = Annual Energy Production

Overall, the wind resource at the selected sites at NAVSTA Newport is sufficient for a wind turbine project. There are a number of other factors to consider before turbine selection is undertaken, including cost, availability, constructability, and transportability. There are also a number of other factors still to be explored as the parameters of this project become more clearly defined, including financing, National Environmental Protection Act (NEPA), electrical interconnection, constructability, subsoil/foundations, impact on neighbors, and transportation planning.

12.2 Recommendations

There are a number of tasks ahead to continue to move this project forward, including:

- NAVSTA Newport to complete the NEPA evaluation already underway
- NREL/DNV to complete an electrical interconnection study
- Complete the economic feasibility study
- Complete the transportation and logistics study

Appendix A. Met Tower Sensors

Met tower components for NAVSTA Newport at Coddington Point and Tank Farm #4:

- **NRG Systems 60 m XHD Tower:**
  - Six NRG Systems #40C anemometers (item 1899)
  - Two NRG Systems #200P wind vanes (item 1904)
  - One NRG Systems #110S temperature sensor (item 1906)
  - One Symphonie*PLUS*® data logger (item 4289)
- **NRG Systems #40C Anemometer** (item: 1899). The NRG Systems #40C Maximum anemometer is the industry standard anemometer used worldwide. NRG Systems #40C anemometers have recorded wind speeds of 96 m/s (214 mph). Their low moment of inertia and unique bearings permit very rapid response to gusts and lulls. Because of their output linearity, these sensors are ideal for use with various data retrieval systems. A four-pole magnet induces a sine wave voltage into a coil producing an output signal with a frequency proportional to wind speed. The #40C is constructed of rugged Lexan cups molded in one piece for repeatable performance. A rubber terminal boot is included.

Figure A-1. Anemometer #40C NRG Systems (item 1899)[19]

- **NRG Systems #200P Wind Direction Vane, 10K** (item: 1904). The NRG Systems #200P wind direction vane is the industry standard wind direction vane used worldwide. The thermoplastic and stainless steel components resist corrosion and contribute to a high strength-to-weight ratio. The vane is directly connected to a precision conductive plastic potentiometer located in the main body. An analog voltage output directly proportional to the wind

[19] Photo courtesy of NRG Systems, Inc. http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

direction is produced when a constant DC excitation voltage is applied to the potentiometer. A rubber terminal boot is included.

Figure A-2. Wind vane NRG Systems #200P (item 1904)[20]

- **Mounting booms.** NRG side-mounting booms allow you to easily mount sensors to your tower or mast at any height. Mounting hardware is included. Heavy-duty mounting booms are designed specifically for icing environments and mounting NRG IceFree sensors.

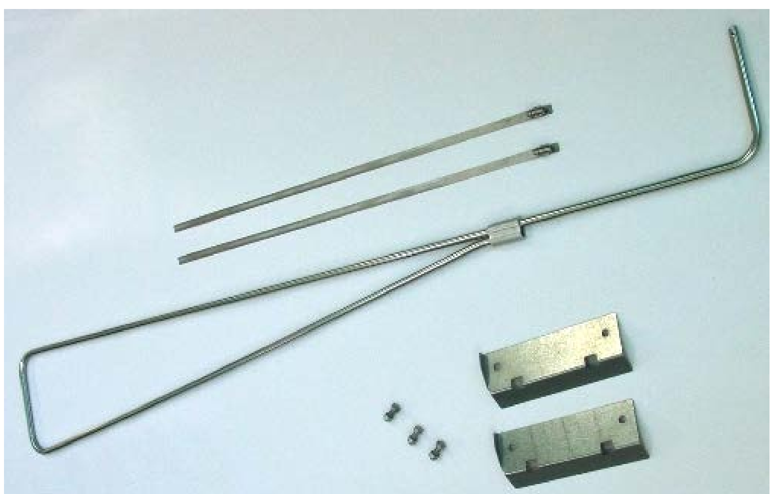

Figure A-3. Boom, side, 1.53m (60.5"), galvanized, with clamps (item: 3390)[21]

