Moving Forward on Wind Energy in RI: An Engineering Perspective

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Narragansett, RI

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))

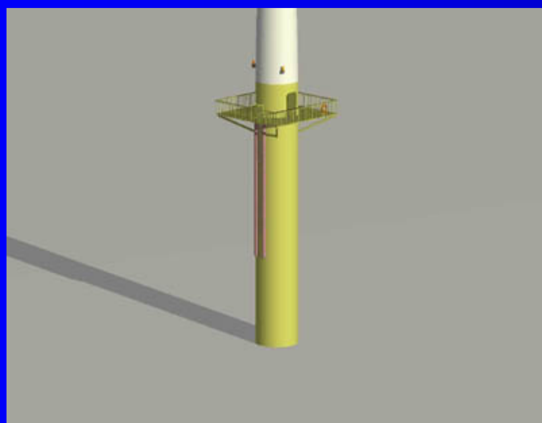
  Winds

  Waves

  Storm Surge
- Bathymetry and stratigraphy (depth to bedrock)

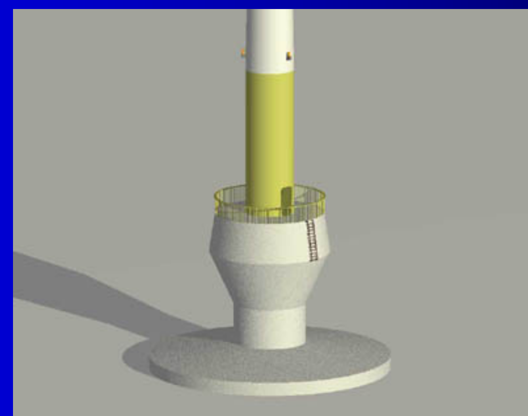
Fixed Bottom Substructure Technology

Proven Designs



Monopile Foundation

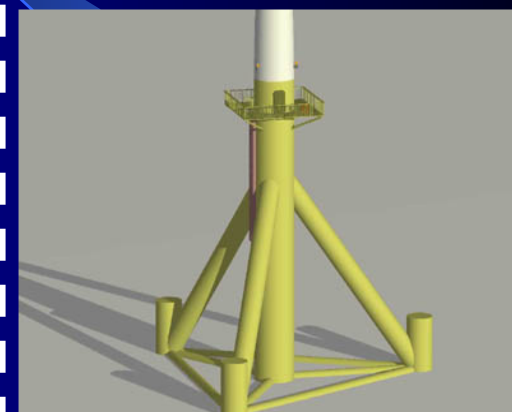
- Most Common Type
- Minimal Footprint
- Depth Limit 25-m
- Low stiffness



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/m^2) at 50 m. (no time series, frequency analysis or direction information available

Validation Sites for AWS True Wind Predictions

Table 1. Comparison of Predicted and Measured/Extrapolated Mean Speeds at 65 m

Station	*State*	*Height (m)*	*Speed (m/s)*	*Shear Exponent*	*Speed at 65m (m/s)*	*Map (m/s)*	*Bias (m/s)*
Bridgeport	CT	10	5.0	0.17	6.9	6.5	-0.4
Hartford, Brainard Field	CT	13.4	3.7	0.20	5.1	5.2	0.1
New London Ledge	CT	15.2	5.6	0.12	6.7	7.1	0.4
Point Judith	CT	18.9	6.2	0.12	7.2	8.0	0.8
Windsor Locks, Bradley Field	CT	6.1	3.8	0.17	5.7	5.2	-0.5
Bedford, Hanscom AFB	MA	4	3.1	0.17	5.0	5.6	0.6
Bishop and Clerks	MA	15	7.0	0.12	8.3	8.4	0.1
Borden Mtn	MA	40	4.6	0.78	6.7	7.1	0.4
Boston	MA	10	5.9	0.12	7.4	6.5	-0.9
Boston Harbor Buoy 44013	MA	5	6.3	0.1	8.2	7.9	-0.3
Boston/Hull	MA	18.9	6.8	0.12	7.9	7.2	-0.7
Brodie Mtn	MA	40	6.9	0.63	9.4	8.7	-0.7
Burnt Hill	MA	40	4.9	0.3	5.6	6.5	0.9
Buzzards Bay CG Light Tower	MA	25	7.8	0.12	8.8	8.6	-0.2
East Falmouth, Otis ANGB	MA	4	4.3	0.17	6.9	6.9	0.0
Gloucester	MA	25	6.7	0.12	7.5	7.5	0.0
Halibut Point	MA	30	5.9	0.3	7.4	7.3	-0.2
Isle of Shoals	MA	17	6.8	0.12	8.0	7.8	-0.2
Mt Tom	MA	45	6.9	0.28	7.6	6.9	-0.7
Mt Wachusett	MA	24	6.2	0.21	7.6	7.3	-0.3
Nantucket	MA	46	8.2	0.27	9.0	8.0	-1.0
Outer Bank Buoy 44008	MA	5	6.7	0.12	9.1	9.2	0.1
Salisbury	MA	27	5.1	0.19	6.0	6.5	0.5
Scituate	MA	18.9	5.9	0.12	6.8	7.2	0.3
Thompson Island	MA	40	5.6	0.13	5.9	6.3	0.4
Wind Mill Point	MA	24	5.8	0.12	6.5	6.7	0.1
Worcester	MA	6.7	4.5	0.20	7.1	6.6	-0.5
Yarmouth Radio Tower	MA	30	6.0	0.27	7.4	7.1	-0.3
Manchester	NH	3	3.1	0.20	5.6	5.5	-0.1
Portsmouth, Pease AFB	NH	10	4.1	0.17	5.7	5.9	0.2
Taconic	NY	26	7.7	0.21	9.3	8.8	-0.5
Block Island DOE	RI	46	7.4	0.24	8.1	8.0	-0.1
Providence	RI	6.1	4.7	0.12	6.2	5.9	-0.3
Average					6.9	6.8	-0.1

(Brower, 2007)

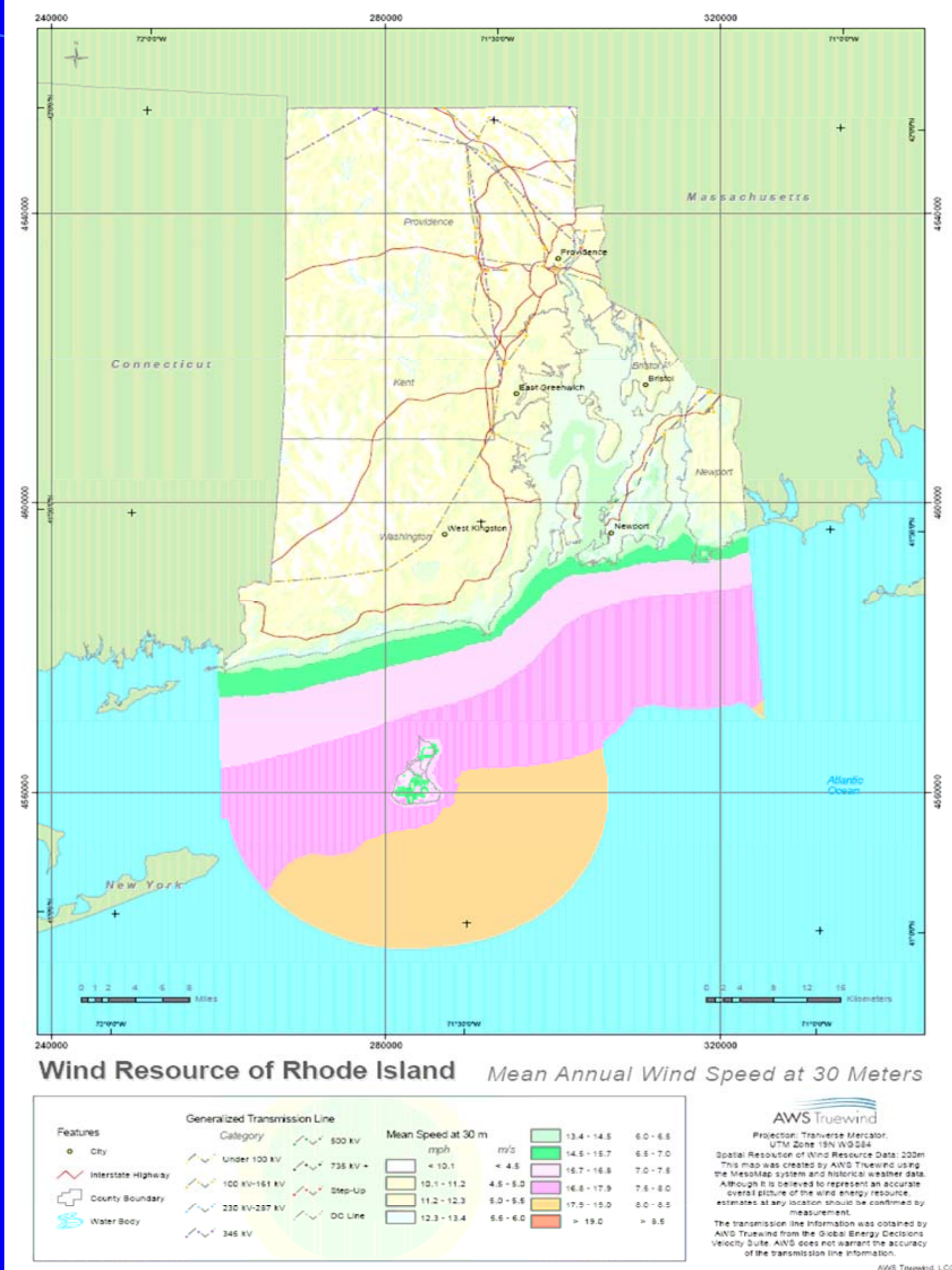
Validation

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

  None in RI coastal waters

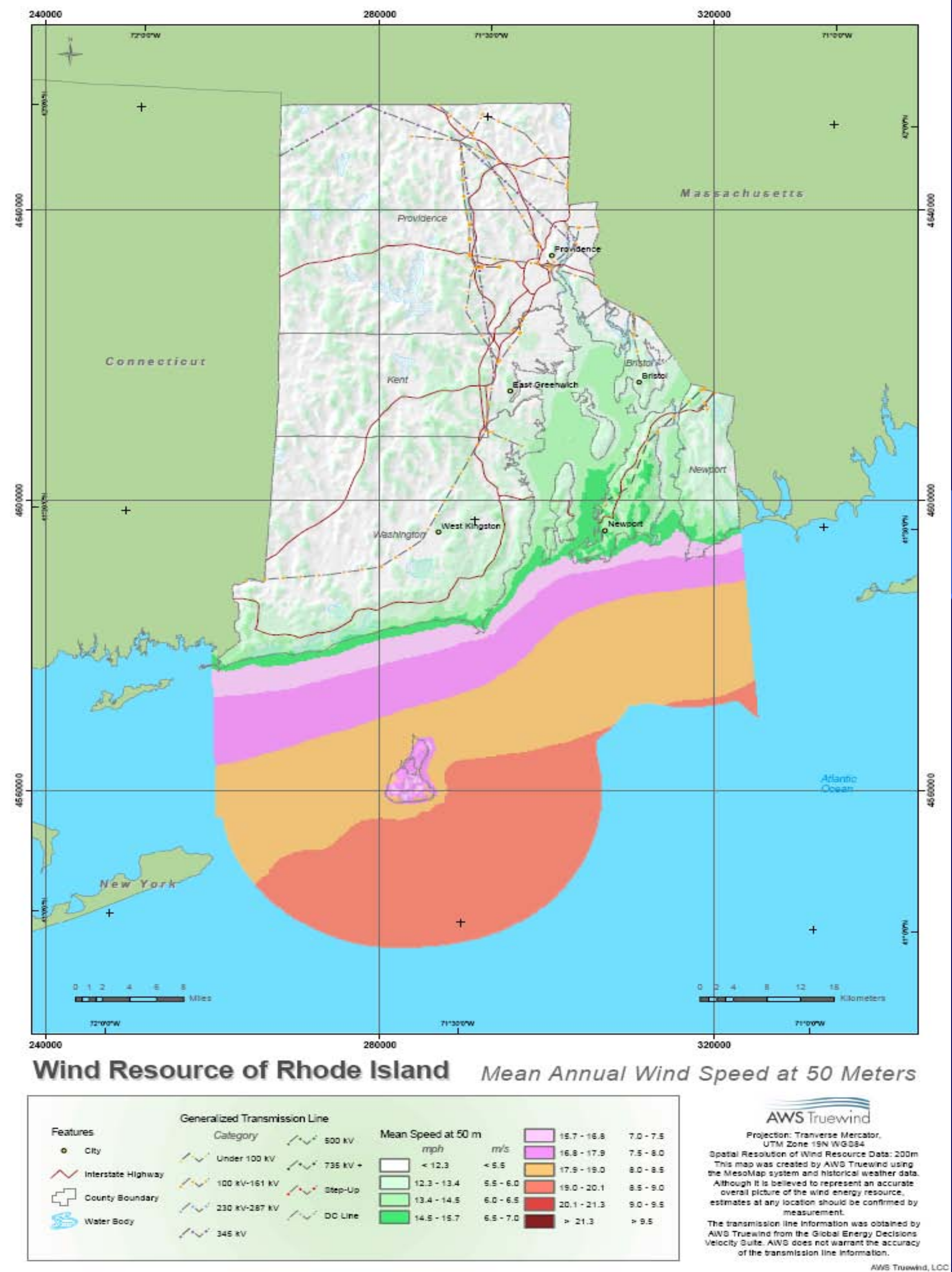
  *** Re-verified by ATM at Buzzards Bay Light

30 m winds



Massachusetts
Connecticut
New York
Providence
Kent
Washington
Bristol
Newport
East Greenwich
West Kingston
Atlantic Ocean
Wind Resource of Rhode Island
Mean Annual Wind Speed at 30 Meters
Features
City
Interstate Highway
County Boundary
Water Body
Generalized Transmission Line
Category
Under 100 kV
100 kV-161 kV
230 kV-287 kV
345 kV
500 kV
735 kV +
Step-Up
DC Line
Mean Speed at 30 m
mph
m/s
< 10.1 < 4.5
10.1 - 11.2 4.5 - 5.0
11.2 - 12.3 5.0 - 5.5
12.3 - 13.4 5.5 - 6.0
13.4 - 14.5 6.0 - 6.5
14.5 - 15.7 6.5 - 7.0
15.7 - 16.8 7.0 - 7.5
16.8 - 17.9 7.5 - 8.0
17.9 - 19.0 8.0 - 8.5
> 19.0 > 8.5
AWS Truewind
Projection: Tranverse Mercator, UTM Zone 19N WGS84
Spatial Resolution of Wind Resource Data: 200m
This map was created by AWS Truewind using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.
The transmission line information was obtained by AWS Truewind from the Global Energy Decisions Velocity Suite. AWS does not warrant the accuracy of the transmission line information.
AWS Truewind, LLC

50 m winds


240000
280000
320000
Massachusetts
Connecticut
New York
Providence
Kent
Washington
Bristol
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0 1 2 4 6 8 Miles
0 2 4 8 12 16 Kilometers
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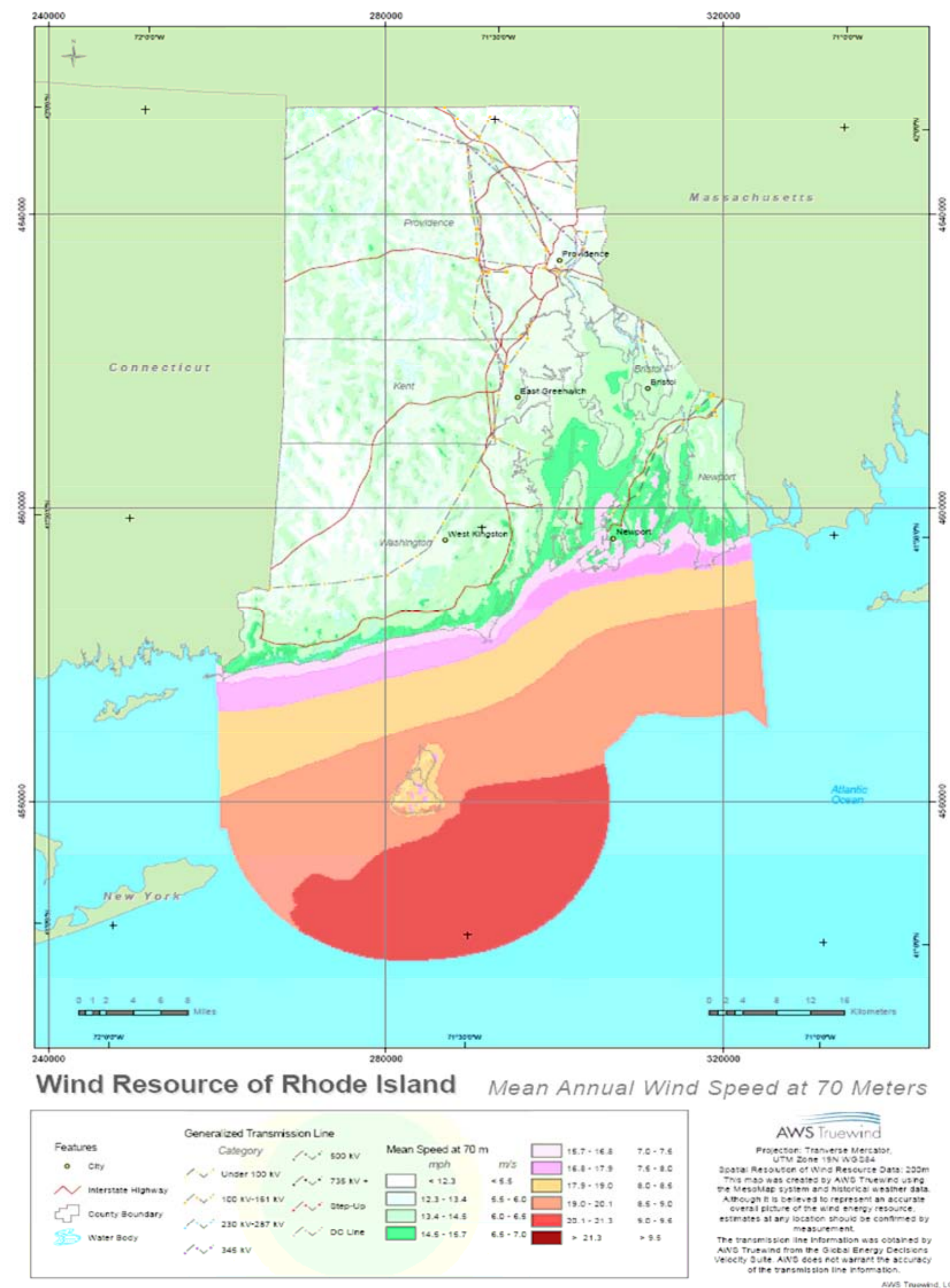
70 m winds


