Moving Forward on Wind Energy in RI: An Engineering Perspective

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EBC Rhode Island Chapter Seminar:
Wind Energy in Rhode Island: An Update
November 30, 2007
Outline

- Site Selection Process
- Wind Resource Characterization
- Environmental Forcing
  - Wind
  - Waves
  - Storm surge
- Steps to move forward
Key Engineering Evaluation Criteria

- Winds (power resource)
- Environmental Forcing (extremes, once in 100 yr; structure design (foundation))
  - Winds
  - Waves
  - Storm Surge
- Bathymetry and stratigraphy (depth to bedrock)
Fixed Bottom Substructure Technology

Proven Designs

- Monopile Foundation
  - Most Common Type
  - Minimal Footprint
  - Depth Limit 25-m
  - Low stiffness

- Gravity Foundation
  - Larger Footprint
  - Depth Limit?
  - Stiffer but heavy

Future

- Tripod/Truss Foundation
  - No wind experience
  - Oil and gas to 450-m
  - Larger footprint
  - Talisman project

Graphics source: http://www.offshorewindenergy.org/
WINDS
RI Winds Study (ATM, 2006)

- Employed AWS TrueWinds Analysis to Characterize Wind Resource
- AWS True Winds:
  * MesoMap System - Based on meteorological model predictions and mass flow analyses, incorporate historical data
  * 200m grid resolution
  * Performed for RI, CT and MA by Brower (2007)
AWS TrueWinds Methodology

- 366 independent days of simulation, selected from 15 yr long historical record.
- Validated against 33 wind monitoring stations (most on land, only 2 in RI and none in RI waters) (65 m elevation).
- RMS error – 4%
- Output maps of mean annual wind speed (m/sec) at 30, 50, 70 and 100 m and mean annual power (kW/m²) at 50 m. (no time series, frequency analysis or direction information available)
### Table 1. Comparison of Predicted and Measured/Extrapolated Mean Speeds at 65 m

<table>
<thead>
<tr>
<th>Station</th>
<th>State</th>
<th>Height (m)</th>
<th>Speed (m/s)</th>
<th>Shear</th>
<th>Speed at 65m (m/s)</th>
<th>Map (m/s)</th>
<th>Bias (m/s)</th>
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<tbody>
<tr>
<td>Bridgeport</td>
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<td>6.9</td>
<td>6.8</td>
<td>-0.1</td>
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</table>

(Brower, 2007)
Validation

- Three sites in RI,
  - Providence
  - Pt Judith
  - Block Island (DOE)

None in RI coastal waters

*** Re-verified by ATM at Buzzards Bay Light
30 m winds
50 m winds
70 m winds
100 m winds
50 m power density
Composite: NY, RI, CT and MA

True Winds, 50m annual power density
Some Concerns with AWS TrueWind Data

• Lack of validation for offshore areas*
  (Adjusted winds, upward by 5% in Boston Harbor and nearby coastal areas to agree with observations, no similar adjustment for RI waters, since no data)

• Analysis may not accurately represent sea breeze (important near land)

• Maps are inconsistent between adjacent regions (states)

* WINDS MAYBE BIASED LOW BASED ON BOSTON HARBOR EXAMPLE
ATM et al Site Screening Criteria

- Minimum wind speed: 7 m/sec at 80 m
- Water depth (8 to 75 ft or 2.4 to 23 m)
- Suitable use (navigation/marine transportation, airport, cables, marine sanctuaries, eel grass beds)
- Minimum area for development
Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation
Potential Energy Estimates

RIWINDS Goal: 1.3 MMWh/yr

Energy (MMWh/yr)

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

Figure 2 - RIWINDS Estimated Energy Generation for Each of the Identified Offshore Areas

ATM (2007)
Figure 3 - RIWINDS Report Figure 6.2: Estimated Levelized Cost of Energy Compared to Levelized Wholesale Electricity Price Forecasts
ATM (2007) Final Ranking