[20] Photo courtesy of NRG Systems, Inc. http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

[21] Photo courtesy of NRG Systems, Inc. http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

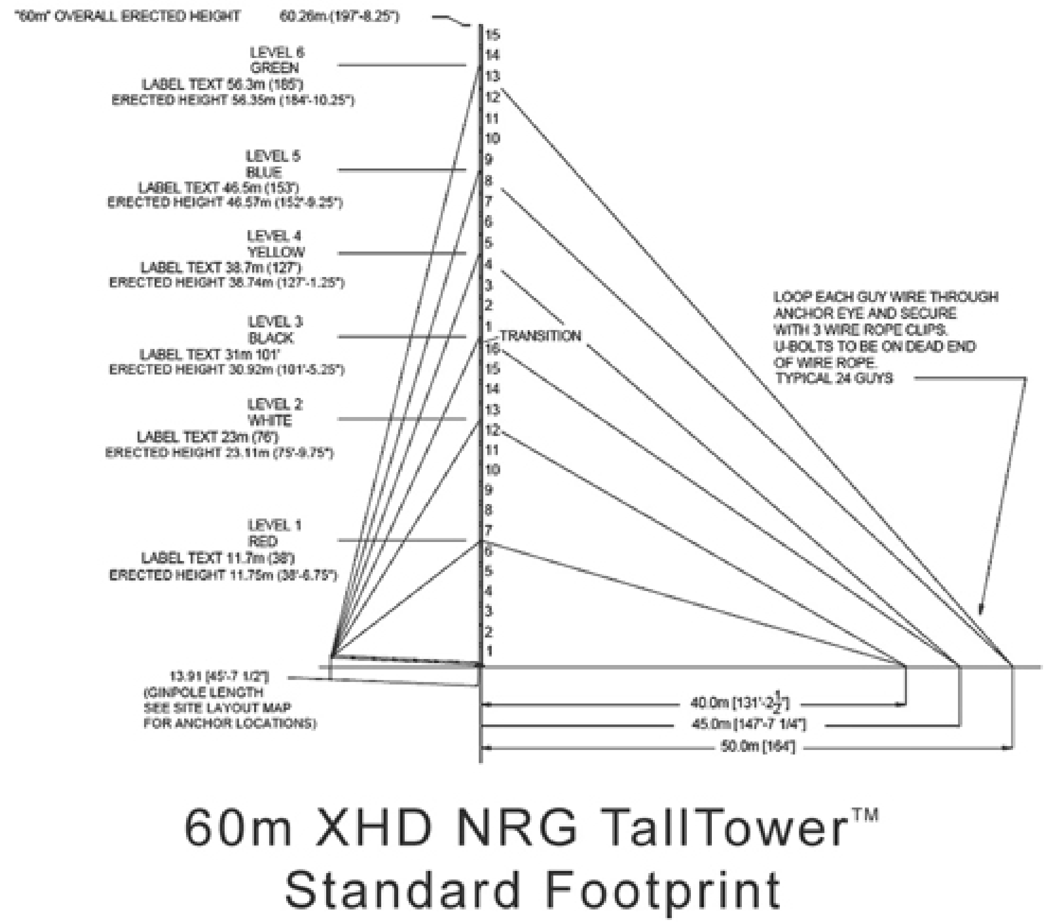

Figure A-4. 50m and 60m XHD Tower configuration[22]

[22] Diagram courtesy of NRG Systems, Inc. http://www.nrgsystems.com/sitecore/content/Products/4063-4290-4199.aspx.

Appendix B. Turbulence Analysis[23]

Figure B-1 shows the turbulence intensity by direction at Coddington Point.