Wind Resource of Rhode Island
Mean Annual Wind Speed at 70 Meters
Massachusetts
Connecticut
New York
Atlantic Ocean
Providence
Kent
Washington
Bristol
Newport
East Greenwich
West Kingston
240000
280000
320000
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15.7 - 16.8
7.0 - 7.5
16.8 - 17.9
7.5 - 8.0
17.9 - 19.0
8.0 - 8.5
19.0 - 20.1
8.5 - 9.0
20.1 - 21.3
9.0 - 9.5
> 21.3
> 9.5
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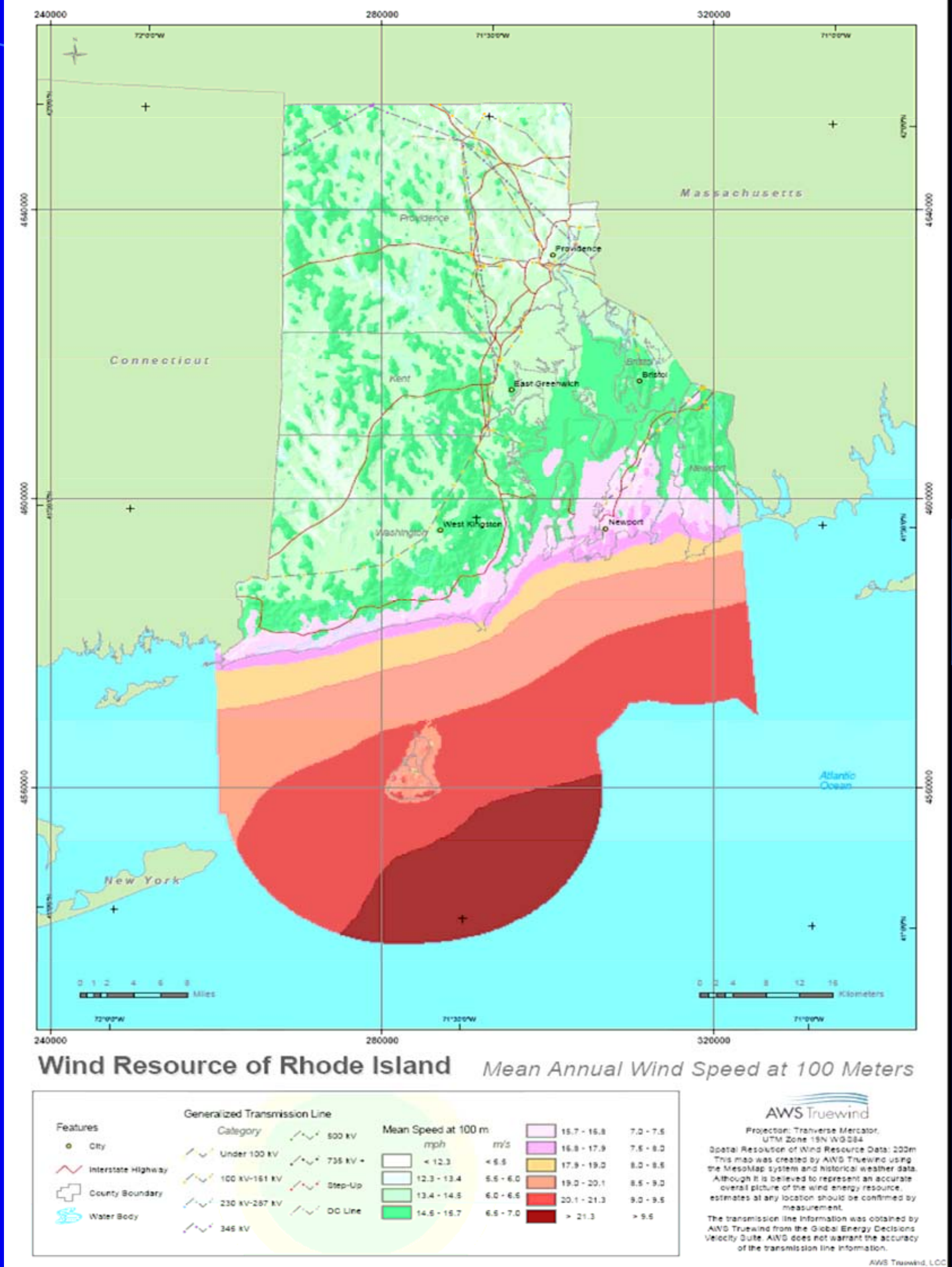
100 m winds



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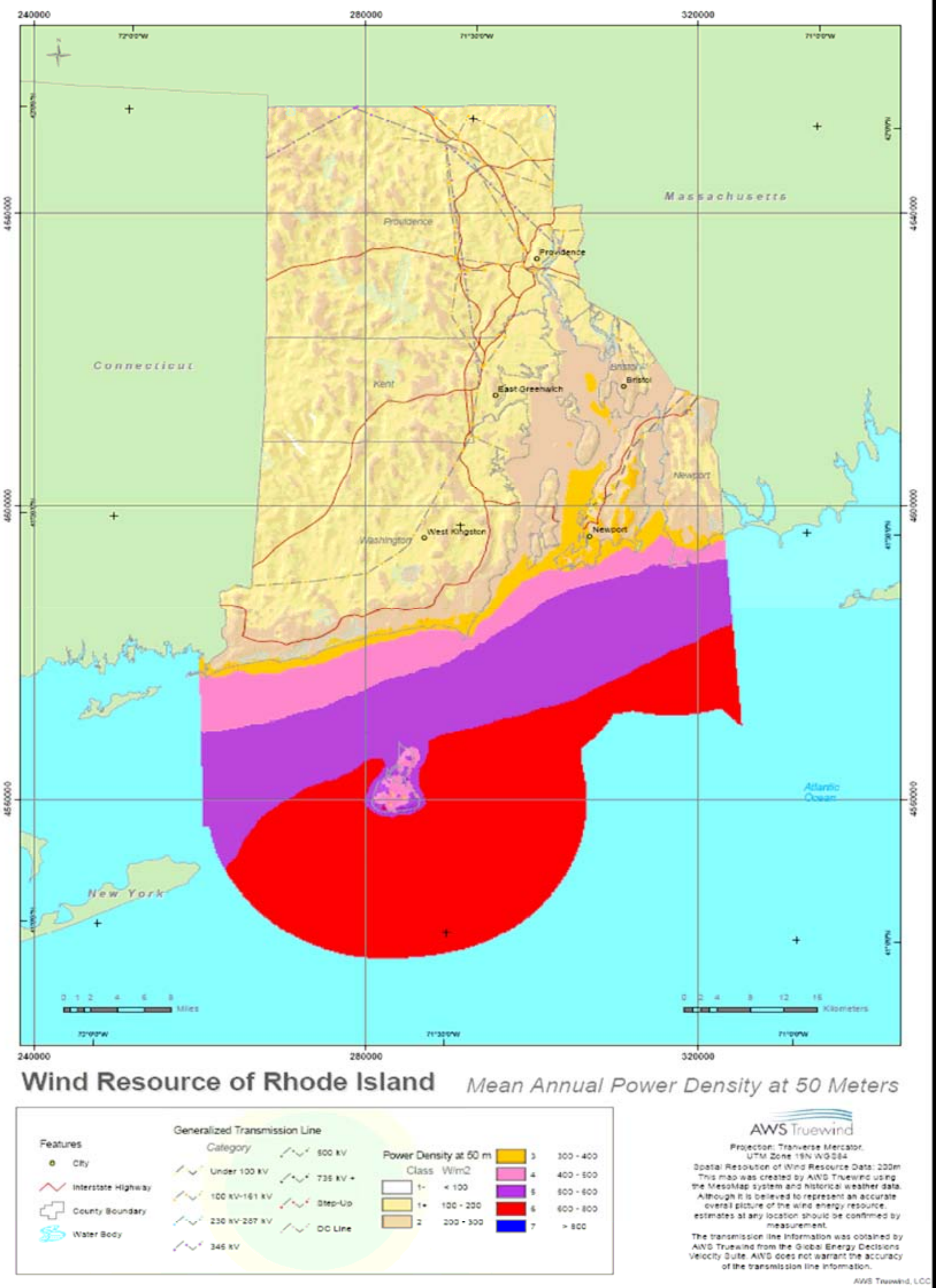
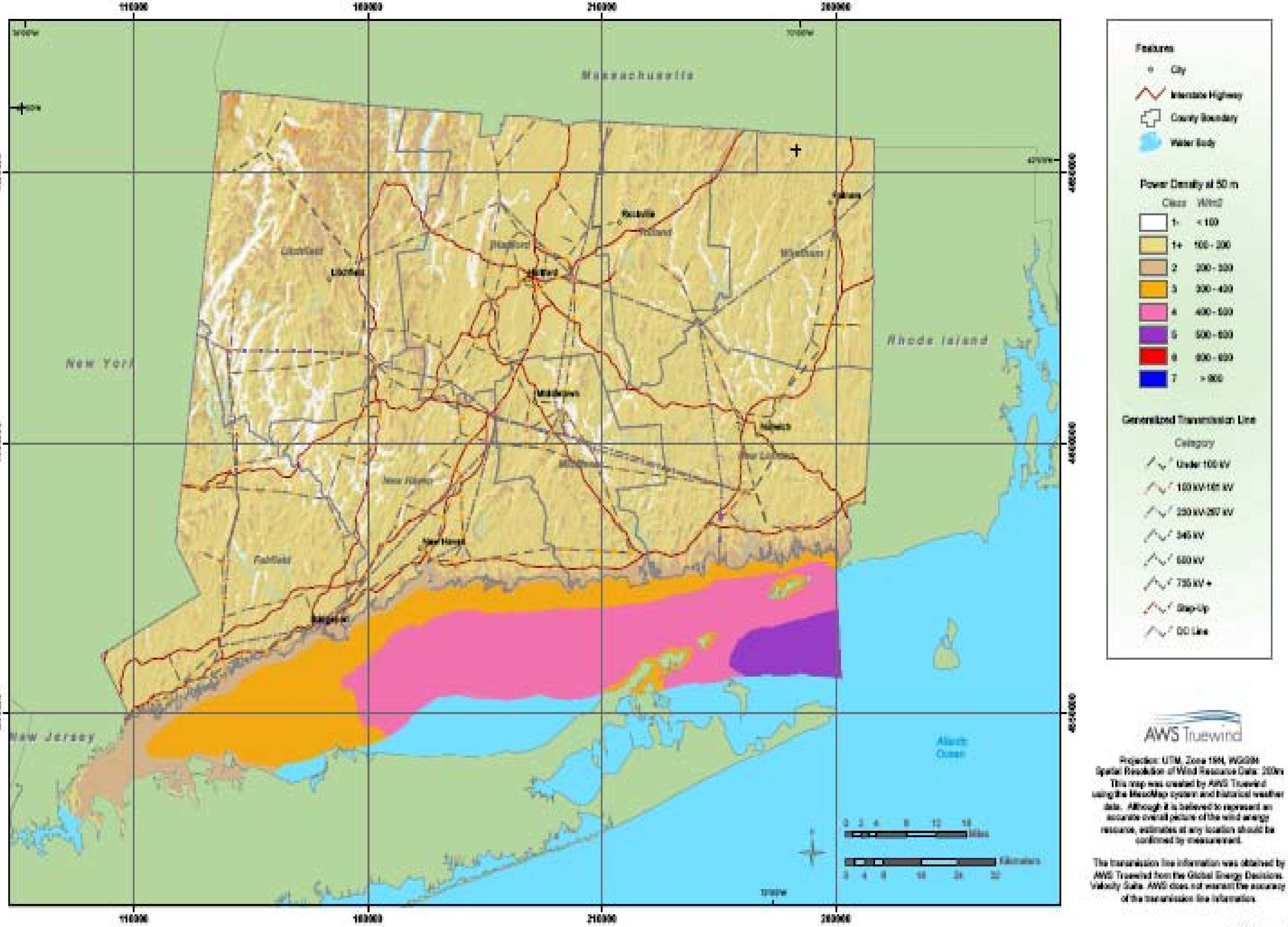
50 m power density

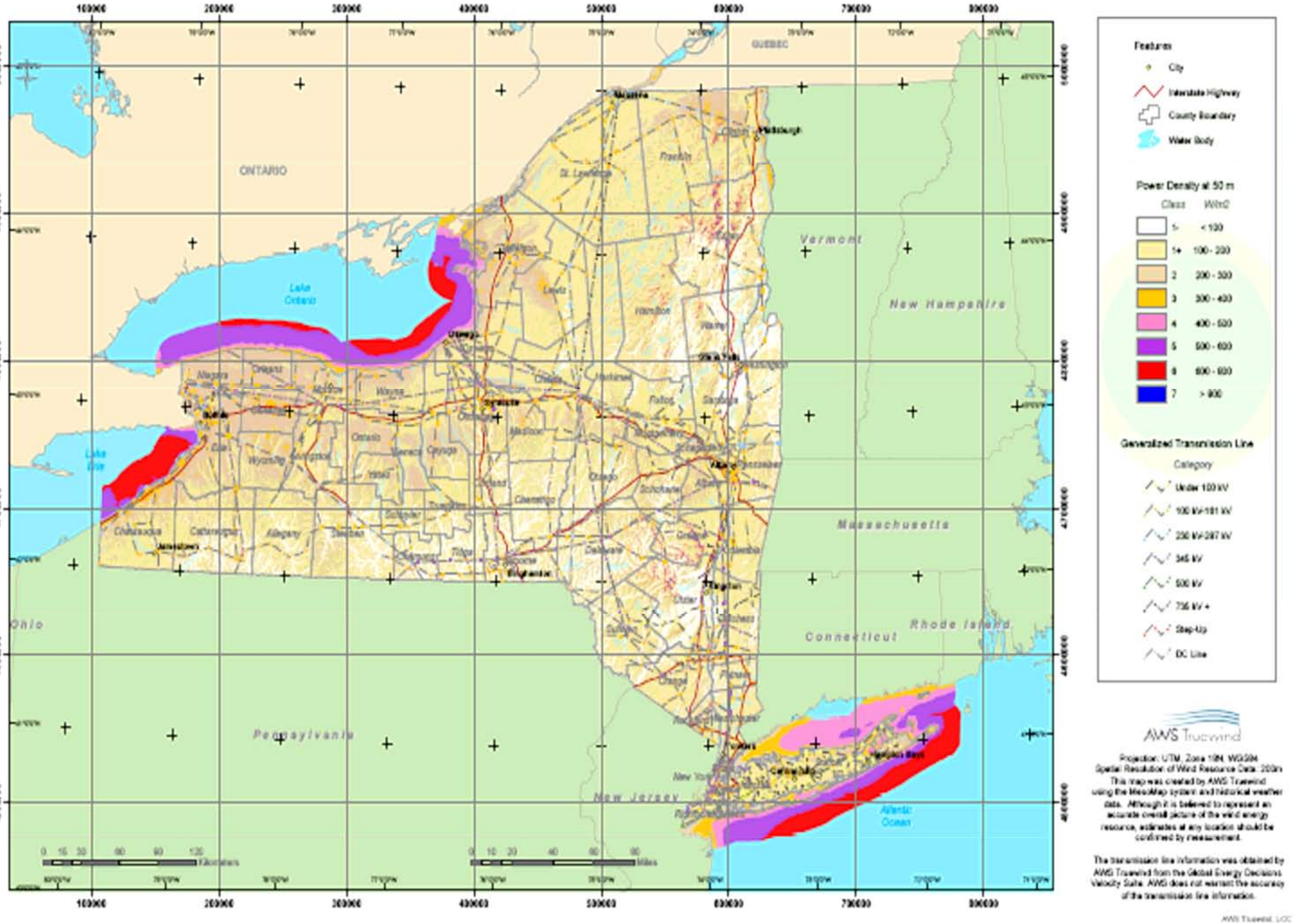


Wind Resource of Connecticut *Mean Annual Power Density at 50 Meters*

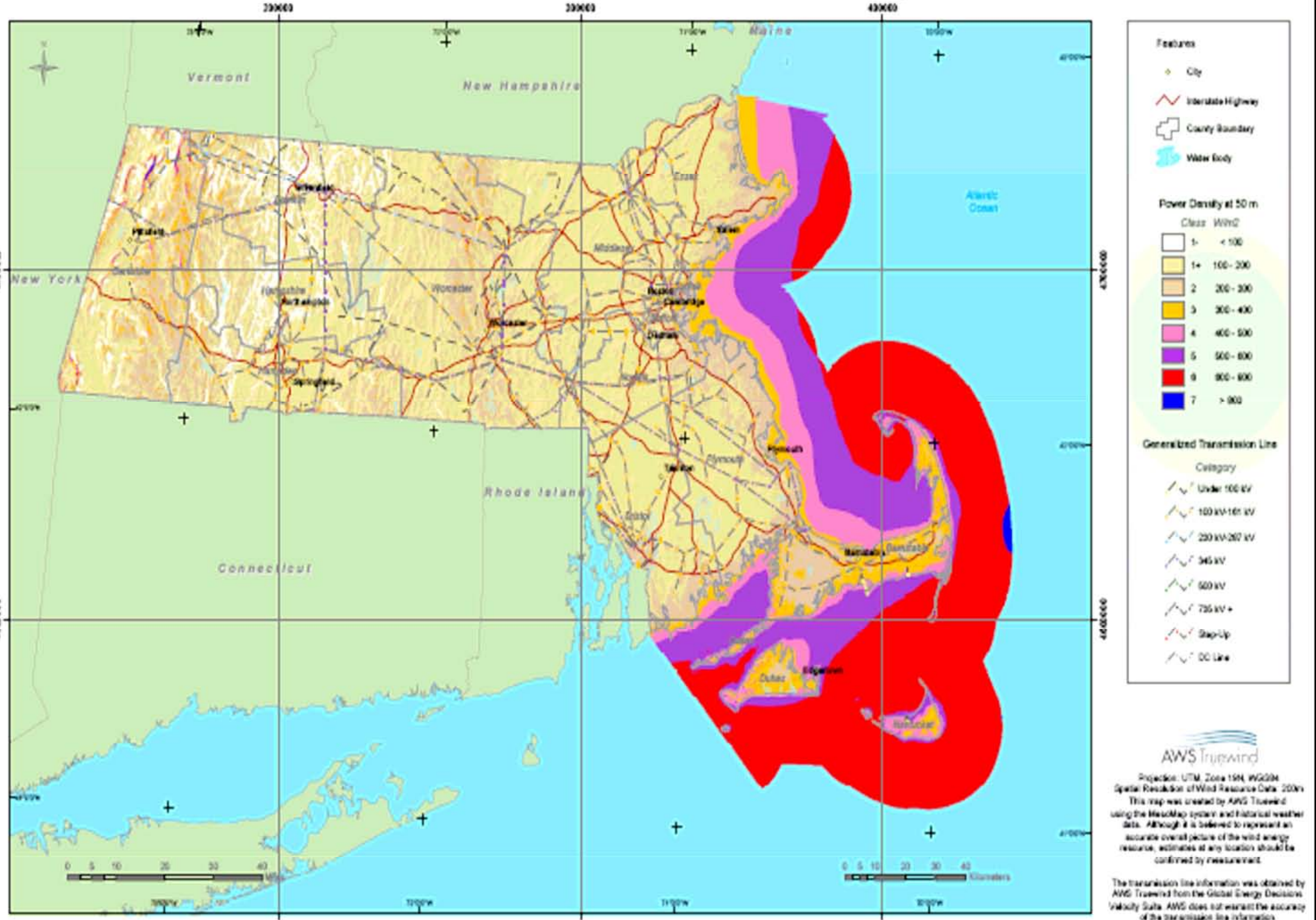


Wind Resource of New York

Mean Annual Power Density at 50 Meters

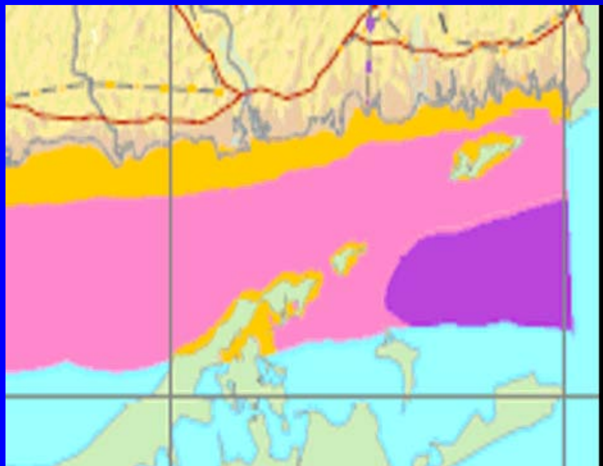


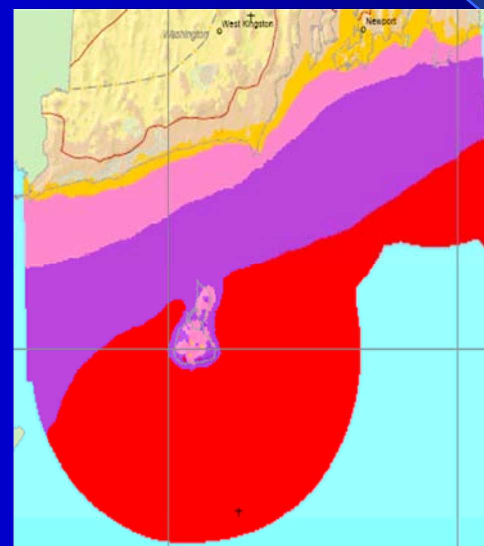
Wind Resource of Massachusetts *Mean Annual Power Density at 50 Meters*



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

ATM (Sep 2007)