- Based on cost/potential, jurisdiction, and visibility from shore
  
  Rank order: E-H and J-K and H-K tied
  
  Eliminated by cost/potential: A, B, C, D, and F.
Readily Available Wind Data for Meso-Map Validation

- US Army Corp Wave Information Study
  Hindcast of wind and wave conditions for selected near coastal sites
- Martha’s Vineyard Observatory
  (http://www.whoi.edu/mvco/data/metdata.html) 2001 to present
- Site characterization data at Charlestown, RI for proposed (1970s) nuclear power plant site
- WeatherFlow (http://www.weatherflow.com) mesonet observations (www.iwindsurf.com)
US Army Corp Wave Information
Study Hindcast Locations

LEGEND
- WIS Model
- NDBC Buoy
- CMAN
- CDIP Gage
- CHL
- FRF
Figure 4. Geographic distribution of normal and survival significant wave heights off southern New England.
**Annual Average Wave Energy Flux**

- Offshore exposed = 25 kW/m
- Nearshore exposed = 15 kW/m
- Nearshore sheltered by Nova Scotia or by Cape Cod and the Nantucket Shoals ~ 10 kW/m

**Nearshore Wave Energy Development Index**

Newport, RI to due south of Nantucket Island = 1.8 to 2.5
West of Newport, RI ~ 2
North of Nantucket Shoals = 1

*Figure 5.* Geographic distribution of mean incident wave energy flux and wave energy development index off southern New England.
Wind Data

- Wind measurements from WIS Station #101 assumed to represent wind speeds at the site location.

\[ R^2 = 0.8818 \]
## Extreme Wind Analysis

<table>
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<tr>
<th>Return Period (yr)</th>
<th>180 deg (S)</th>
<th>270 deg (W)</th>
<th>30 deg (NNE)</th>
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<tr>
<td>5 year</td>
<td>20.11</td>
<td>22.91</td>
<td>22.99</td>
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<tr>
<td>10 year</td>
<td>21.92</td>
<td>25.07</td>
<td>25.32</td>
</tr>
<tr>
<td>25 year</td>
<td>24.32</td>
<td>27.92</td>
<td>28.41</td>
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<tr>
<td>50 year</td>
<td>26.14</td>
<td>30.08</td>
<td>30.74</td>
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<tr>
<td>100 year</td>
<td>27.95</td>
<td>32.24</td>
<td>33.07</td>
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WAVES
Offshore Wave Analysis

- 52.78% waves are from the 3 dominant directions
  - 22.26% from South
  - 18.47% from SSW
  - 12.05% from SSE

- WIS Stations #100 and #102
Probability distribution WIS 101 (South)
# Average and Extreme Wave Estimates

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<tr>
<th></th>
<th>150 deg (SSE)</th>
<th>180 deg (S)</th>
<th>210 deg (SSW)</th>
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<tr>
<td></td>
<td>Hs [m]</td>
<td>Ts [s]</td>
<td>Hs [m]</td>
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<tr>
<td>Average yearly</td>
<td>1.09</td>
<td>6.12</td>
<td>1.15</td>
</tr>
</tbody>
</table>

- wave heights in meters; wave periods in seconds
Wave Environment

- Example STWAVE input

- Bathymetry grid (depths in meters)

- $H_s = 4 \text{ m}$
- $T_p = 12 \text{ s}$
- $\theta = 30^\circ$
NOAA Bathymetry
Wave Environment

- Extremes
  - 100 year return period
    - $H_s$ (WIS) = 8.99 m; $H_s$ (site) = 3.98 m; $T_p$ = 14.99 s
    - Dir (WIS) = 180° (S); Dir (site) = 159° (SSE)

Wave Height (meters)  
Angle of Propagation (degrees)
Wave Environment

- Extremes
  - 100 year return period
    - $H_s$ (WIS) = 8.85 m; $H_s$ (site) = 4.07 m; $T_p$ = 14.88 s
    - Dir (WIS) = 150° (SSE); Dir (site) = 151° (SSE)
Wave Environment