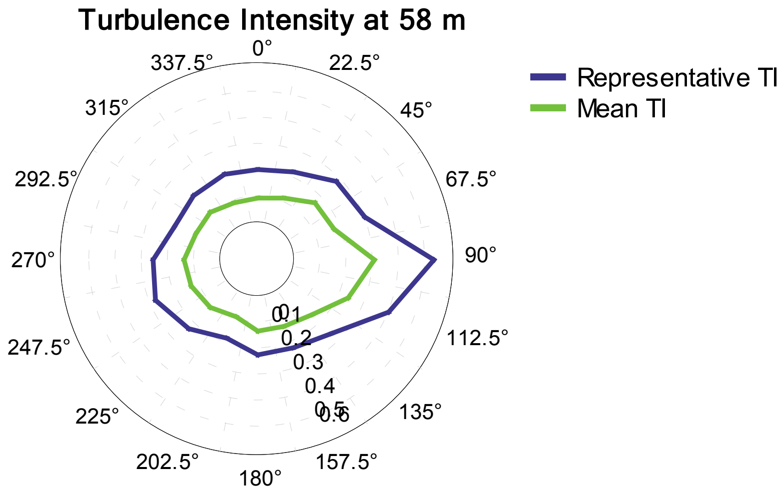

Figure B-1. Turbulence intensity by direction at Coddington Point

Figure B-2 shows the turbulence intensity by direction at Tank Farm #4. As can be seen, overall the turbulence is higher at Tank Farm #4 than Coddington Point in almost all directions except east.

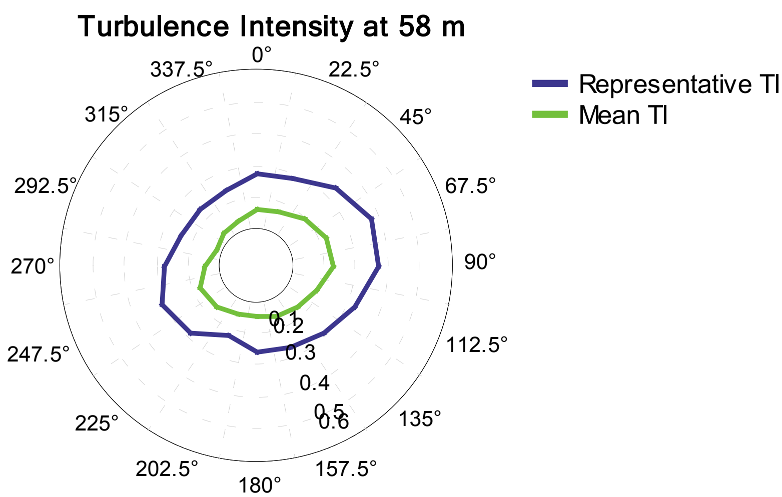

Figure B-2. Turbulence intensity by direction at Tank Farm #4

Figure B-3 illustrates how the turbulence changes at Coddington Point over the course of the day. As can been seen, the periods of lowest turbulence are in the afternoon when wind speeds are typically higher.

[23] Charts generated using Windographer, a product of Mistaya Engineering Inc.