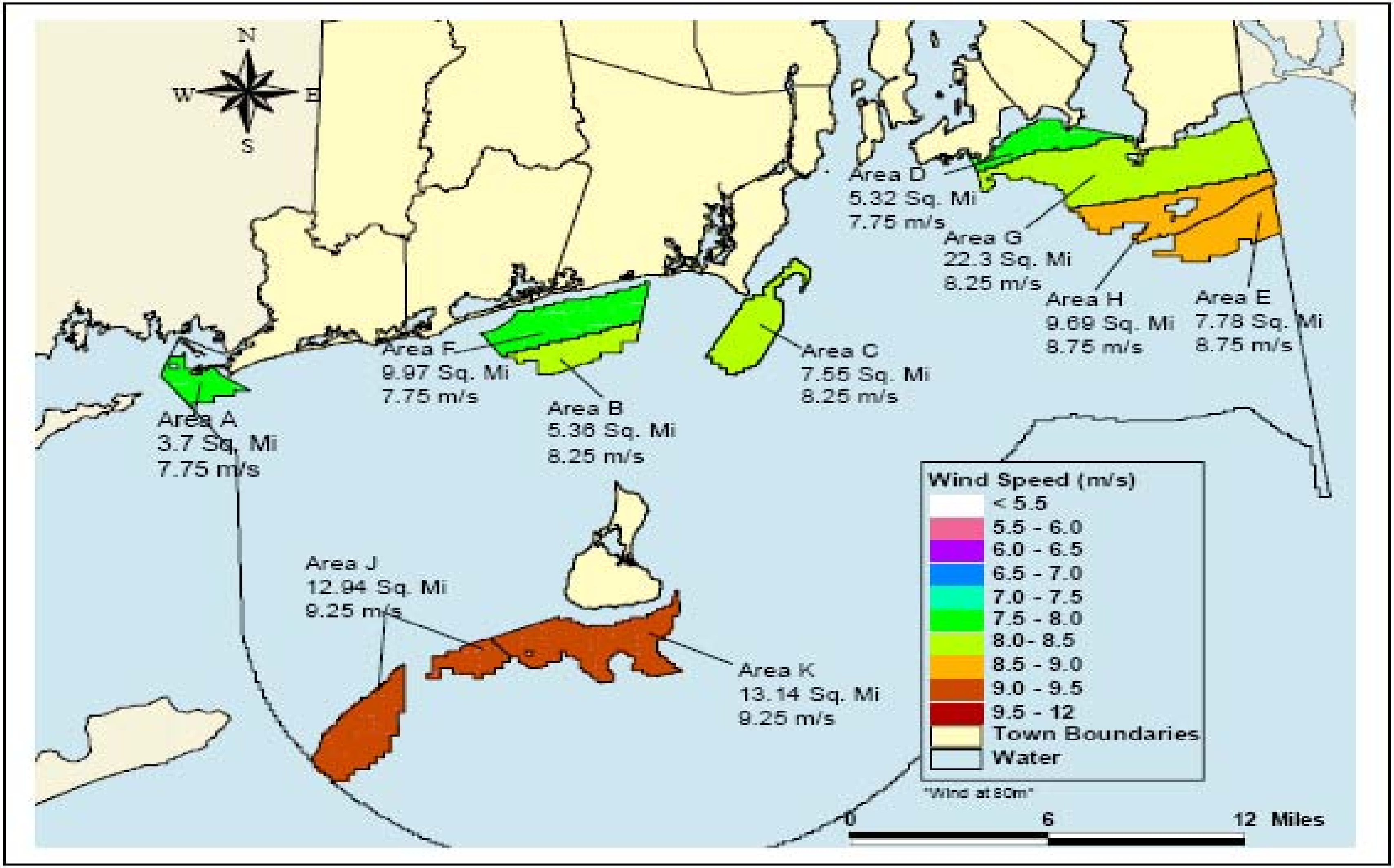


Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation

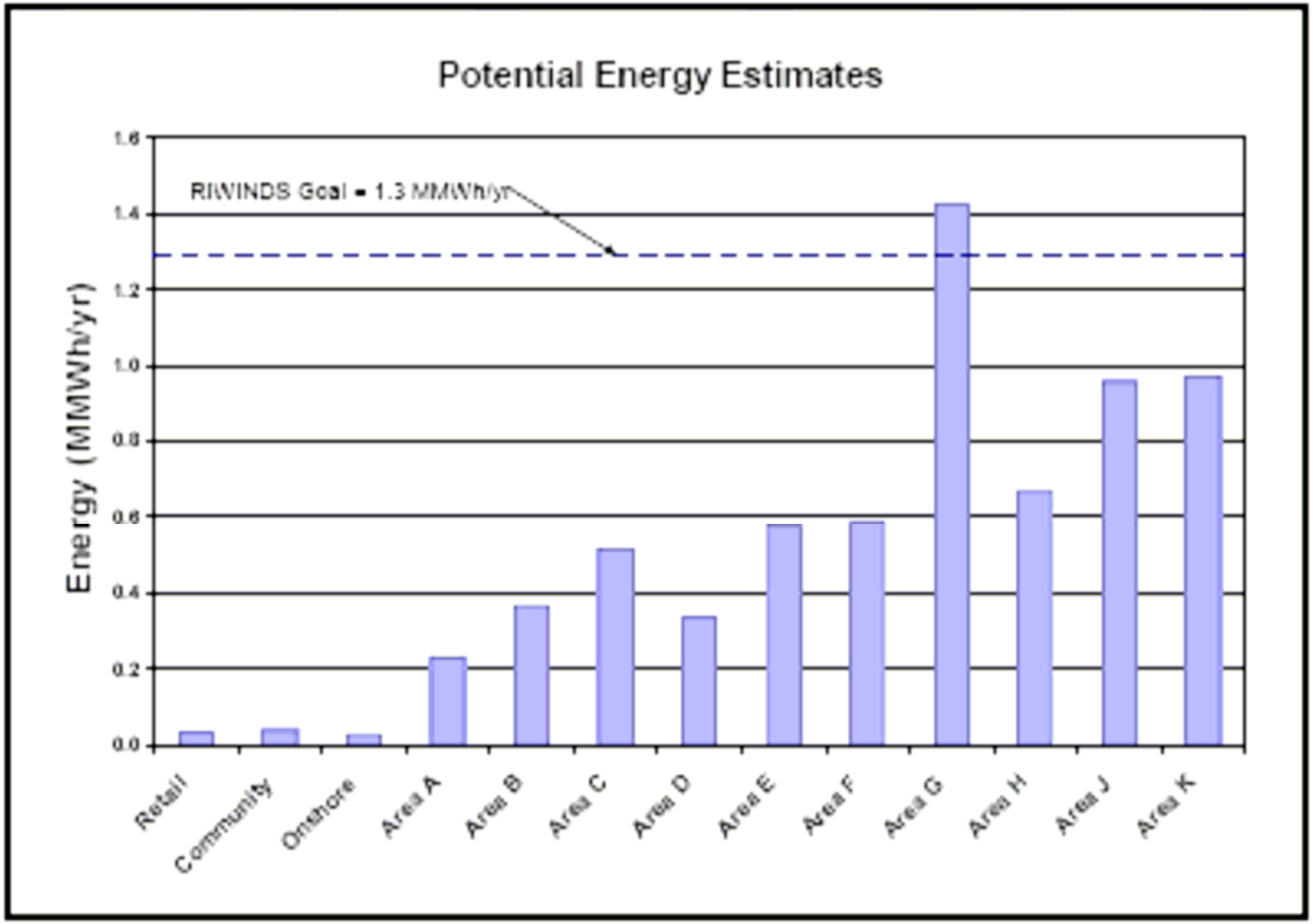


Figure 2 - RIWINDS Estimated Energy Generation for Each of the Identified Offshore Areas

ATM (2007)

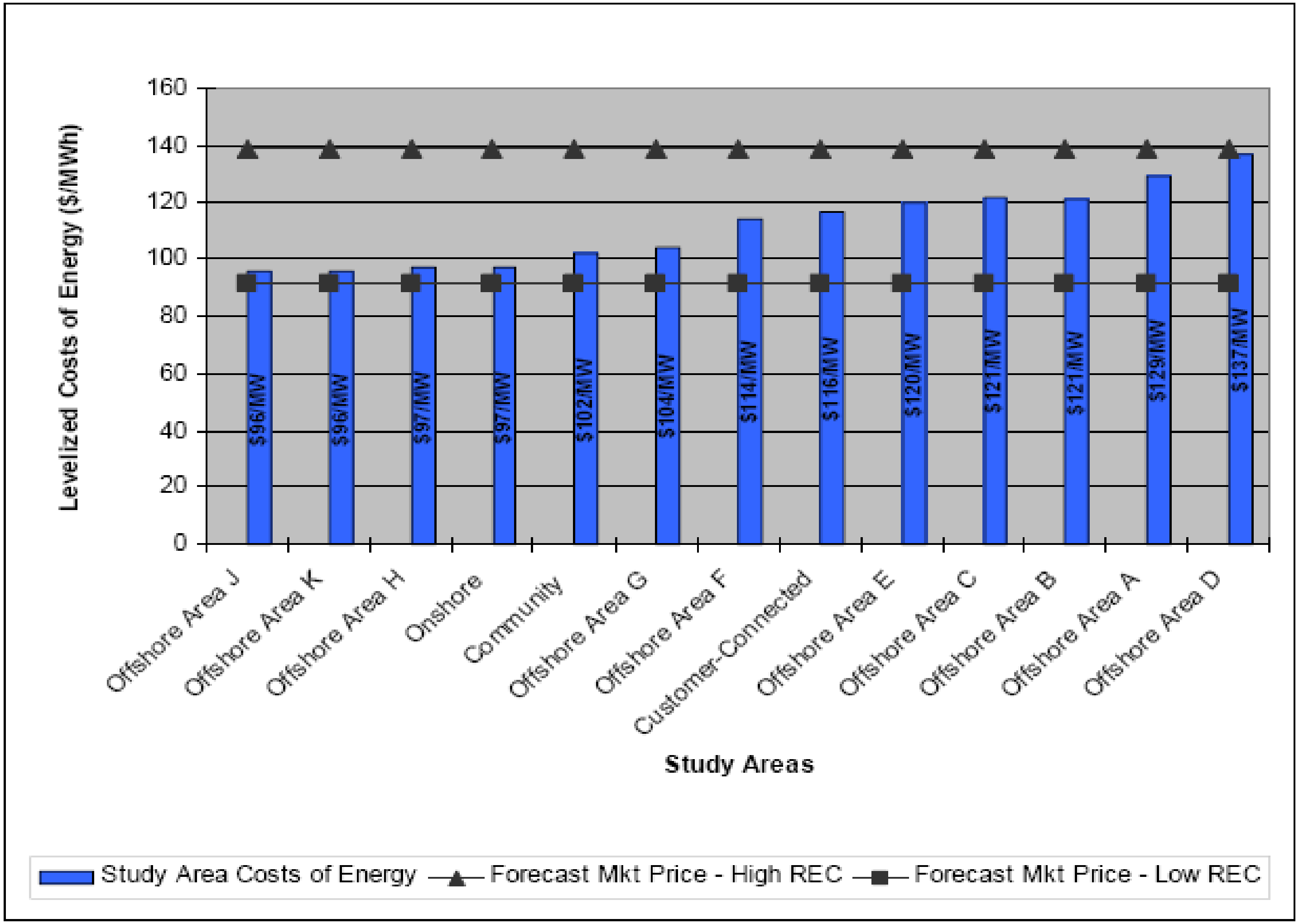


Figure 3 - RIWINDS Report Figure 6.2: Estimated Levelized Cost of Energy Compared to Levelized Wholesale Electricity Price Forecasts

ATM (2007)

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.

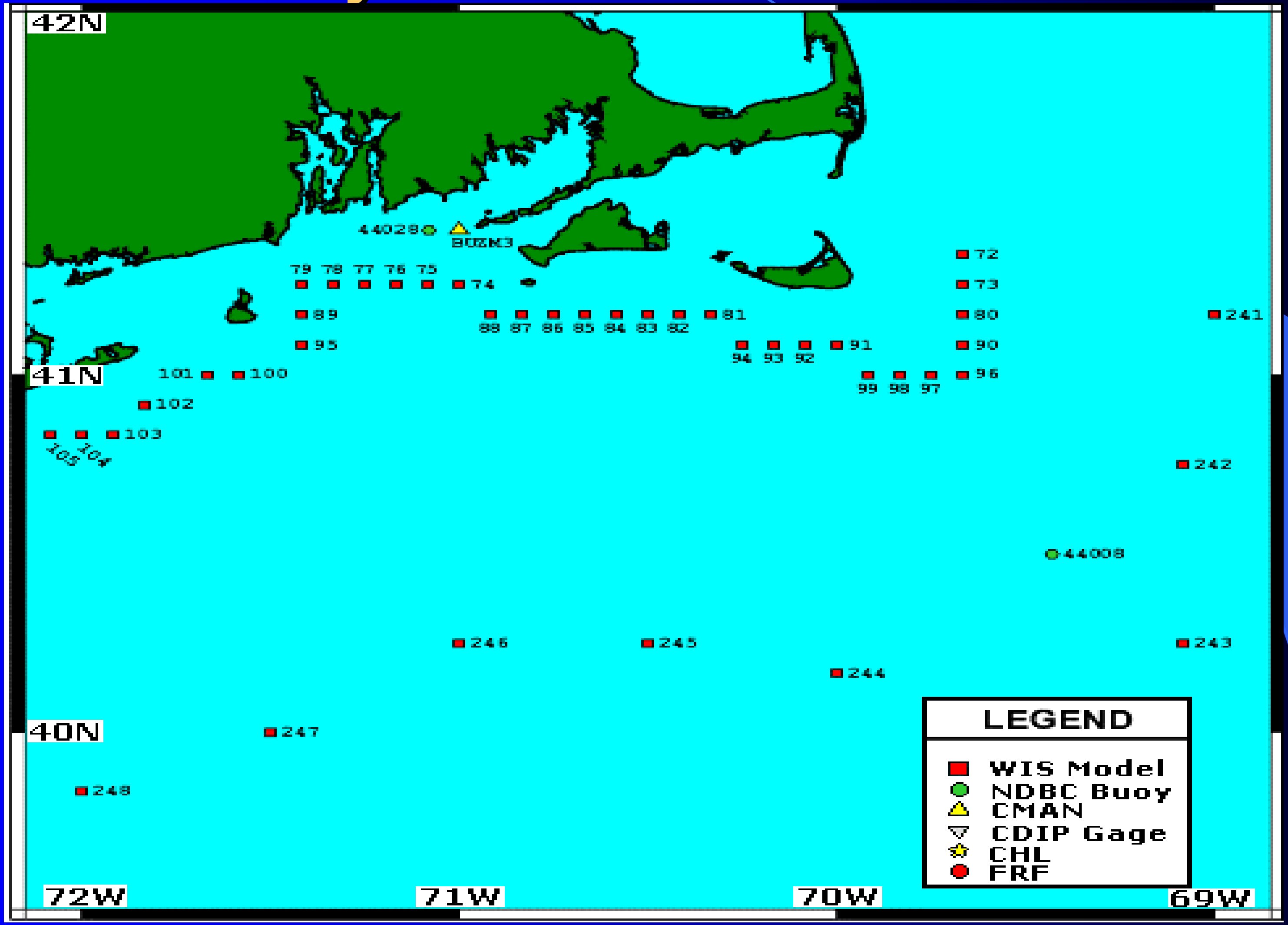
Readily Available Wind Data for Meso-Map Validation

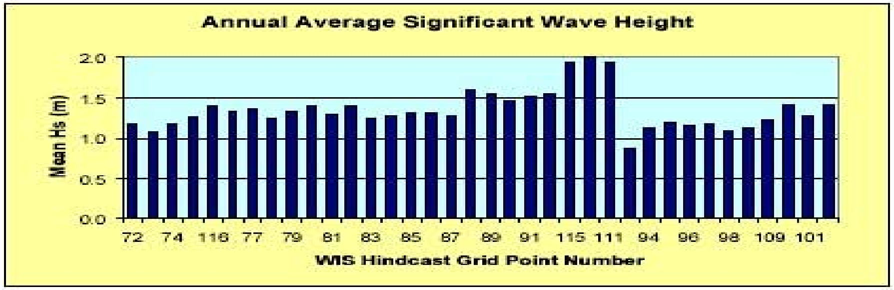
- US Army Corp Wave Information Study

  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





Annual Average Significant Wave Heights

Offshore exposed = 2.0 m

Nearshore exposed = 1.5 m

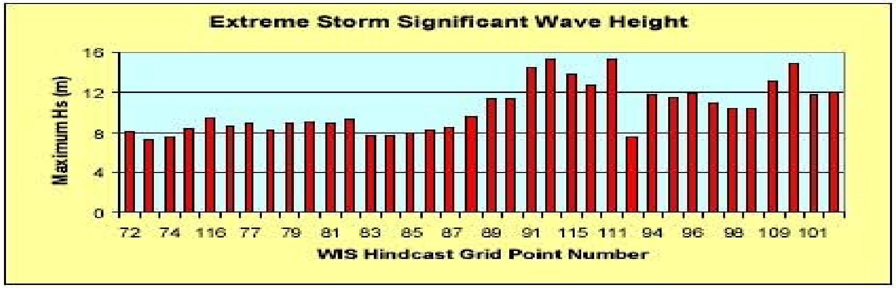
Nearshore sheltered by Nova Scotia or by Cape Cod and the Nantucket Shoals = 1.1 - 1.4 m

Extreme Storm Significant Wave Heights

Exposed locations = 12 - 15 m

Sheltered locations north of Cape Cod = 10 - 14 m

Sheltered locations south and west of Nantucket = 7 - 9 m



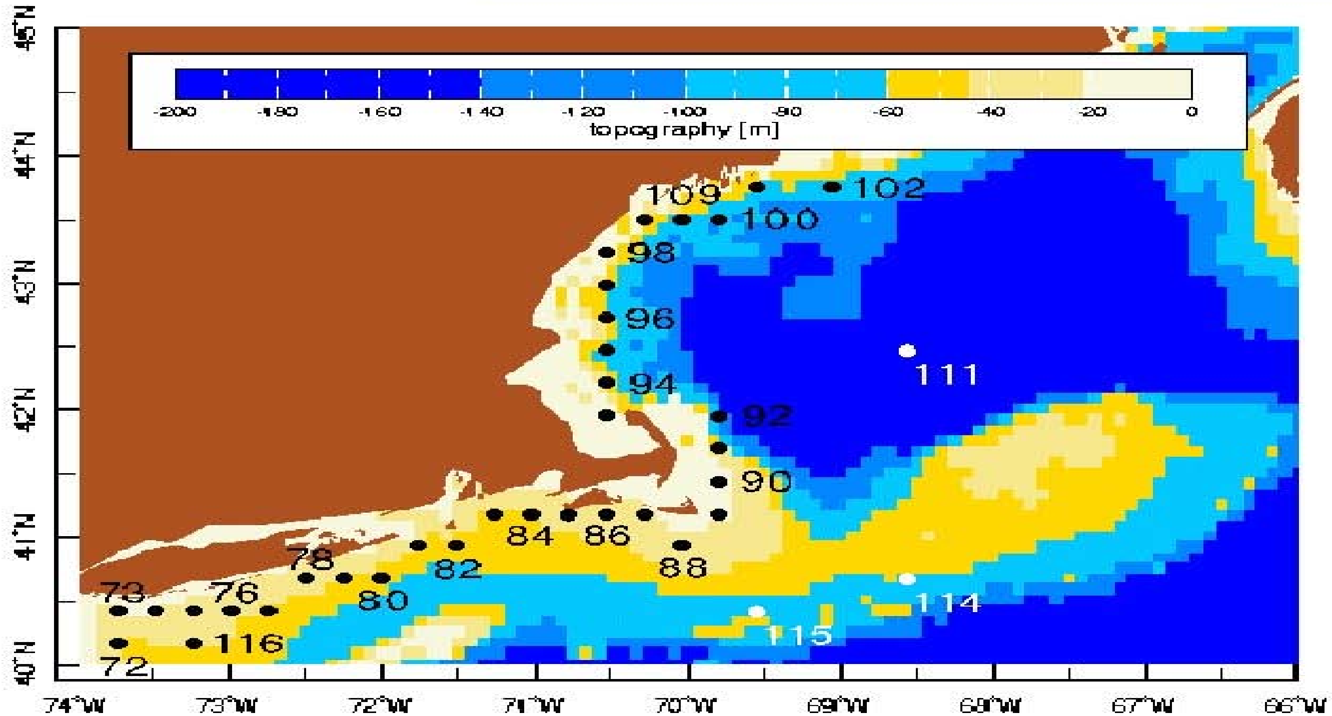
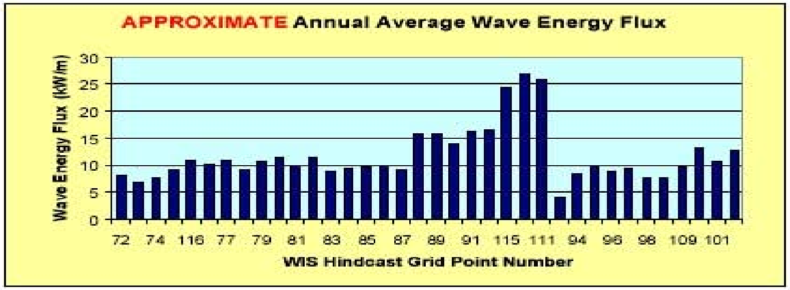


Figure 4. Geographic distribution of normal and survival significant wave heights off southern New England.