- **Extremes**
  - 100 year return period
    - $H_s (\text{WIS}) = 8.81 \text{ m}$; $H_s (\text{site}) = 3.59 \text{ m}$; $T_p = 14.84 \text{ s}$
    - Dir (WIS) = 210° (SSW); Dir (site) = 164° (SSE)

Wave Height (meters)  
Angle of Propagation (degrees)
Bathymetry South of Pt Judith Harbor of Refuge

Off shore of Point Judith
Bathymetry (m/MLLW)

Data Source: NOAA (ASA) and J. King’s bathymetric Survey 2004 (G80)
100 yr storm waves off Pt Judith (Grilli et al, 2005)
100 yr storm wave off Pt Judith (Grilli et al, 2005)
100 yr storm waves off Pt Judith with 4.5 m surge (Grilli et al, 2005)
100 yr storm waves off Pt Judith with 4.5 m storm surge (Grilli et al, 2005)
Wave Summary (BIS)

- Block Island Sound (western and central) is protected from large offshore waves
  - Significant wave height within Block Island Sound 40 – 60 % smaller than offshore
  - Shoals between Montauk and Block Island dissipate wave energy and cause significant refraction
Wave Summary (RIS)

- Waves propagate into RIS with little refraction/diffraction and modest shoaling, hence overall change from offshore conditions is small.
- Wave breaking dissipates wave energy at depths comparable to wave height for extreme waves; including surge moves breaking location shoreward.
Extreme Wave Heights and Periods (1/100yr)

- 9 m, 15.6 sec
- 8.5 m, 14.5 sec
- 8 m, 14.5 sec
- 4 m, 15 sec

Map showing post level 2 screening areas separated by wind speed and final area designation.
Storm Surge Heights

- 1, 10, 50, and 100 yr return period surges and Standard Project Hurricane (SPH)
## Storm Surge Heights (US Army Corp)

<table>
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<tr>
<th></th>
<th>Storm Surge [feet]*</th>
<th>Storm Surge [meters]*</th>
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<tbody>
<tr>
<td>10 year</td>
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<td>2.51</td>
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<td>50 year</td>
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<td>100 year</td>
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<td>SPH</td>
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Extreme Storm Surge (once in 100yr), NGVD Vertical Reference (Army Corps, 1988)

Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation
NOAA ENC Bathymetry
USGS Needell and Lewis
Track lines and topography
Geologic Seismic Cross Section Lines (A-A’)

Scale 1:125,000

Sautigel Miles Kilometers

1 0 2 4 6 8 10

New York B.C.D. Chart and Soundings Survey charts 95099-12 and 95099-11
Hydrographic projection.
Bedrock is located approx 35 meters below seafloor

(Needell and Lewis, 1984)
MMS Use Summary

MMS Use Summary
AIS Tracks Oct 31 to Nov 26, 2007 (ASA)
SUMMARY FINDINGS

Viable Sites, Resource use conflicts ??

Extreme waves, costly structure?

Extreme waves, close to breakwater

Extreme waves, may limit seaward extent
Major Fishing Areas (URI, EDC)
Lessons Learned

- Wind data used to perform analysis unverified in RI coastal waters (except at Buzzards Bay Light by ATM), may be biased low.
- Extreme wave heights may make areas J and K financially untenable and limit southern extent of Areas E and H.
- Surge height and extreme winds comparable for most locations and hence not useful as a site location discriminator.
The Way Forward

- Additional validation of AWS TrueWind predictions for coastal RI with existing wind data sets (WIS, Martha’s Vineyard Observatory, and WeatherFlow data)
- Re-evaluate site ranking including consideration of 100 yr winds, storm surge, and wave conditions.
- Verify marine transportation corridors with USCG AIS track data and recent revision of traffic lanes
- Include grid connection distance and commercial fishing areas in evaluation