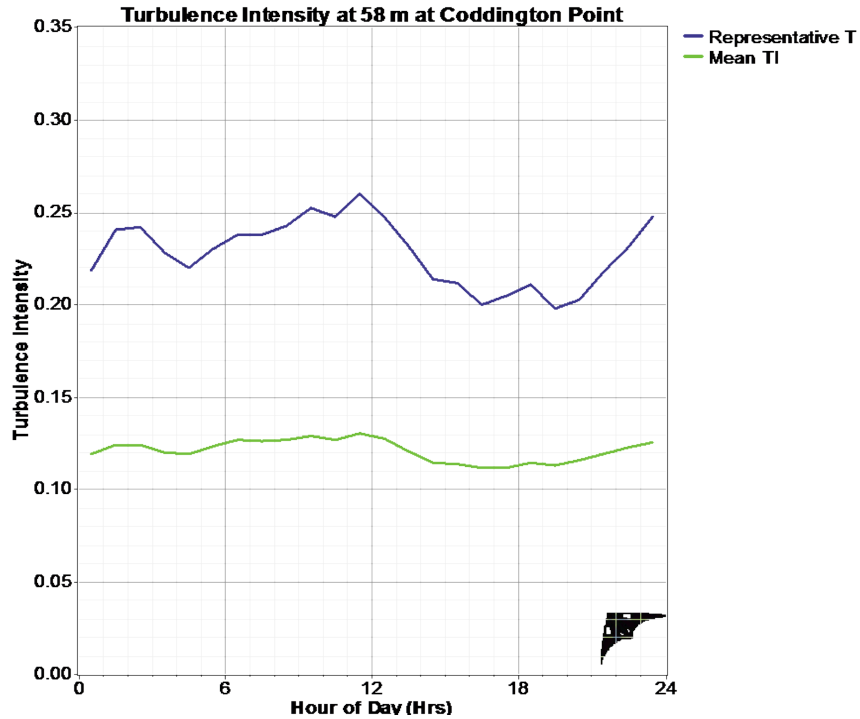

Figure B-3. Diurnal turbulence intensity at 58 m at Coddington Point

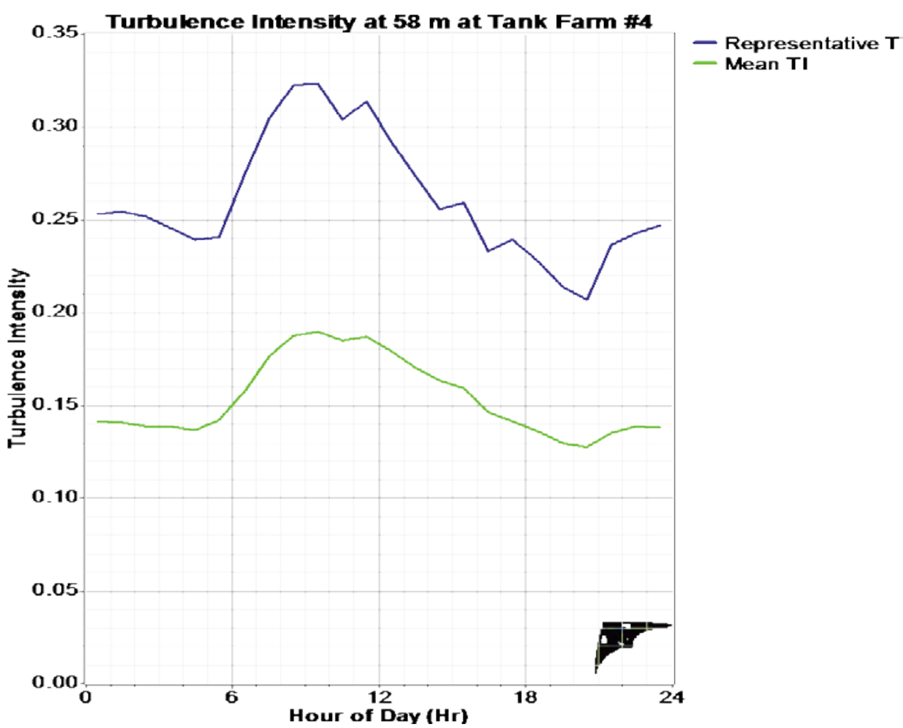

Figure B-4. Diurnal turbulence intensity at 58 m at Tank Farm #4

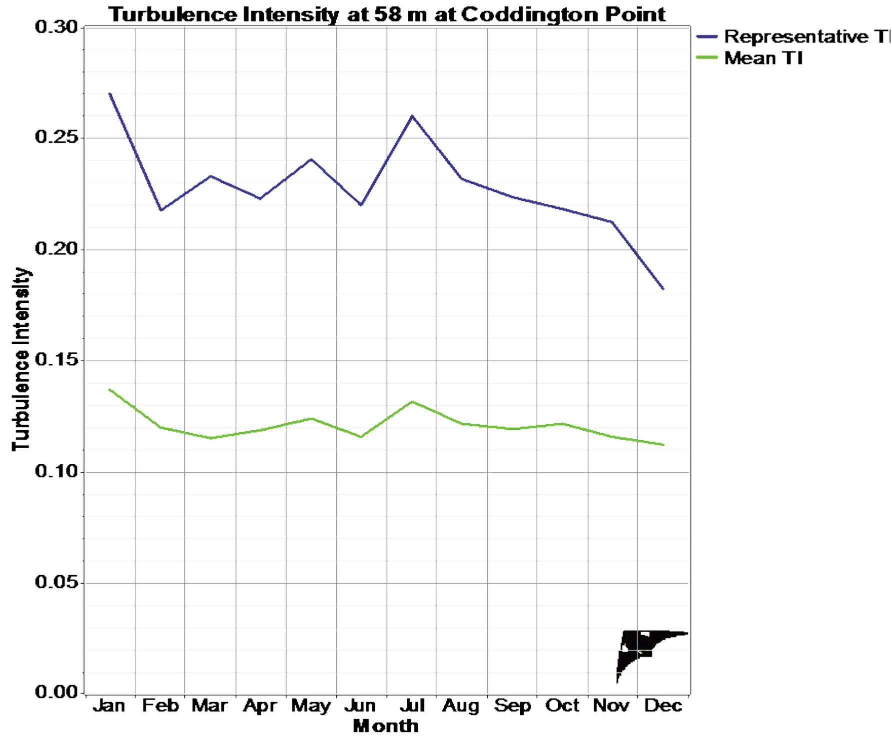