Annual Average Wave Energy Flux

Offshore exposed = 25 kW/ m

Nearshore exposed = 15 kW/m

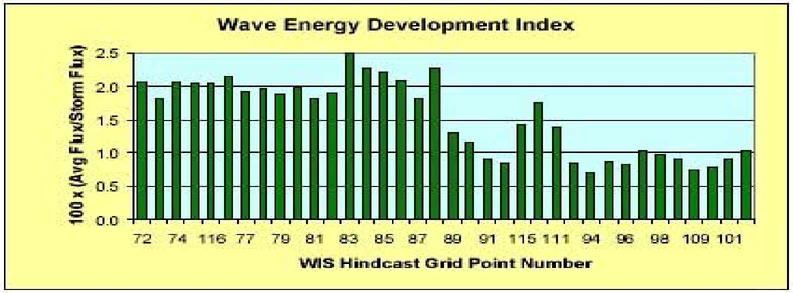
Nearshore sheltered by Nova Scotia or by Cape Cod and the Nantucket Shoals ~ 10 kW/m

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



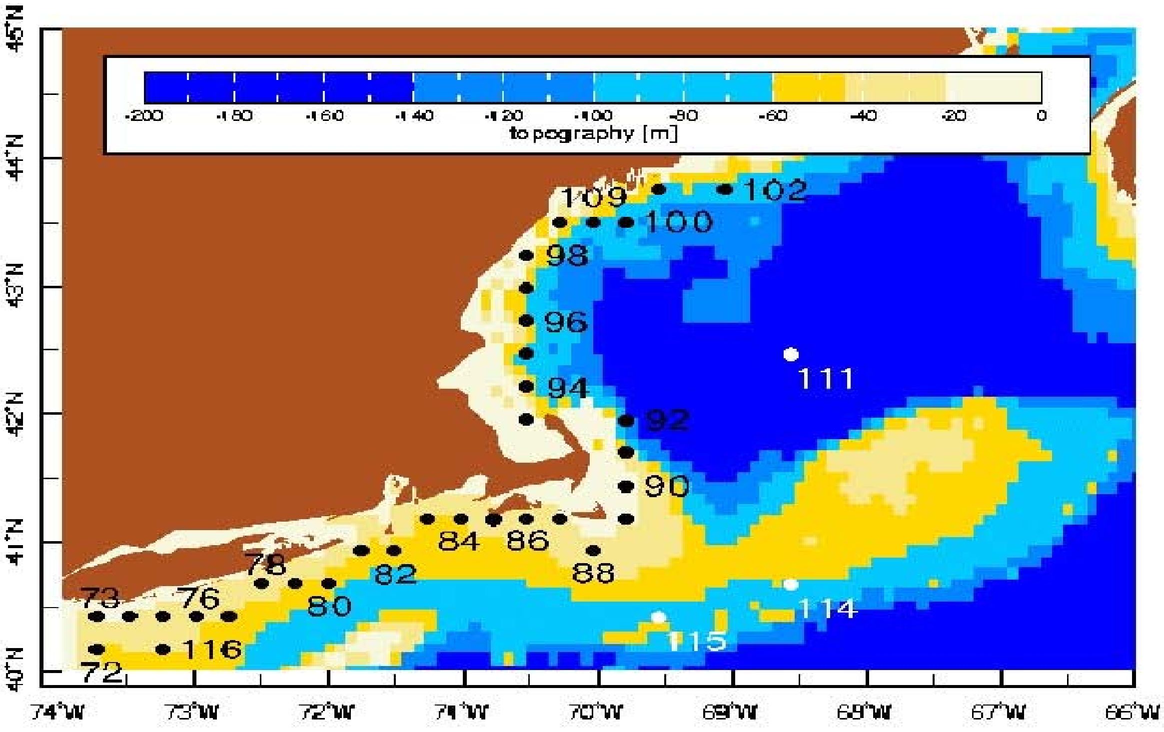
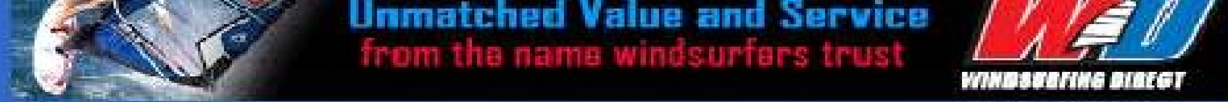


Figure 5. Geographic distribution of mean incident wave energy flux and wave energy development index off southern New England.

iWINDSURF.com



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RI- Rhode Island

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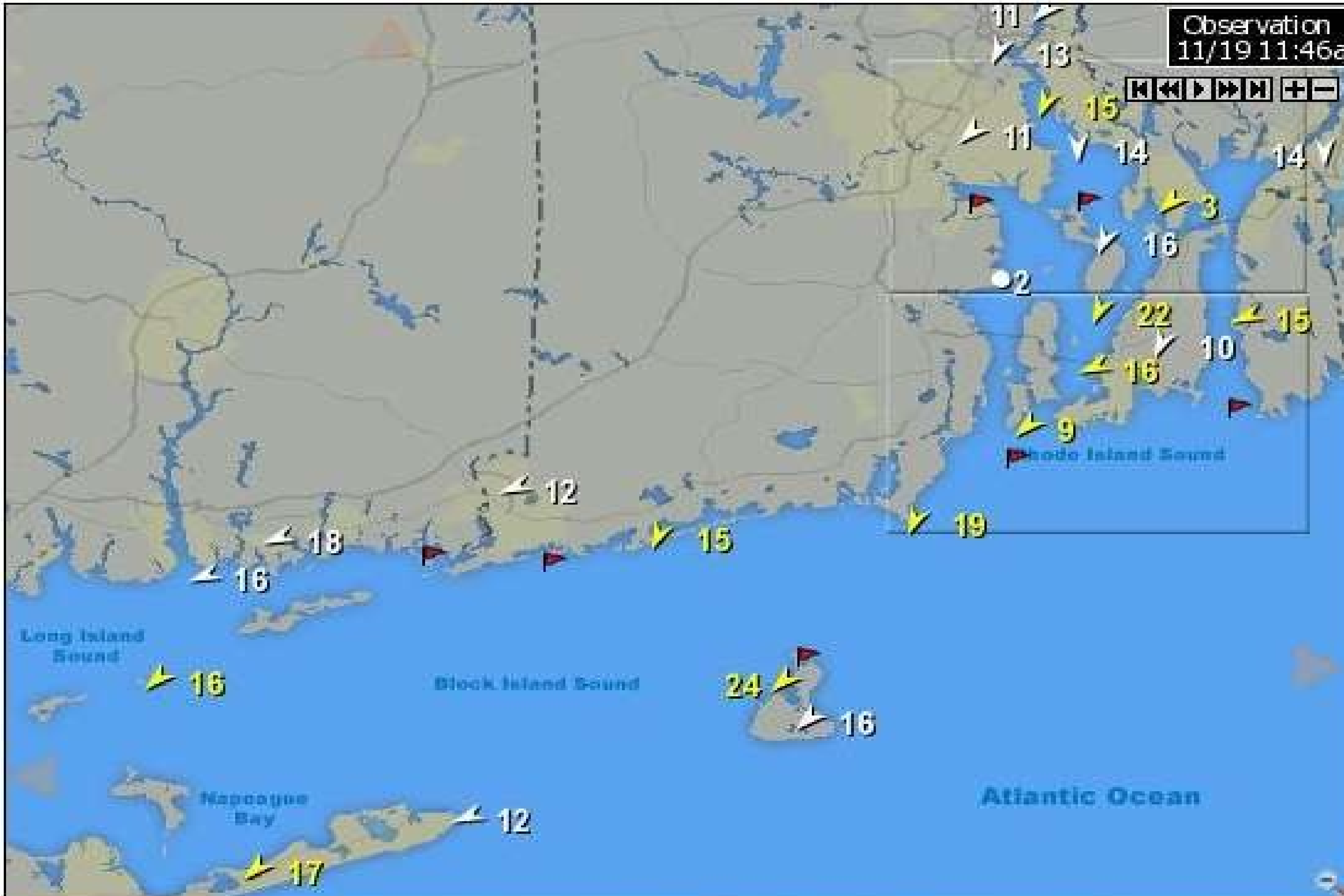
Real-Time Data
- > Dynamic Map
- > Wind Obs Map
- > Radar + Satellite Map
- > Wind Obs Summary

Computer Forecasts
- > Model Tables
- > Wind Vector Fx Map

More Maps
Other Resources
Wind Graphs
Meteograms

Switch Region

Map Time: LATEST OBSERVATIONS



WeatherFlow Sensor | Non-WeatherFlow Sensor | WeatherFlow Forecast | Forecast Only Site

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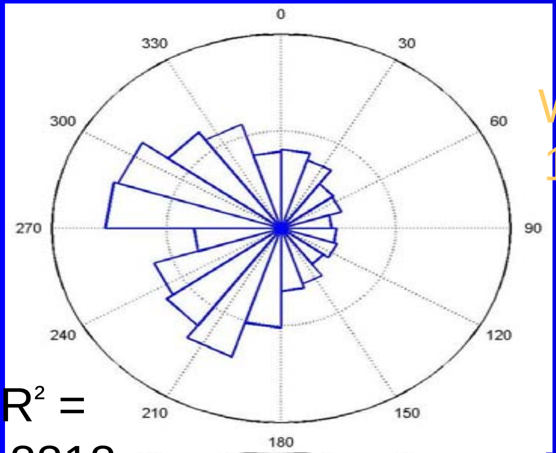
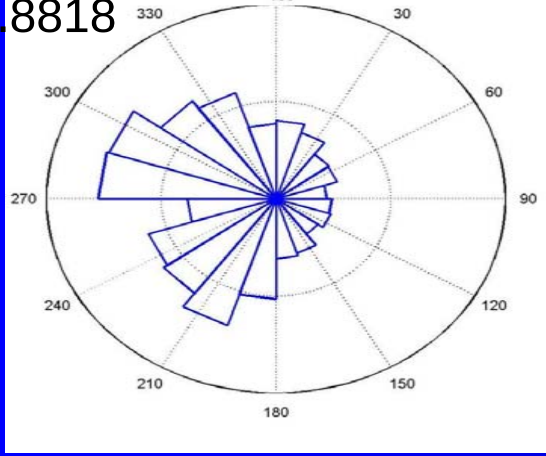
Wind Data

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

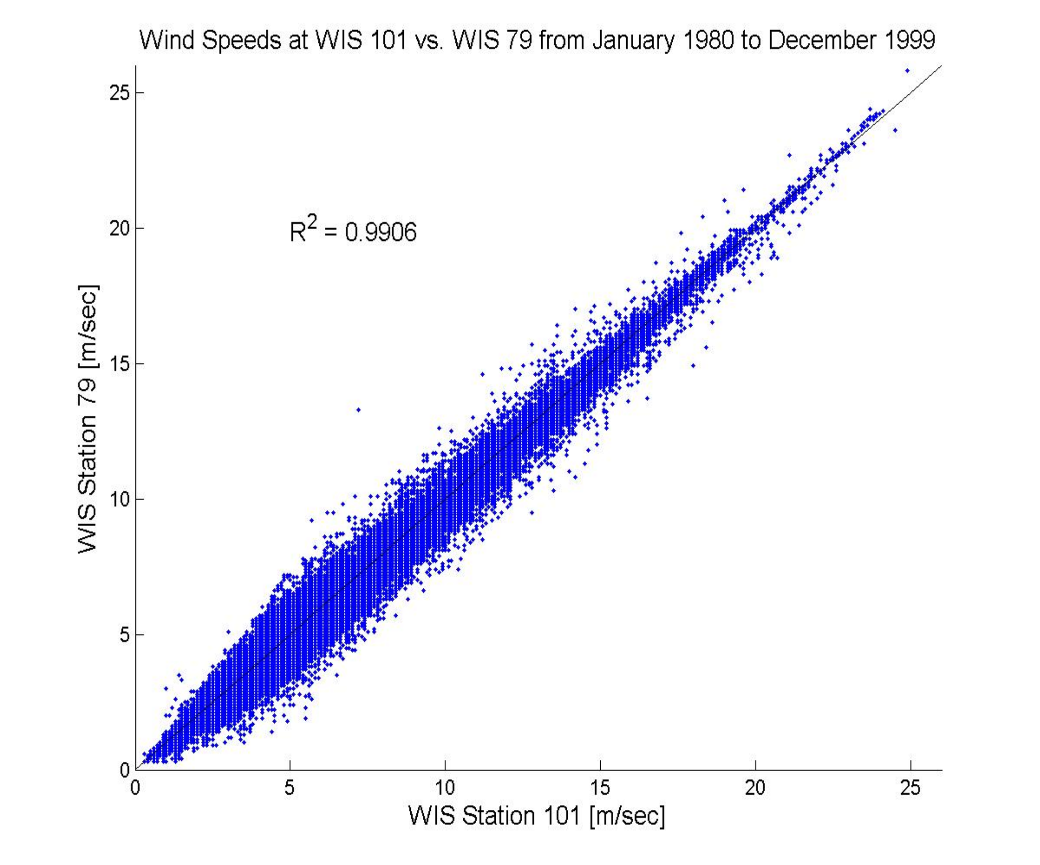


WIS 101

R^2 = 0.8818

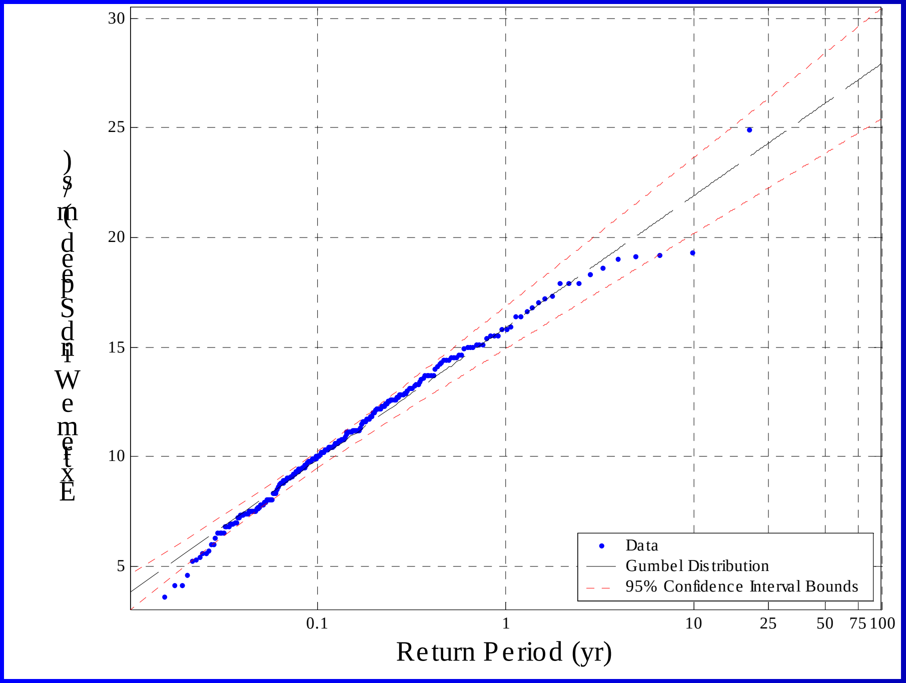


WIS 79



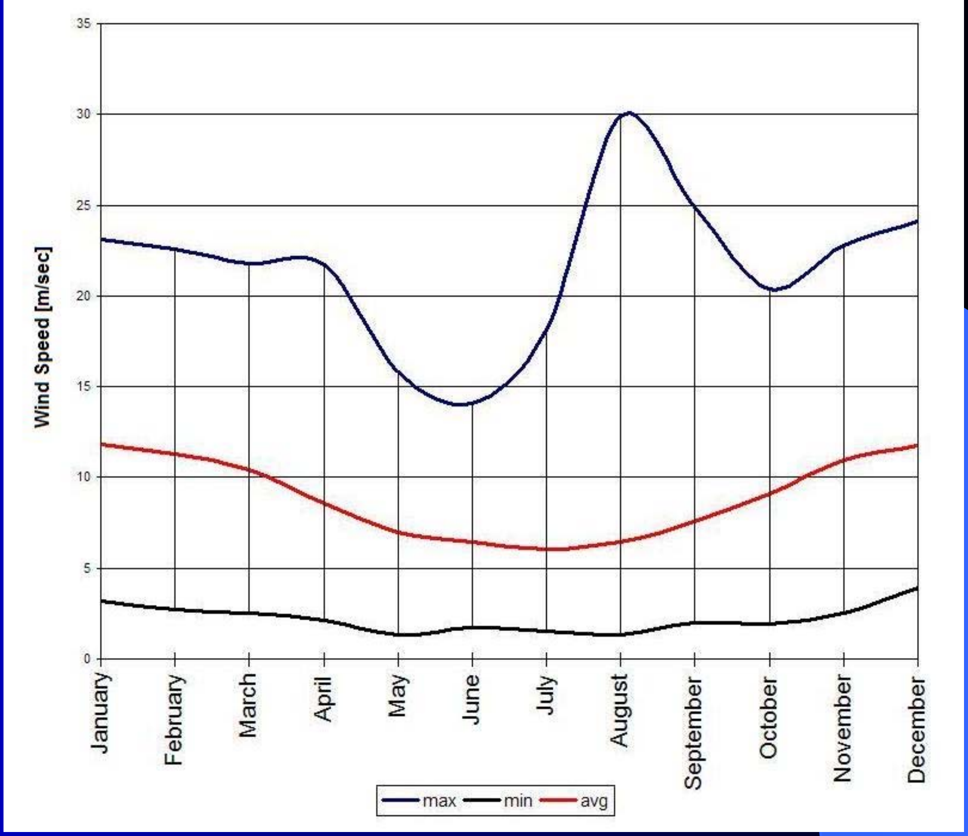
Wind Data

Extreme Wind Analysis



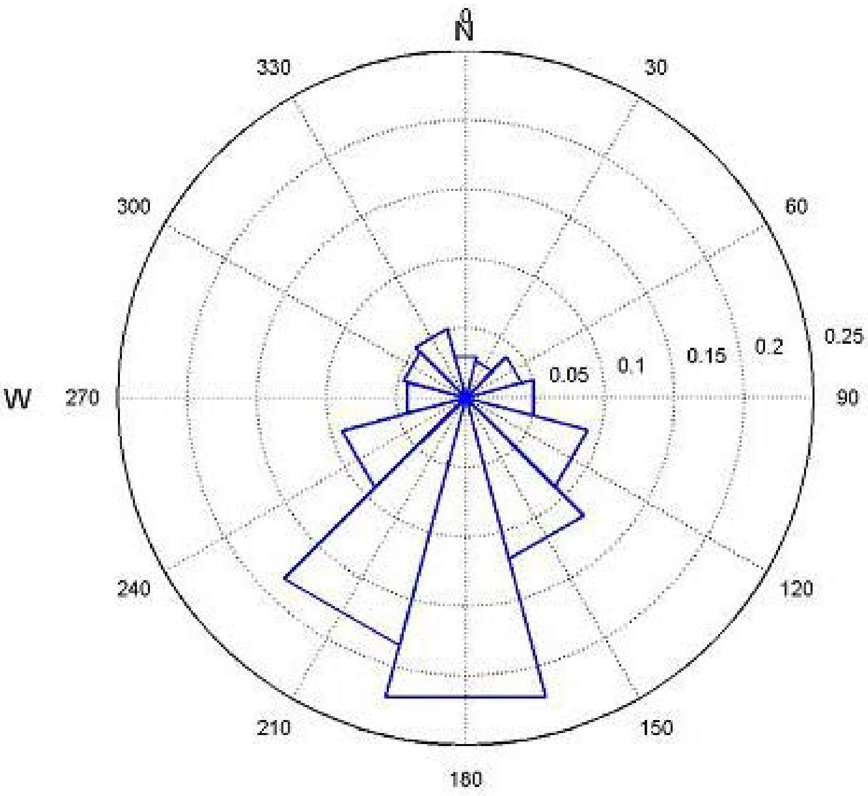
	180 deg (S)	270 deg (W)	30 deg (NNE)
	Wind Speed [m/sec]	Wind Speed [m/sec]	Wind Speed [m/sec]
5 year	20.11	22.91	22.99
10 year	21.92	25.07	25.32
25 year	24.32	27.92	28.41
50 year	26.14	30.08	30.74
100 year	27.95	32.24	33.07