Figure B-5. Seasonal turbulence intensity at 58 m at Coddington Point

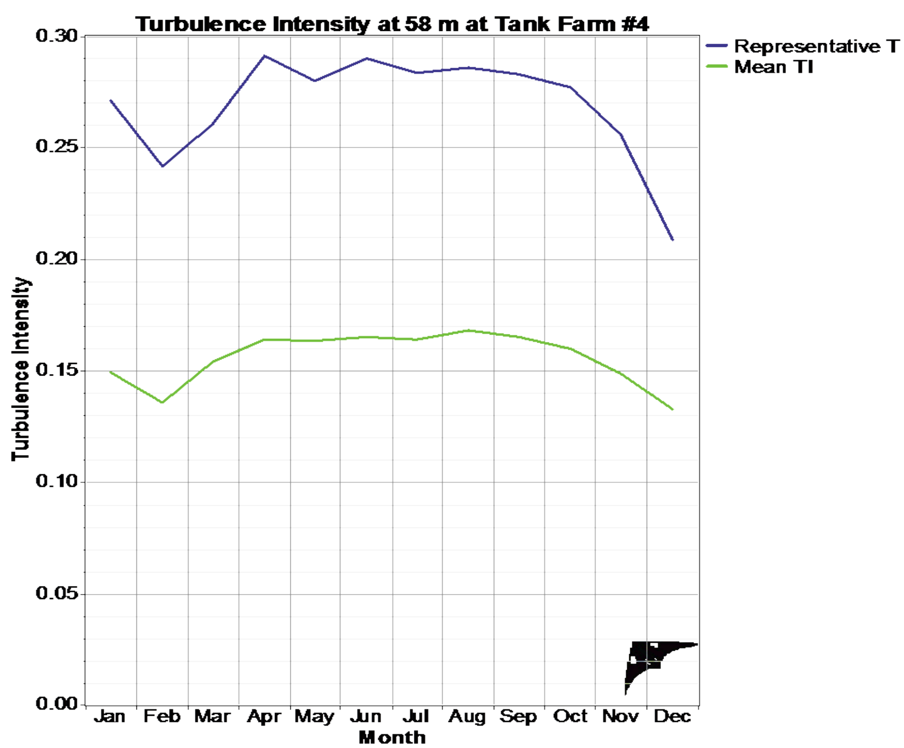

Figure B-6. Seasonal turbulence intensity at 58 m at Tank Farm #4

Figure B-7 shows a plot of the turbulence intensity versus wind speed at Coddington Point. As shown, the windier it was, the less turbulence there was in the wind.

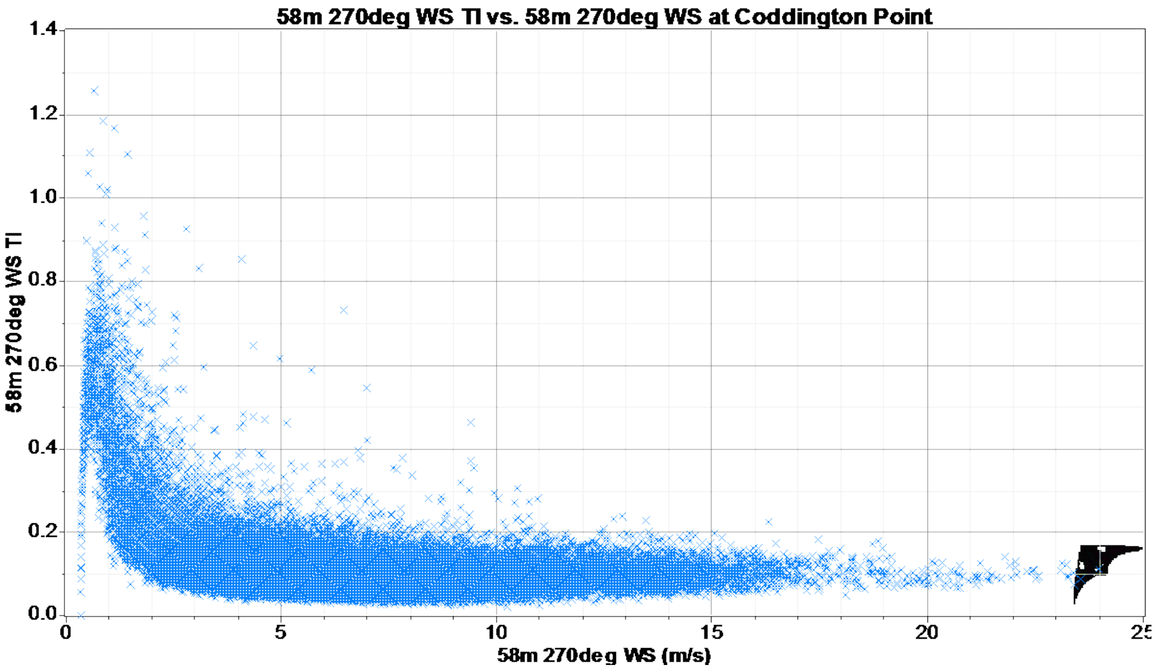

Figure B-7. Turbulence intensity vs. wind speed at Coddington Point

Figure B-8 shows a plot of the turbulence intensity versus wind speed at Tank Farm #4.