Average Maximum Winds



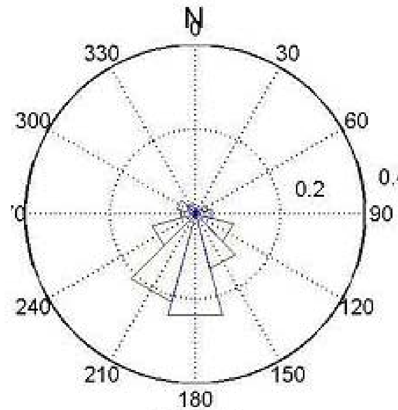
WAVES

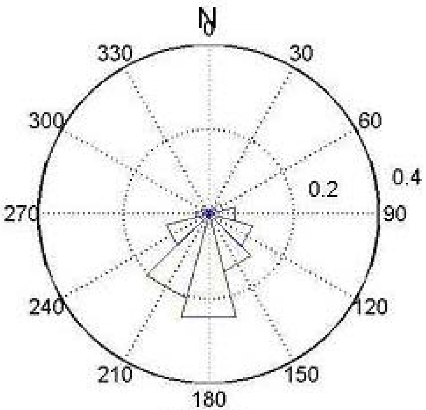
Offshore Wave Analysis



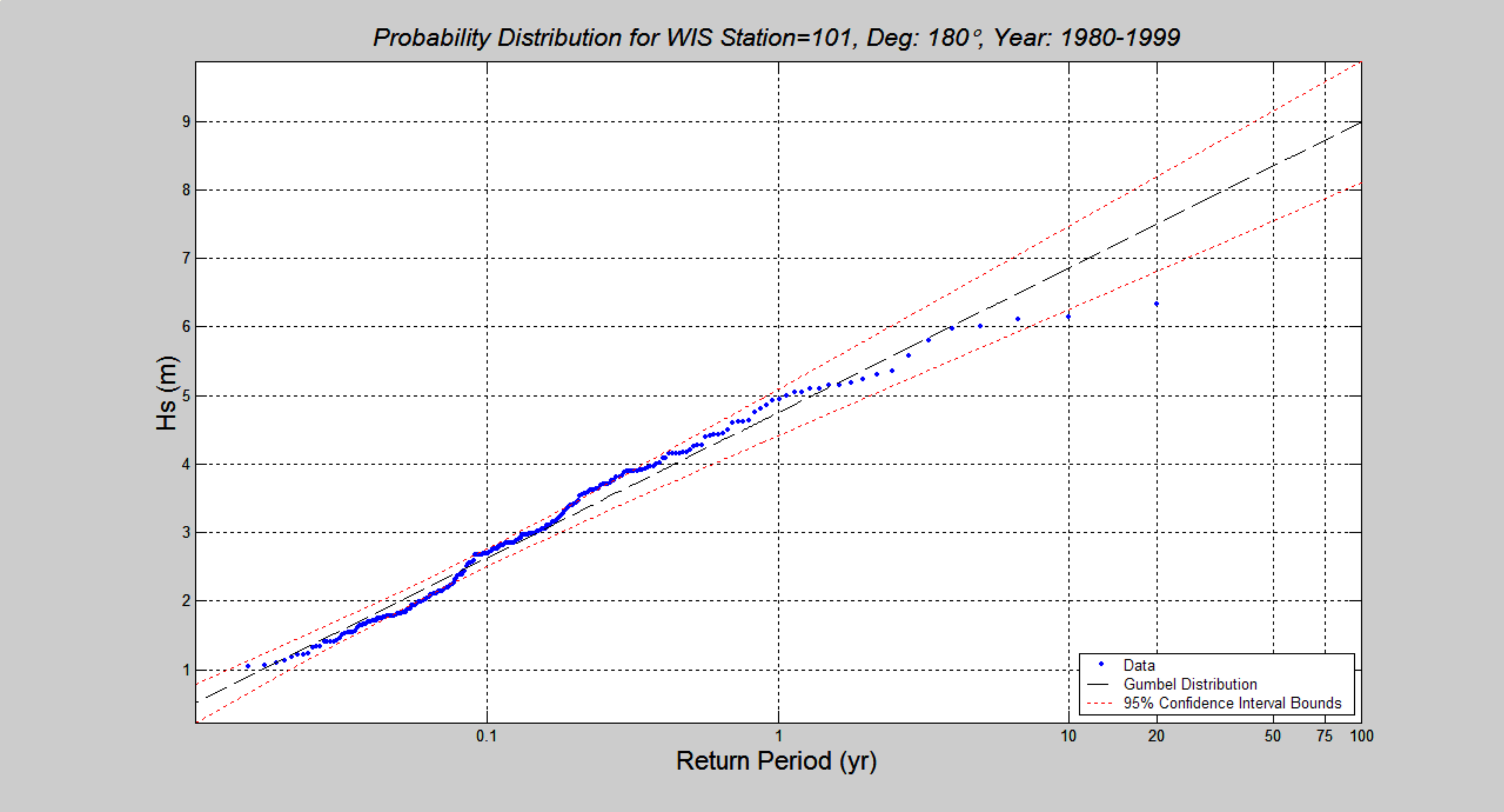
WIS Station #101
Wave Rose

- 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

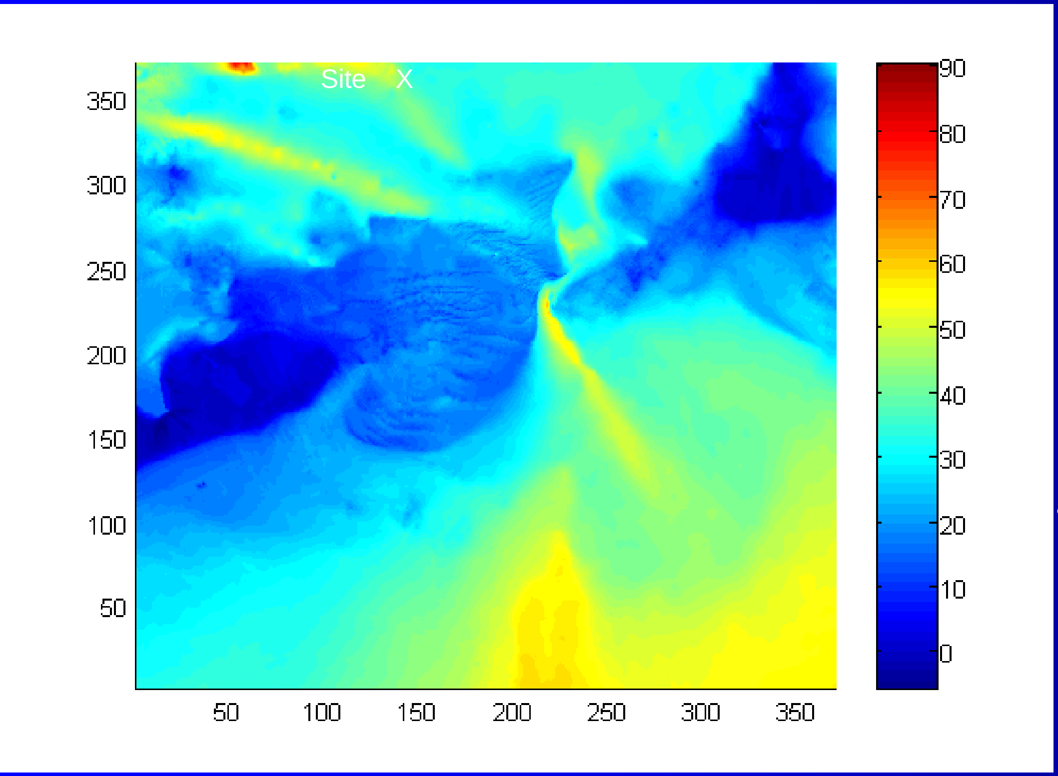
	150 deg (SSE)		180 deg (S)		210 deg (SSW)	
	Hs [m]	**Ts [s]**	**Hs [m]**	**Ts [s]**	**Hs [m]**	**Ts [s]**
Average yearly	1.09	6.12	1.15	5.75	1.29	5.34

	150 deg (SSE)		180 deg (S)		210 deg (SSW)	
	Hs [m]	**Ts [s]**	**Hs [m]**	**Ts [s]**	**Hs [m]**	**Ts [s]**
10 year	6.65	12.90	6.87	13.11	6.70	12.94
95% UL	*7.29*	*13.50*	*7.48*	*13.67*	*7.31*	*13.52*
25 year	7.53	13.72	7.72	13.89	7.54	13.73
95% UL	*8.27*	*14.38*	*8.43*	*14.52*	*8.26*	*14.37*
50 year	8.19	14.31	8.35	14.45	8.18	14.30
95% UL	*9.02*	*15.02*	*9.16*	*15.13*	*8.98*	*14.98*
100 year	8.85	14.88	8.99	14.99	8.81	14.84
95% UL	*9.77*	*15.63*	*9.88*	*15.72*	*9.70*	*15.57*

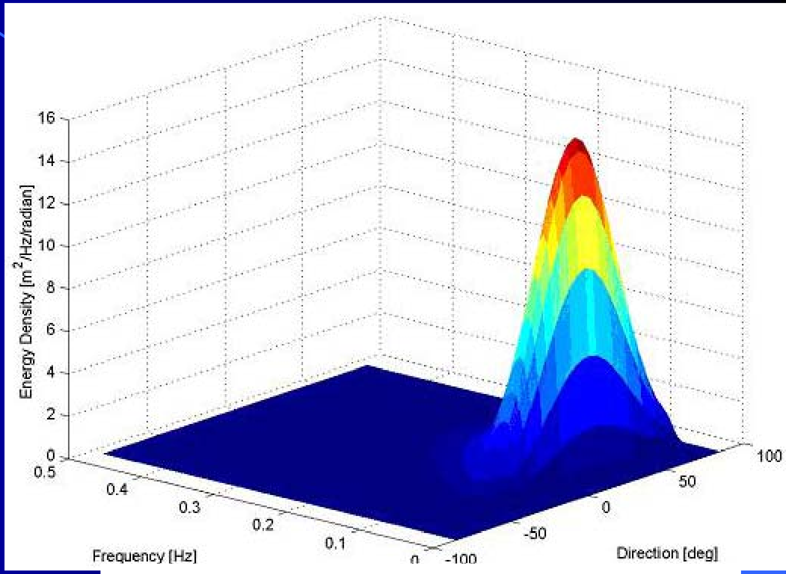
- wave heights in meters ; wave periods in seconds

Wave Environment

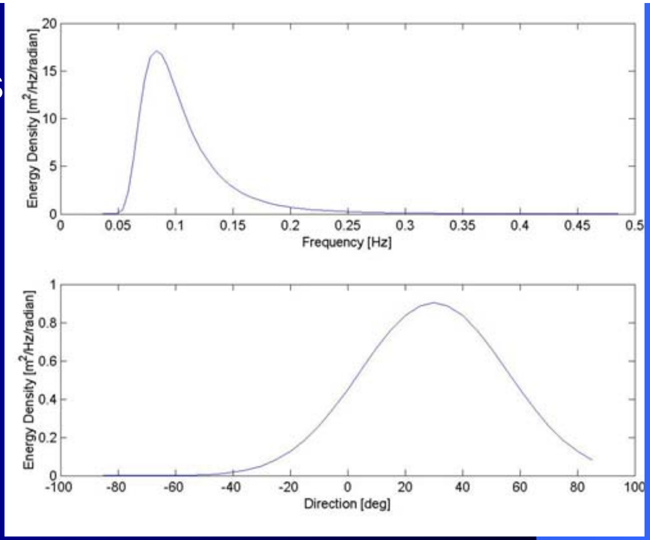
- Example STWAVE input



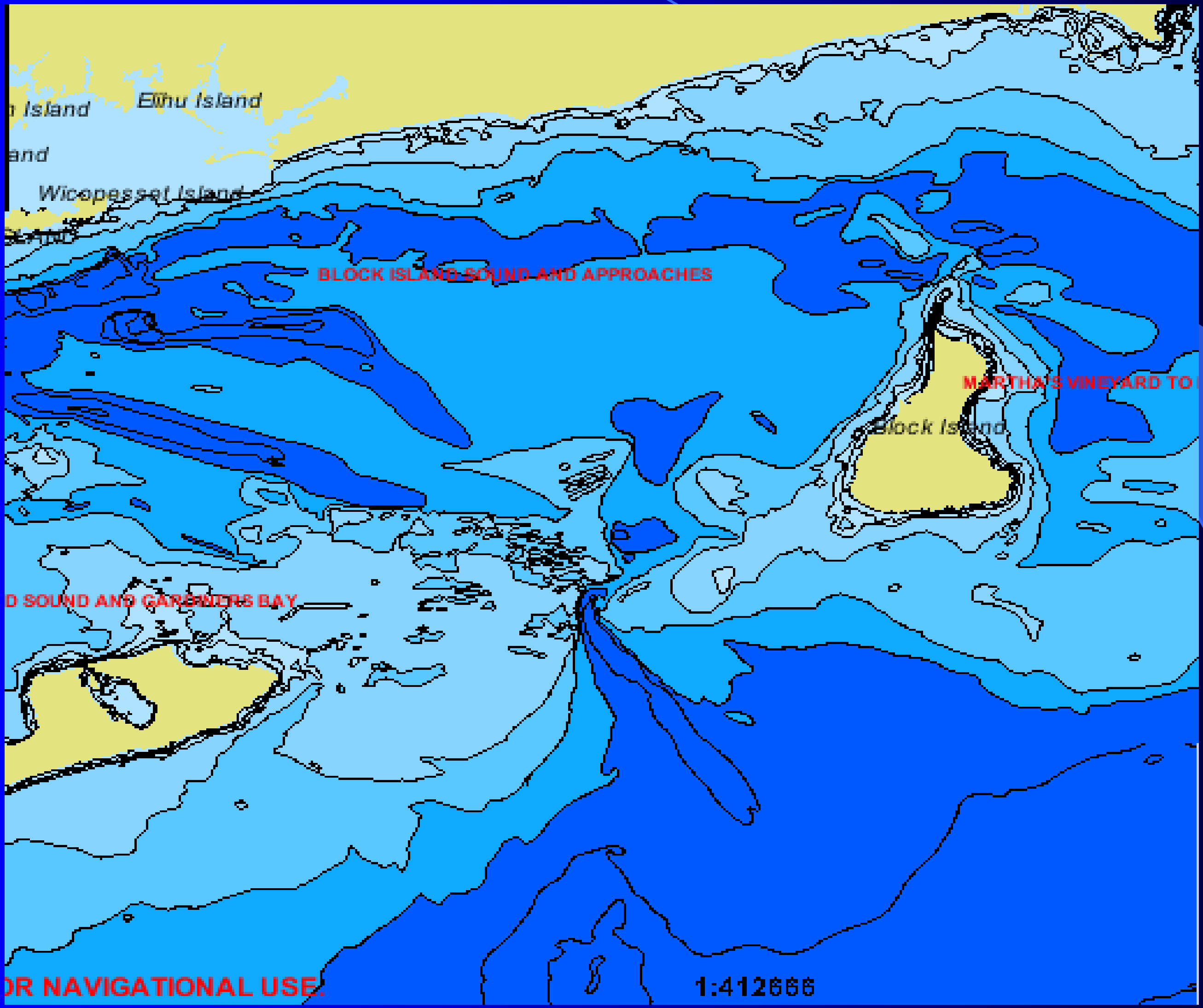
Bathymetry grid (depths in meters)



H_s = 4 m
T_p = 12 s
θ = 30°

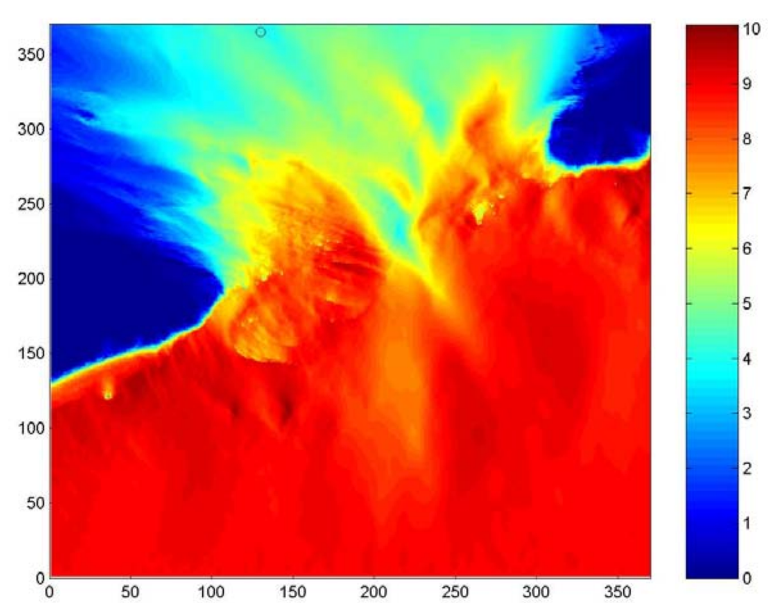


NOAA Bathymetry

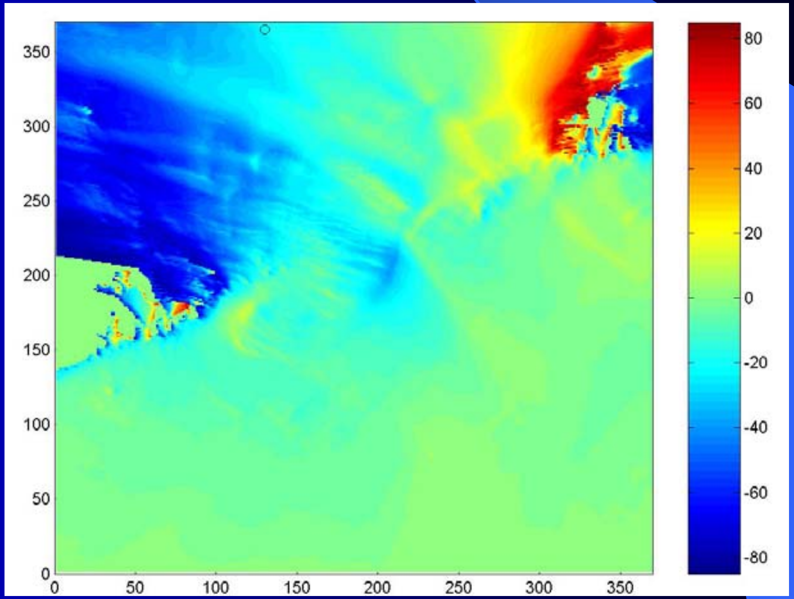


Wave Environment

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



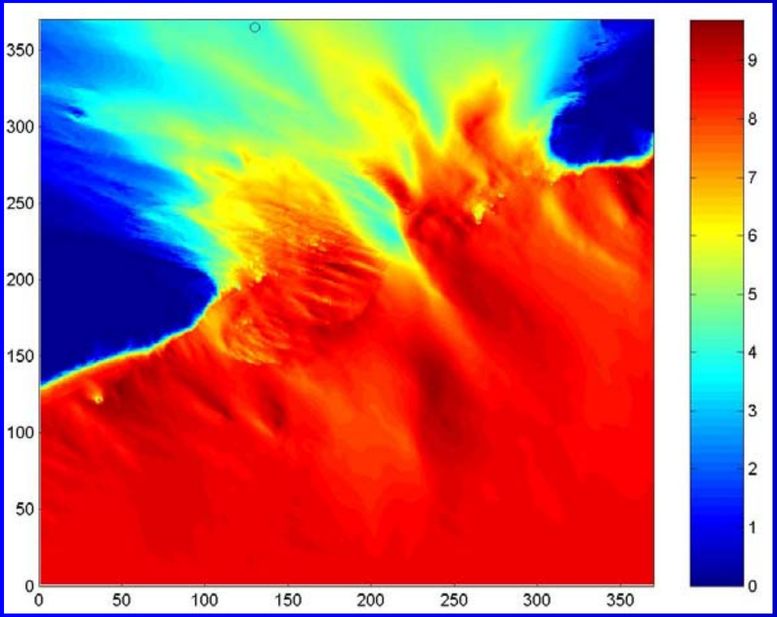
Wave Height (meters)