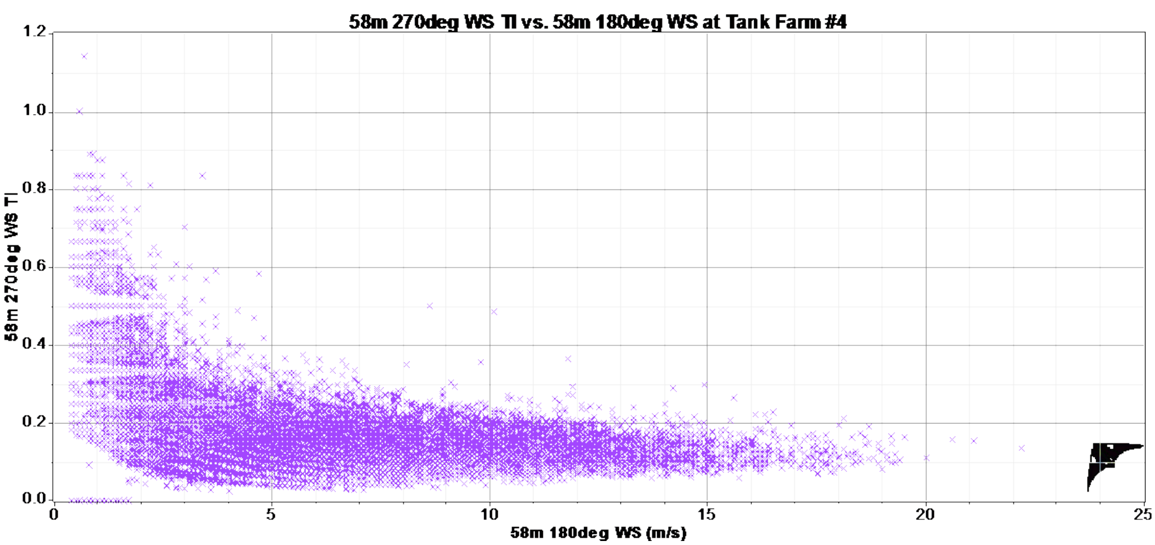

Figure B-8. Turbulence intensity vs. wind speed at Tank Farm #4

Appendix C. Additional Site Information

Though the report was essentially completed using metric units, one table in particular, Table 16, was considered of interest to base personnel and is included (Table C-1) with English units for reference.

Table C-1. FAA-Approved Heights for Each Site

Site Name	Lat (NAD 83)				Long(NAD 83)							
	Deg	Min	Sec	Zone	Deg	Min	Sec	Zone	FAA - AGL*	FAA - AMSL**	Site Elevation - ASL***	Max Turbine Height
	°	'	"	dir	°	'	"	dir	ft	ft	ft	ft
Coddington Point Bishop Rock	41	31	3.56	N	71	19	49.86	W	459	469	10	459
Building 6/ Derecktor Shipyard	41	31	29.47	N	71	18	41.00	W	335	350	15	335
Coddington Point Bldg 1112	41	31	22.73	N	71	19	24.95	W	459	499	40	459
Bldg 1285 CP	41	31	11.38	N	71	18	58.14	W	345	350	5	345
Katy Field	41	30	50.00	N	71	19	40.47	W	459	474	15	459
NUWC	41	32	12.55	N	71	18	26.74	W	294	350	56	294
Pritchard Field North	41	31	9.17	N	71	19	38.30	W	459	474	15	459
Pritchard Field South	41	31	3.04	N	71	19	37.11	W	459	469	10	459
Coastal Harbor Island Helipad	41	30	14.28	N	71	19	33.91	W	459	474	15	459
Tank Farm 3	41	34	11.98	N	71	17	16.06	W	290	379	89	290
Tank Farm 3 A	41	34	16.60	N	71	17	18.38	W	307	379	72	307
Tank Farm 4 A	41	33	53.14	N	71	17	40.62	W	339	379	40	339
Tank Farm 4 B	41	33	53.60	N	71	17	25.48	W	290	379	89	290
Tank Farm 5	41	33	8.05	N	71	18	17.24	W	296	339	43	296
Tank Farm 5 C	41	32	52.79	N	71	18	12.49	W	211	305	94	211
W36 CP	41	30	42.04	N	71	19	20.66	W	459	479	20	459

*FAA AGL is the FAA Above Ground limit

**FAA AMSL is the FAA Above Mean Sea Level limit

***Above Sea Level