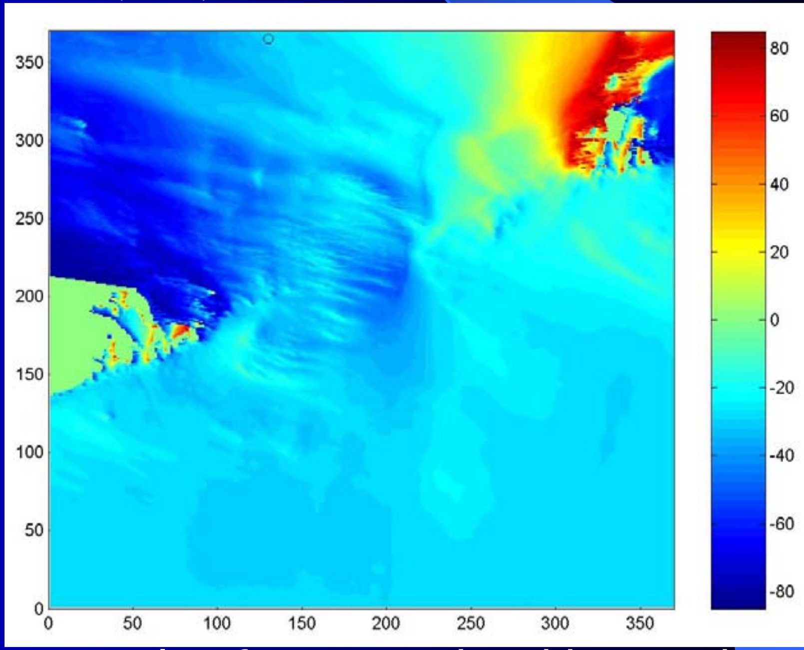
Angle of Propagation (degrees)

Wave Environment

- Extremes
  - 100 year return period
    - Hs (WIS) = 8.85 m; Hs (site) = 4.07 m; Tp = 14.88 s
    - Dir (WIS) = 150° (SSE); Dir (site) = 151° (SSE)



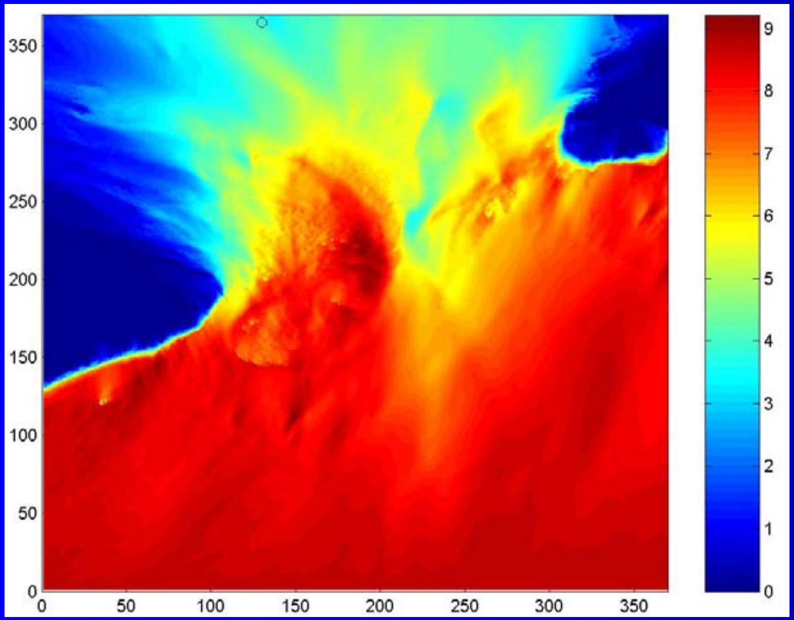
Wave Height (meters)



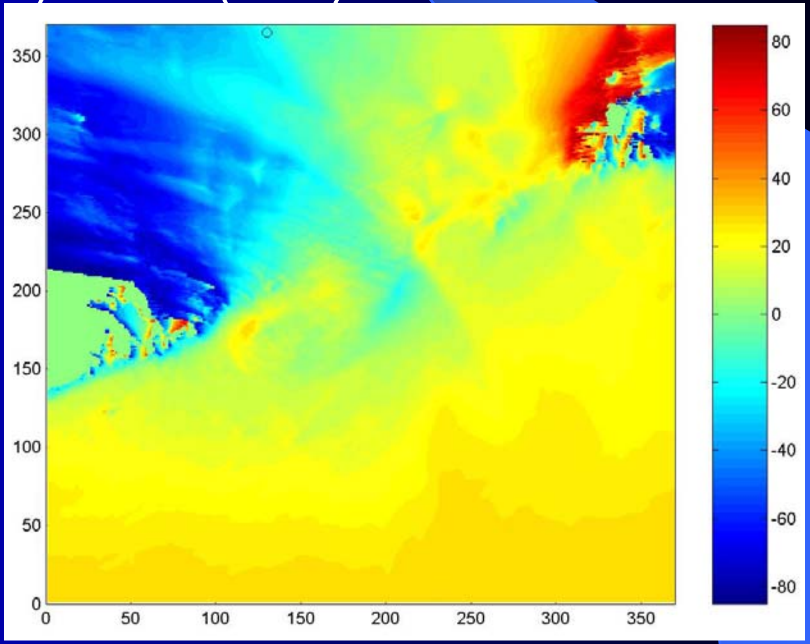
Angle of Propagation (degrees)

Wave Environment

- Extremes
  - 100 year return period
    - Hs (WIS) = 8.81 m; Hs (site) = 3.59 m; Tp = 14.84 s
    - Dir (WIS) = 210° (SSW); Dir (site) = 164° (SSE)

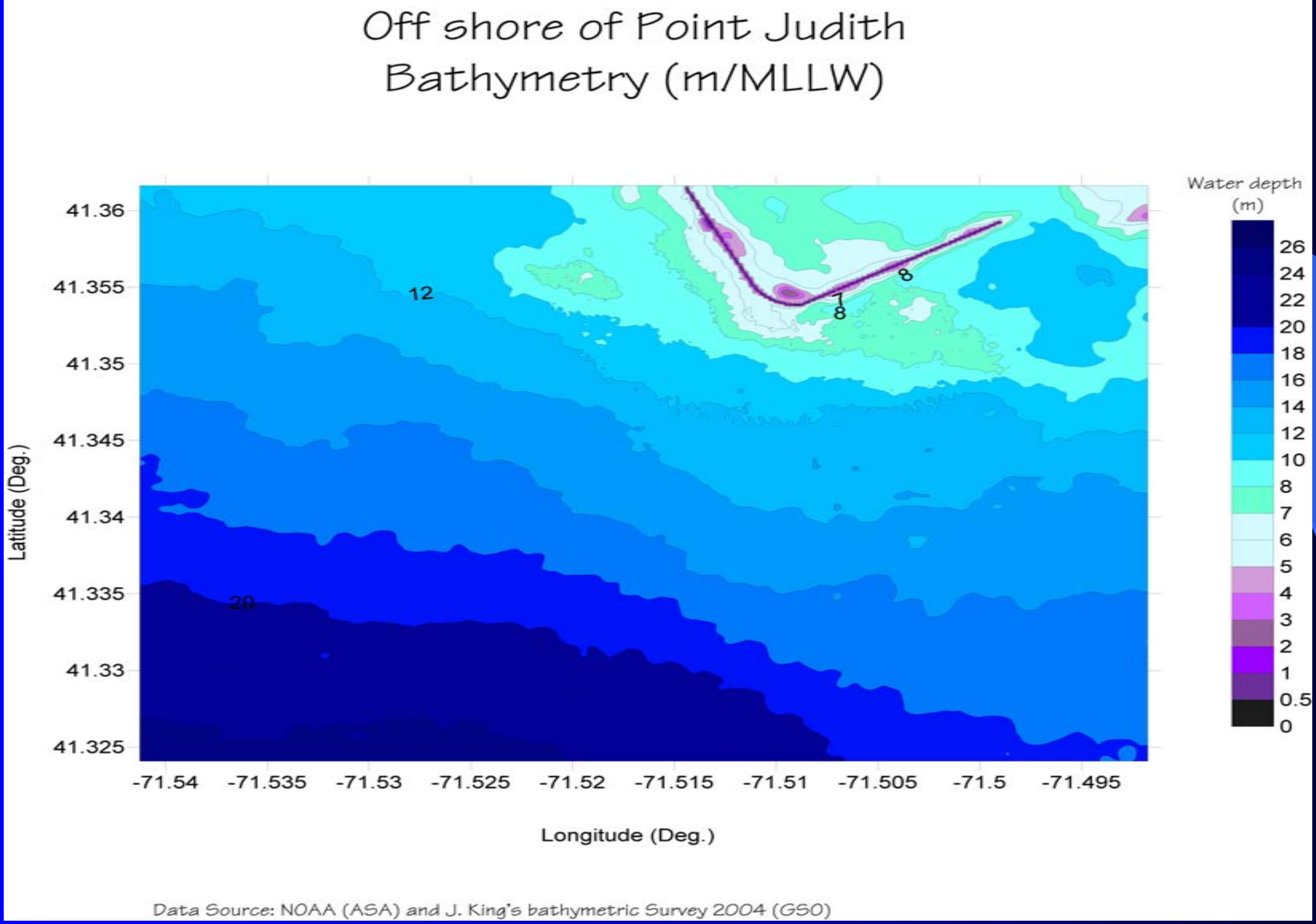


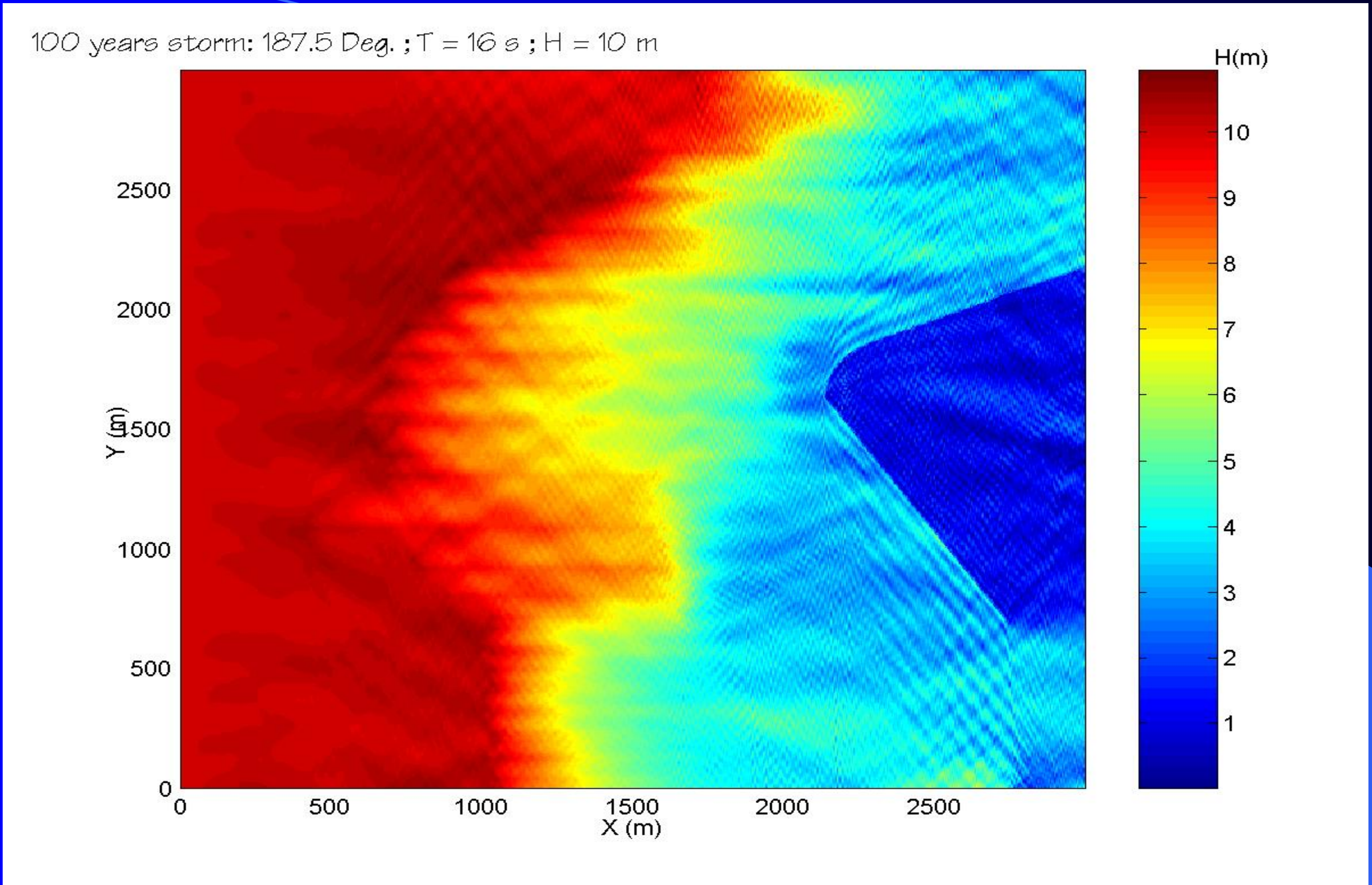
Wave Height (meters)



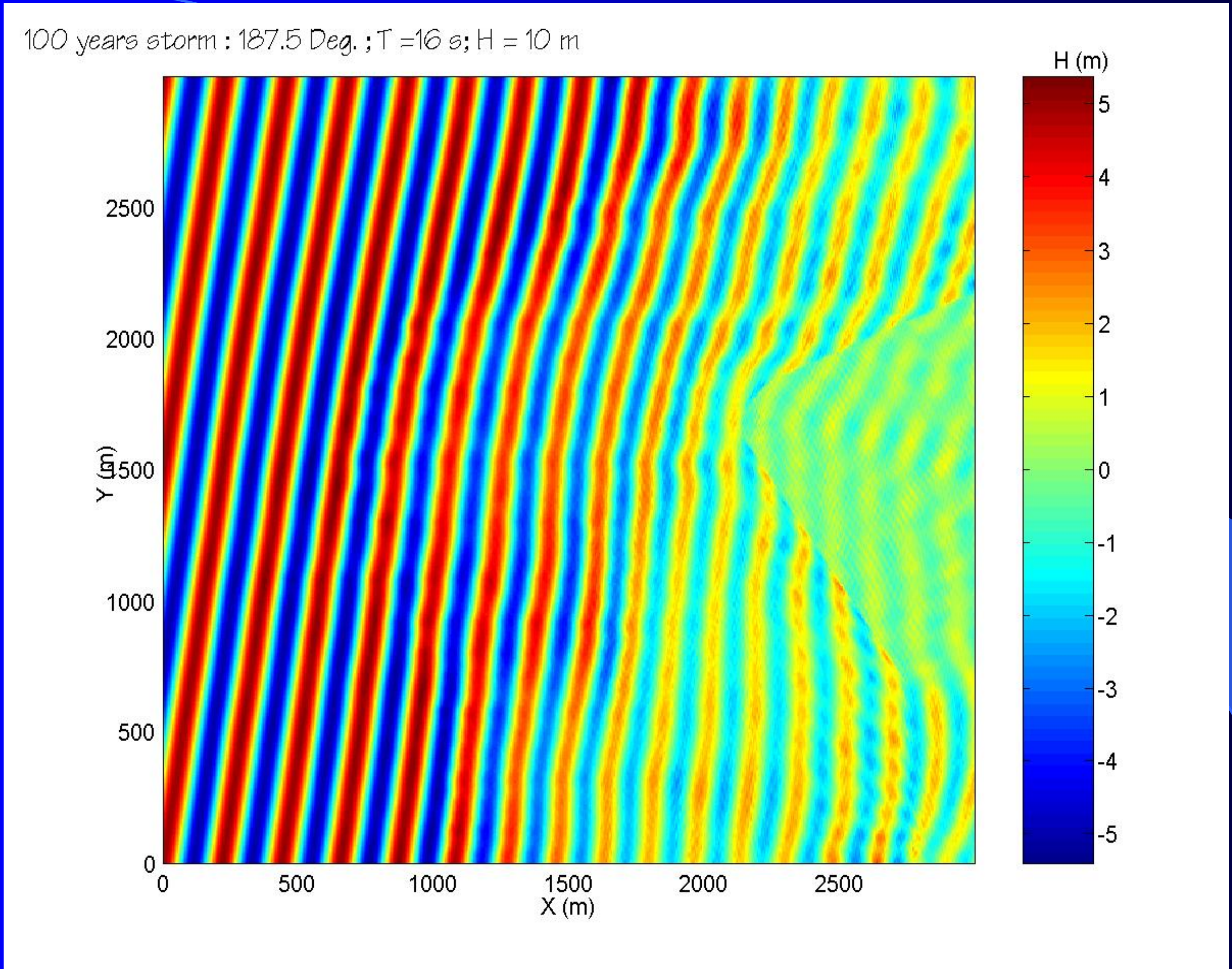
Angle of Propagation (degrees)

Bathymetry South of Pt Judith Harbor of Refuge

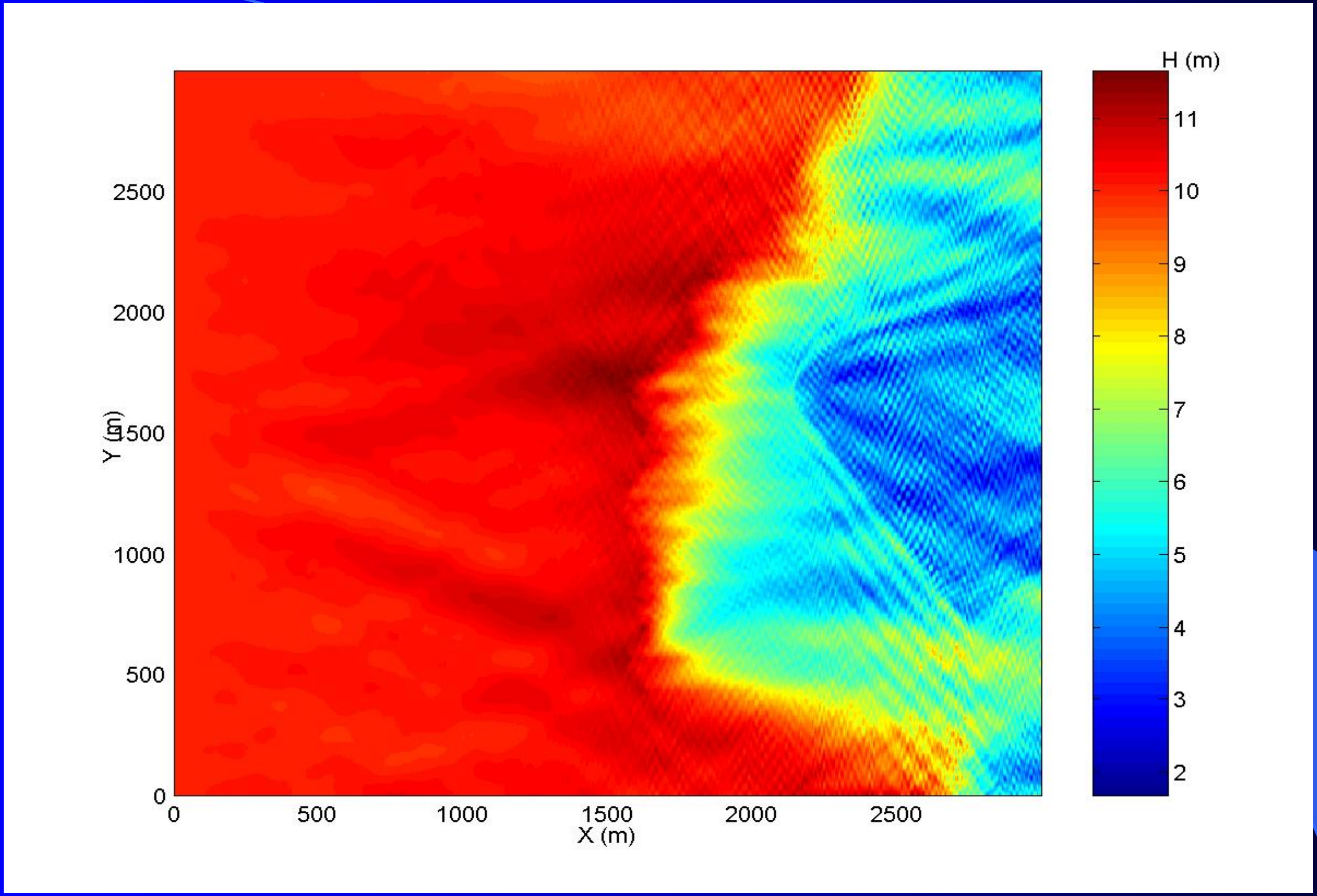




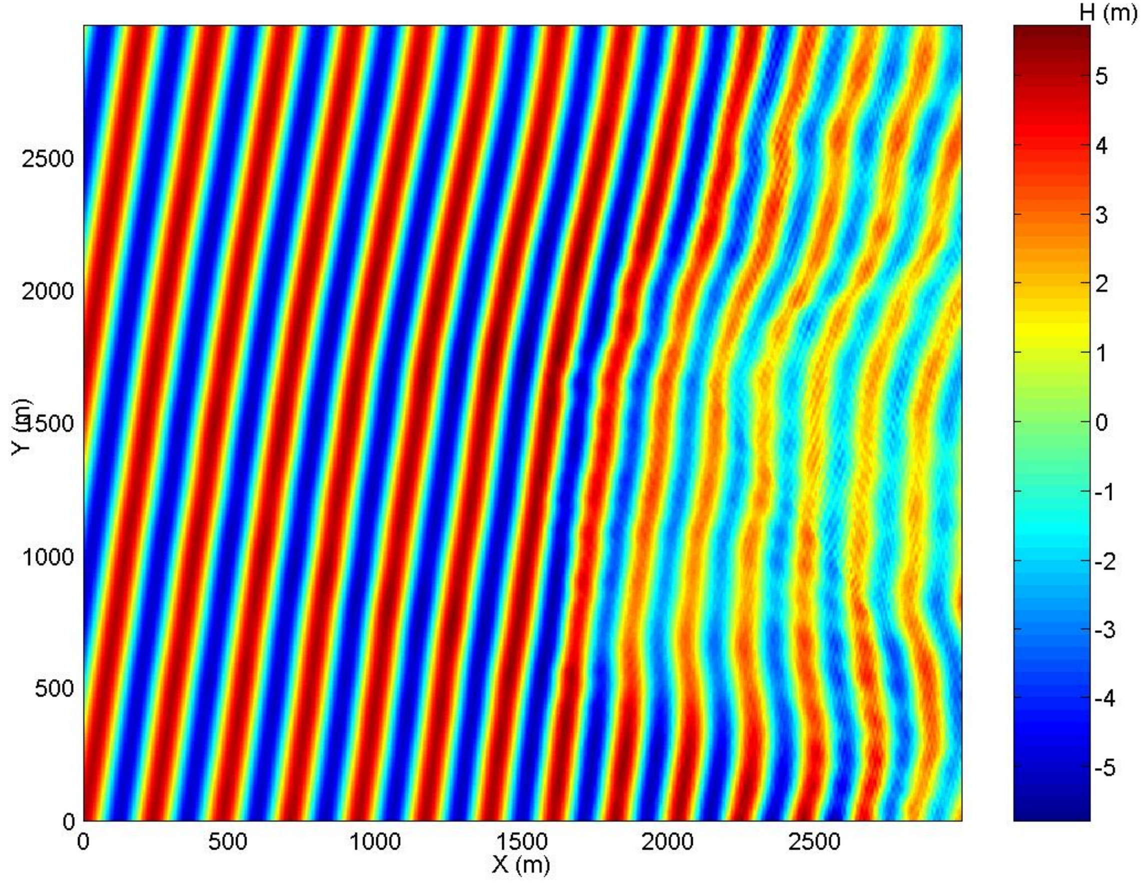
100 yr storm waves off Pt Judith (Grilli et al, 2005)



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)

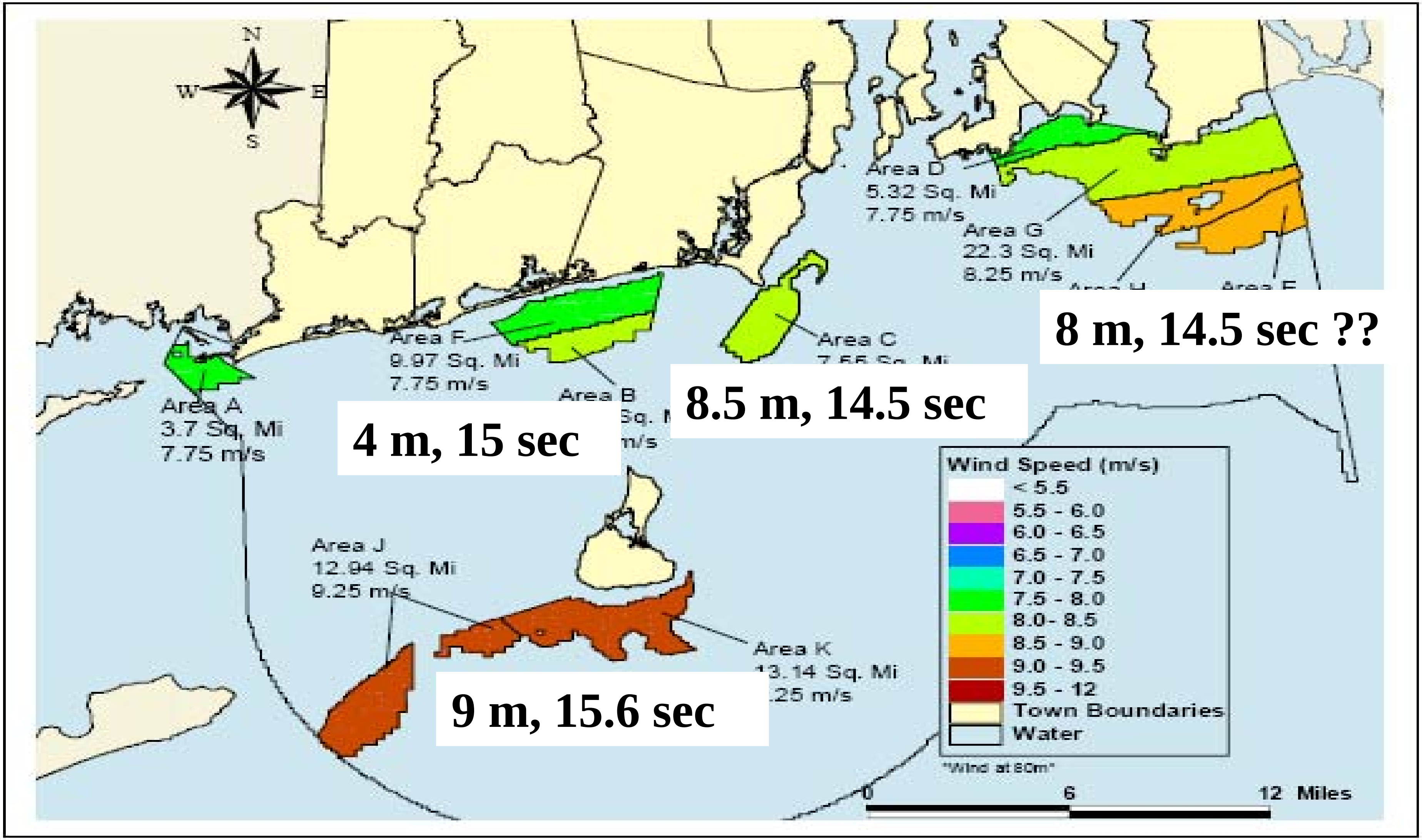
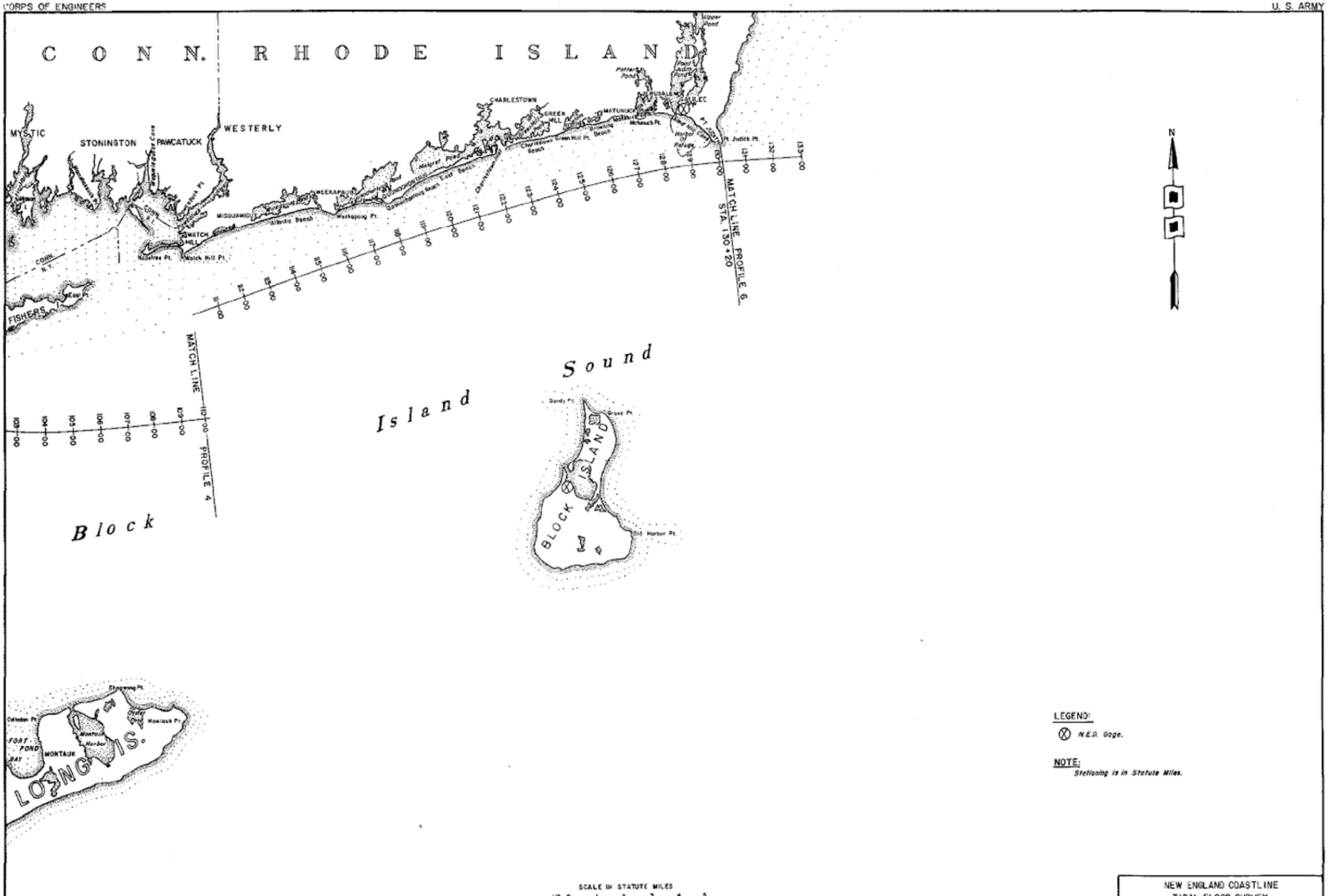


Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation

STORM SURGE

Storm Surge Heights

- US Army Corp of Engineers, Tidal Flood Profiles New England Coastal Waters (1988)
- 1, 10, 50, and 100 yr return period surges and Standard Project Hurricane(SPH)

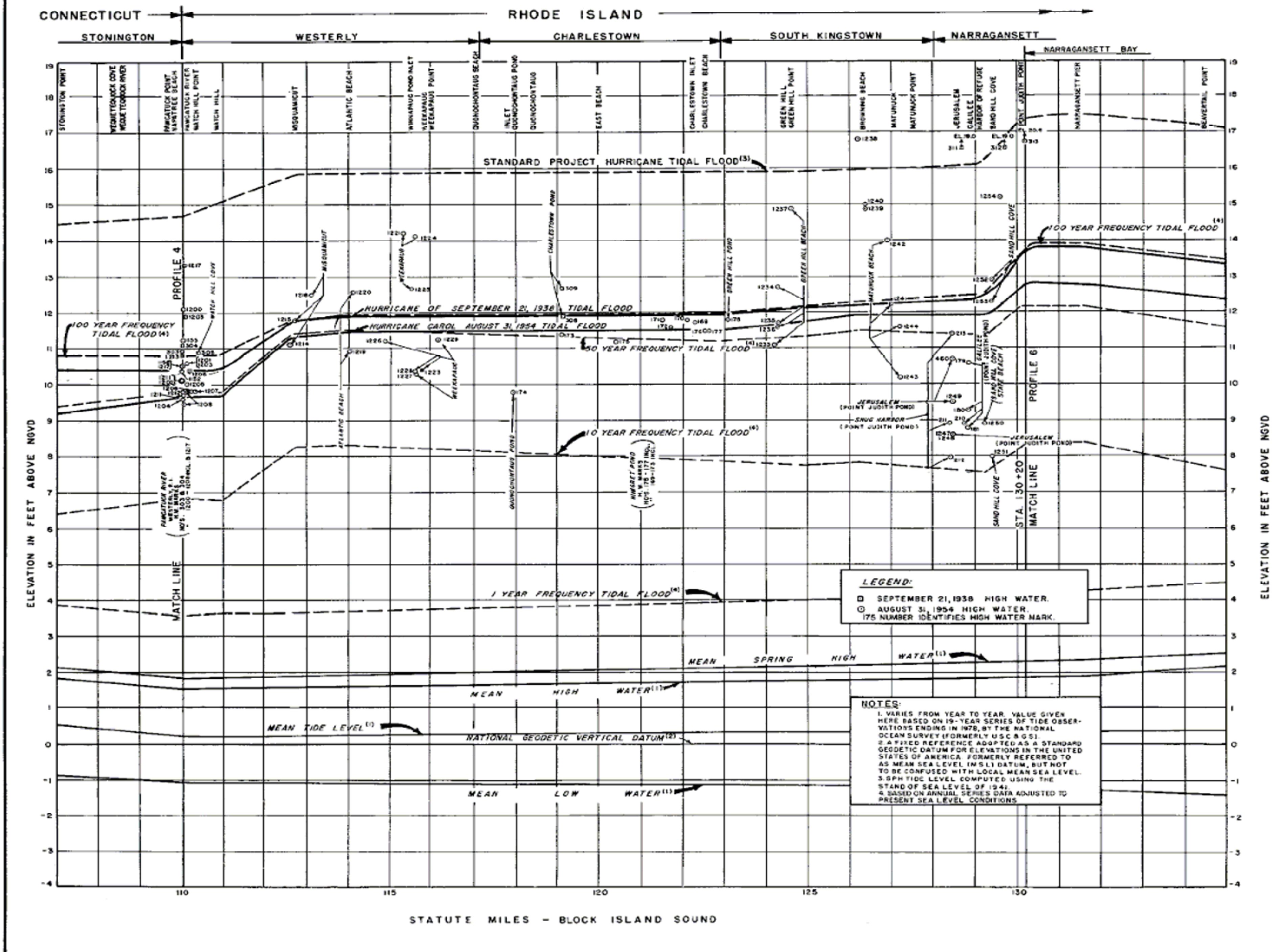


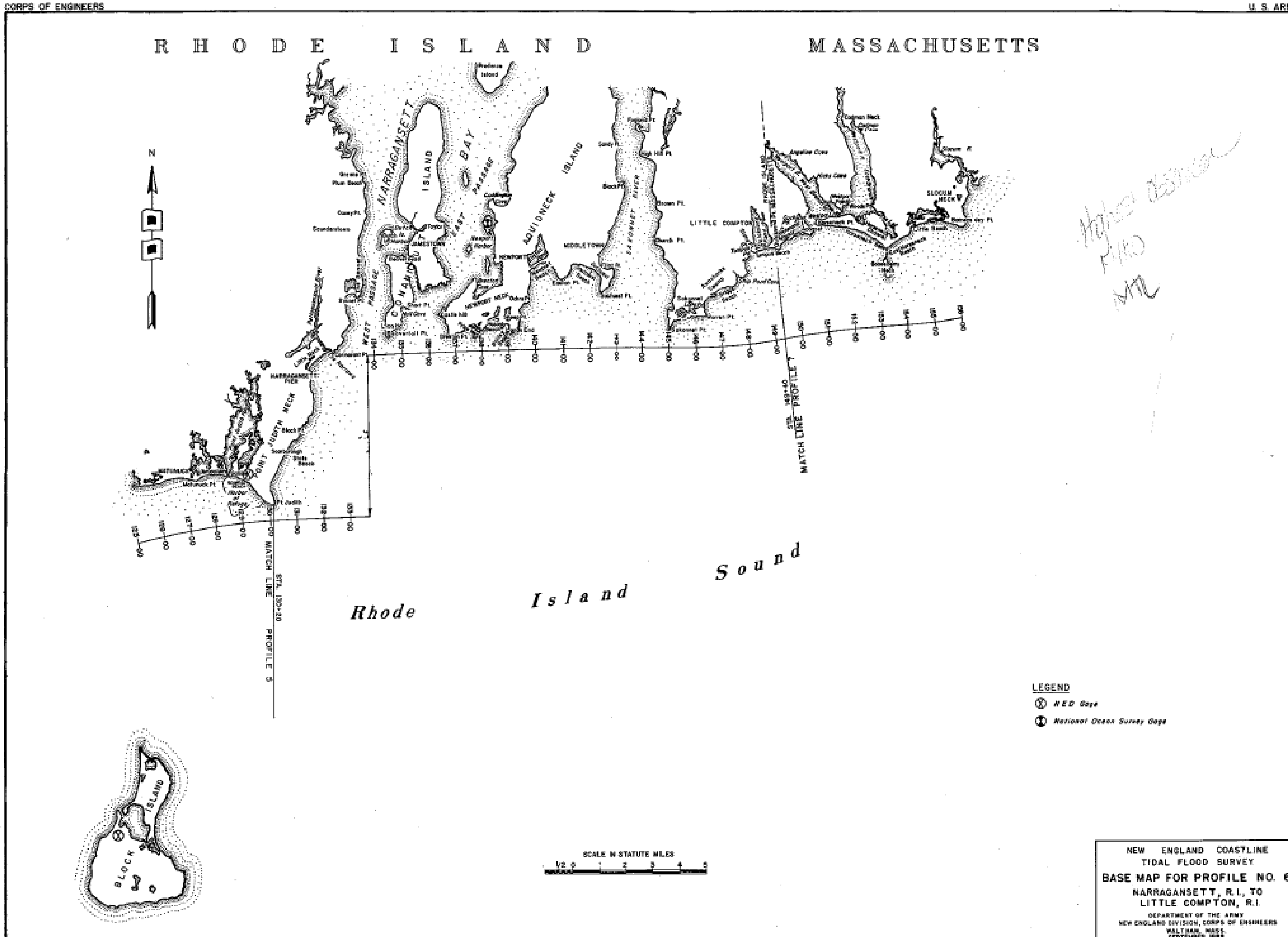
NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY

BASE MAP FOR PROFILE NO. 5

WESTERLY, R. I. TO
SOUTH KINGSTOWN, R. I.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988


CONNECTICUT
RHODE ISLAND
STONINGTON
WESTERLY
CHARLESTOWN
SOUTH KINGSTOWN
NARRAGANSETT
NARRAGANSETT BAY
STANDARD PROJECT HURRICANE TIDAL FLOOD(3)
100 YEAR FREQUENCY TIDAL FLOOD(4)
HURRICANE OF SEPTEMBER 21, 1938 TIDAL FLOOD
HURRICANE CAROL AUGUST 31, 1954 TIDAL FLOOD
50 YEAR FREQUENCY TIDAL FLOOD(4)
10 YEAR FREQUENCY TIDAL FLOOD(4)
1 YEAR FREQUENCY TIDAL FLOOD(4)
MEAN SPRING HIGH WATER(1)
MEAN HIGH WATER(1)
MEAN TIDE LEVEL(1)
NATIONAL GEODETIC VERTICAL DATUM(2)
MEAN LOW WATER(1)
PROFILE 4
MATCH LINE
PROFILE 6
STA. 130+20
MATCH LINE
LEGEND:
SEPTEMBER 21, 1938 HIGH WATER.
AUGUST 31, 1954 HIGH WATER.
175 NUMBER IDENTIFIES HIGH WATER MARK.
NOTES:
1. VARIES FROM YEAR TO YEAR. VALUE GIVEN HERE BASED ON 19-YEAR SERIES OF TIDE OBSERVATIONS ENDING IN 1978, BY THE NATIONAL OCEAN SURVEY (FORMERLY U.S.C.& G.S.).
2. A FIXED REFERENCE ADOPTED AS A STANDARD GEODETIC DATUM FOR ELEVATIONS IN THE UNITED STATES OF AMERICA. FORMERLY REFERRED TO AS MEAN SEA LEVEL (M.S.L.) DATUM, BUT NOT TO BE CONFUSED WITH LOCAL MEAN SEA LEVEL.
3. SPH TIDE LEVEL COMPUTED USING THE STAND OF SEA LEVEL OF 1942.
4. BASED ON ANNUAL SERIES DATA ADJUSTED TO PRESENT SEA LEVEL CONDITIONS.
ELEVATION IN FEET ABOVE NGVD
STATUTE MILES - BLOCK ISLAND SOUND



NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY

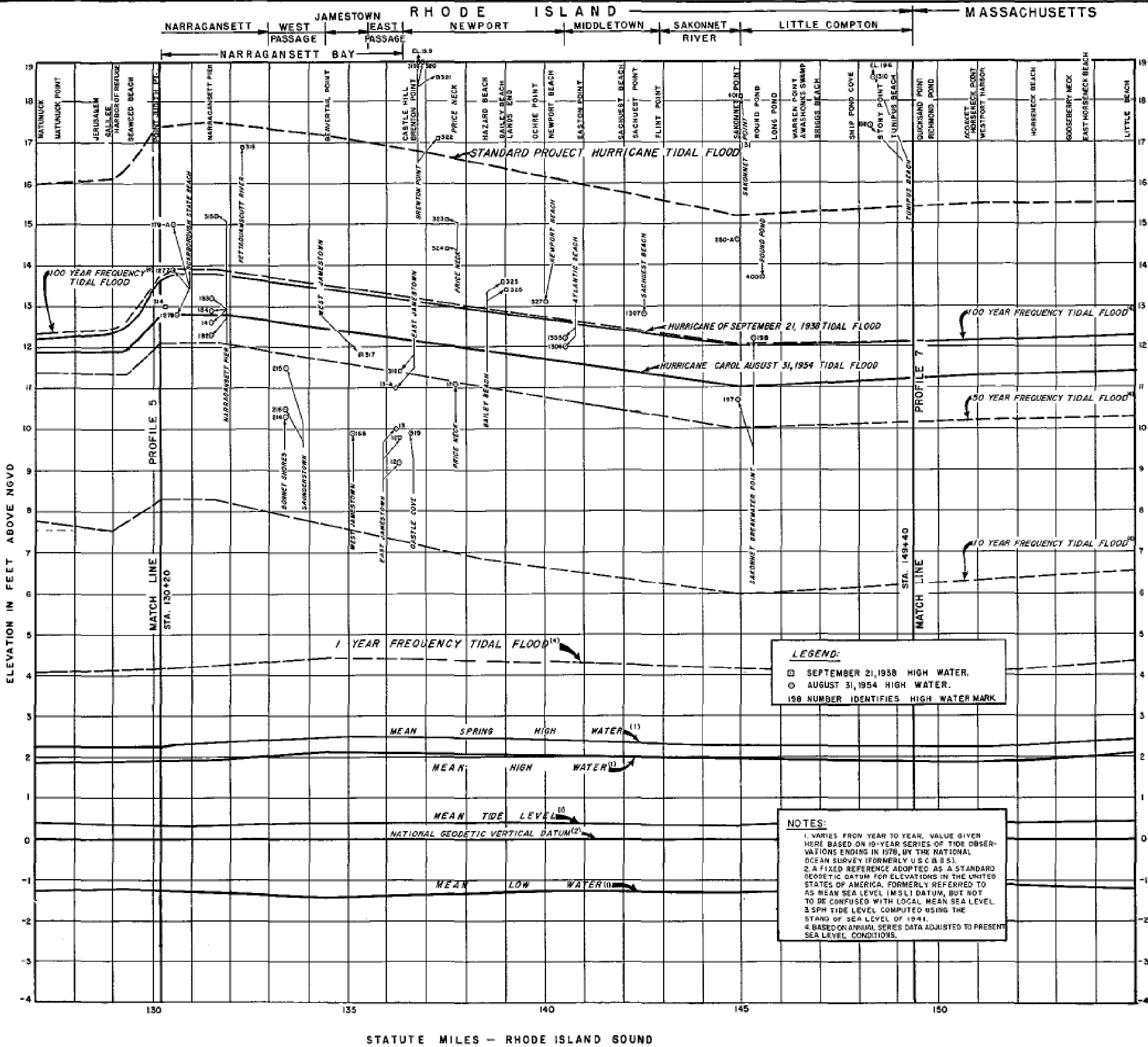
BASE MAP FOR PROFILE NO. 6

NARRAGANSETT, R.I., TO
LITTLE COMPTON, R.I.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988

CORPS OF ENGINEERS

U. S. ARMY



NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY

TIDAL FLOOD PROFILE NO. 6

NARRAGANSETT, R.I. TO
LITTLE COMPTON, R.I.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988

Storm Surge Heights (US Army Corp)

	Storm Surge [feet]*	Storm Surge [meters]*
10 year	8.25	2.51
50 year	11.50	3.51
100 year	11.75	3.58
SPH	15.90	4.85

Extreme Storm Surge (once in 100yr), NGVD Vertical Reference (Army Corp, 1988)

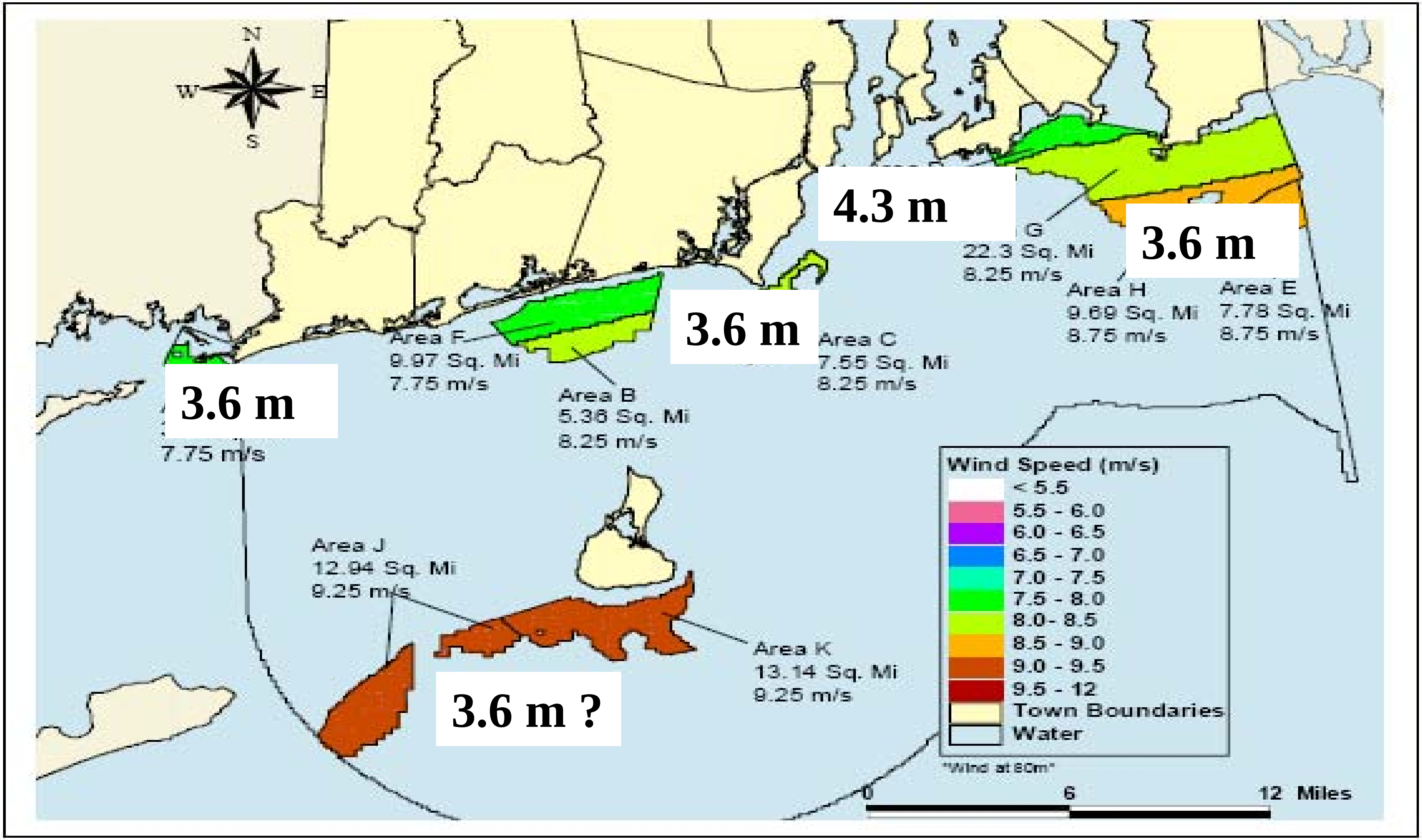
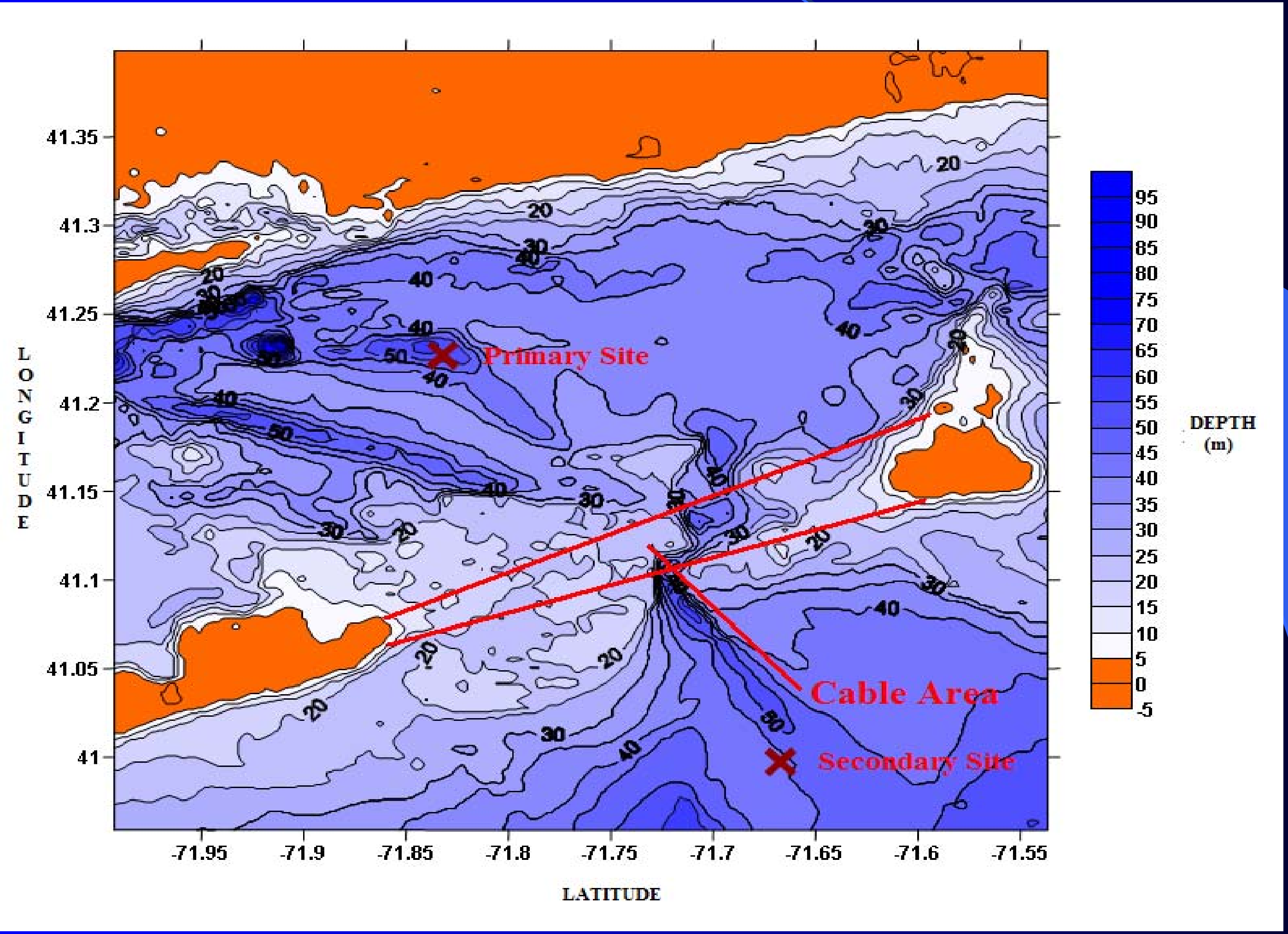


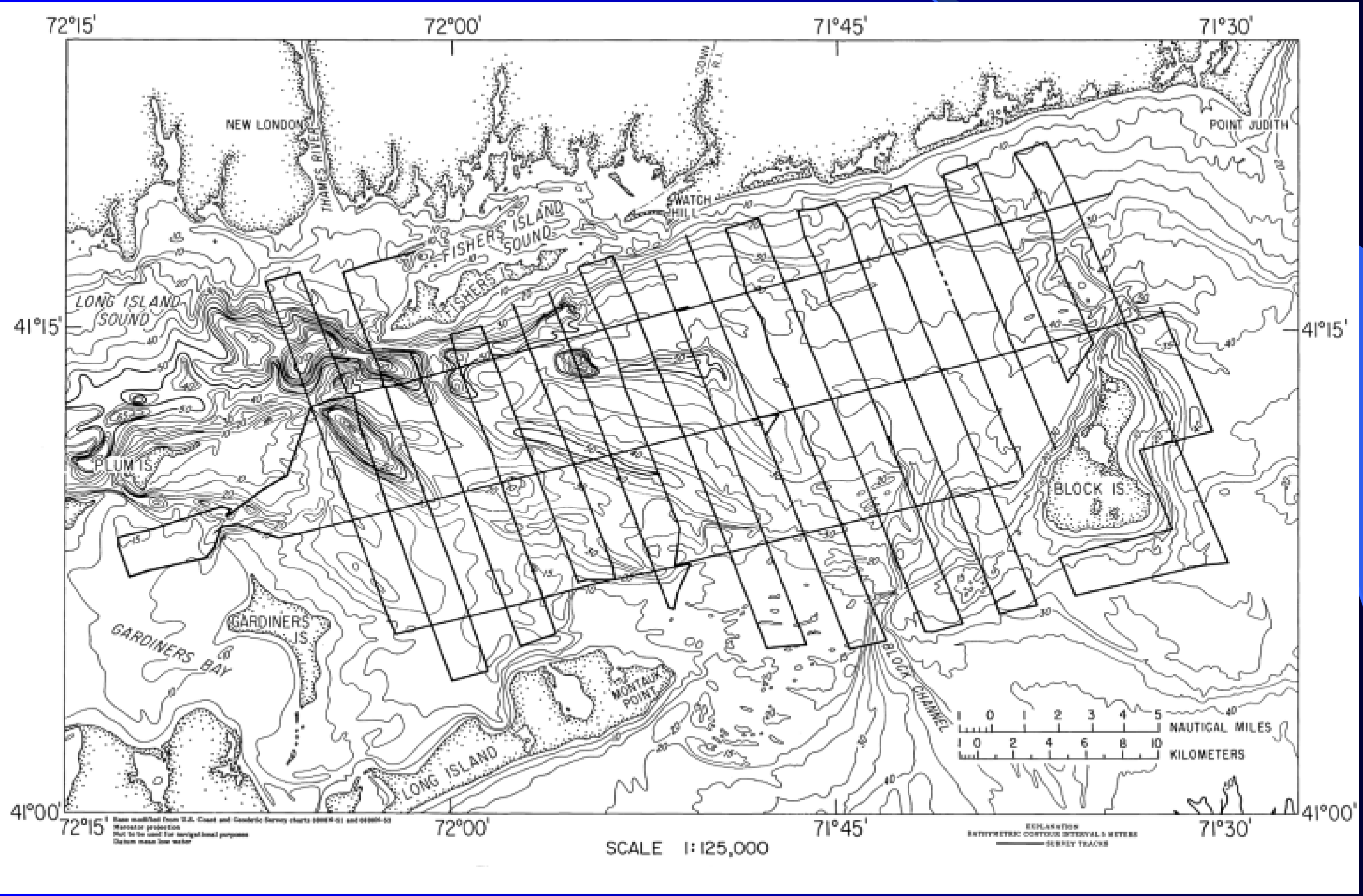
Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation

BATHYMETRY AND BEDROCK

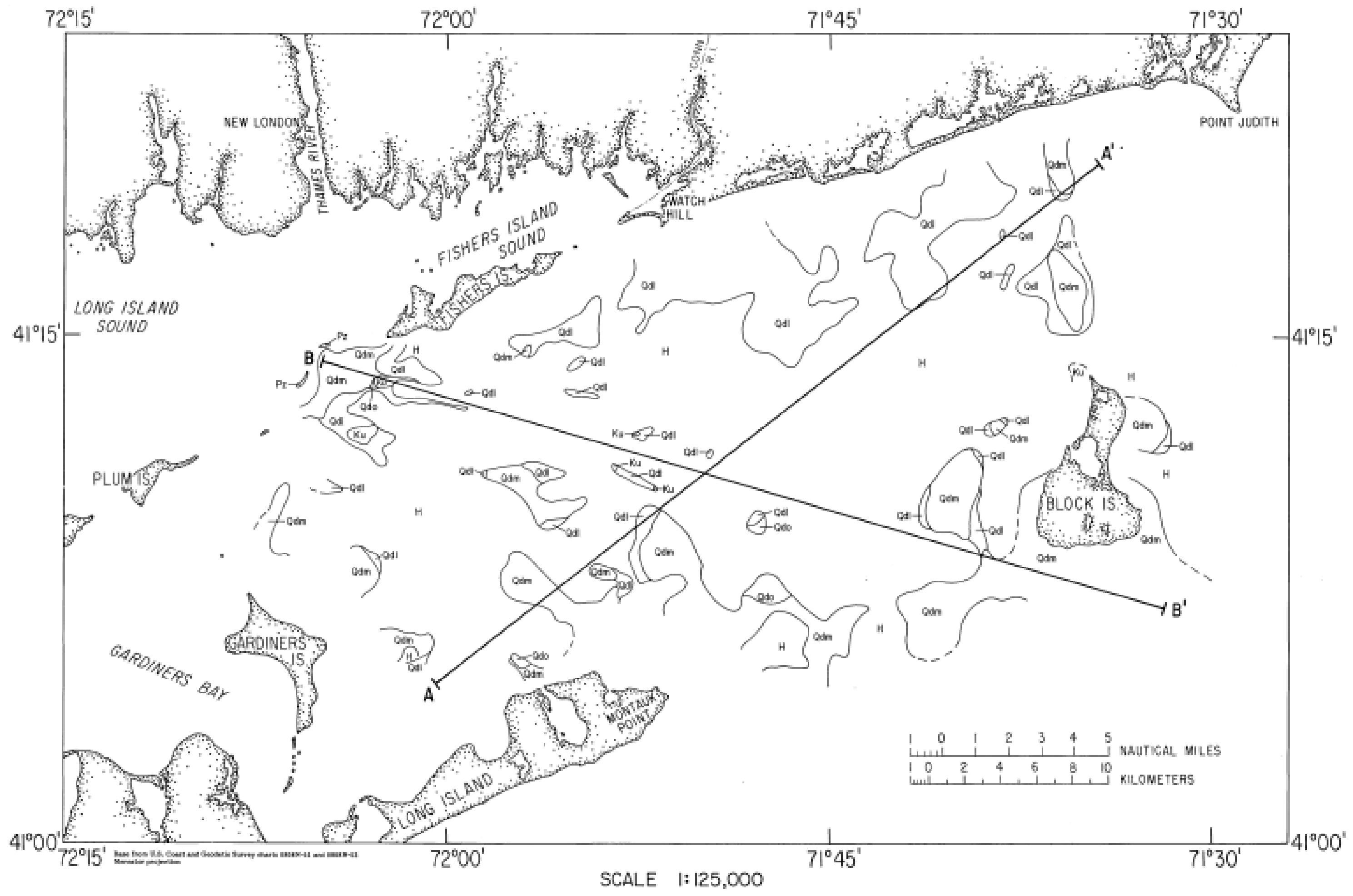
NOAA ENC Bathymetry



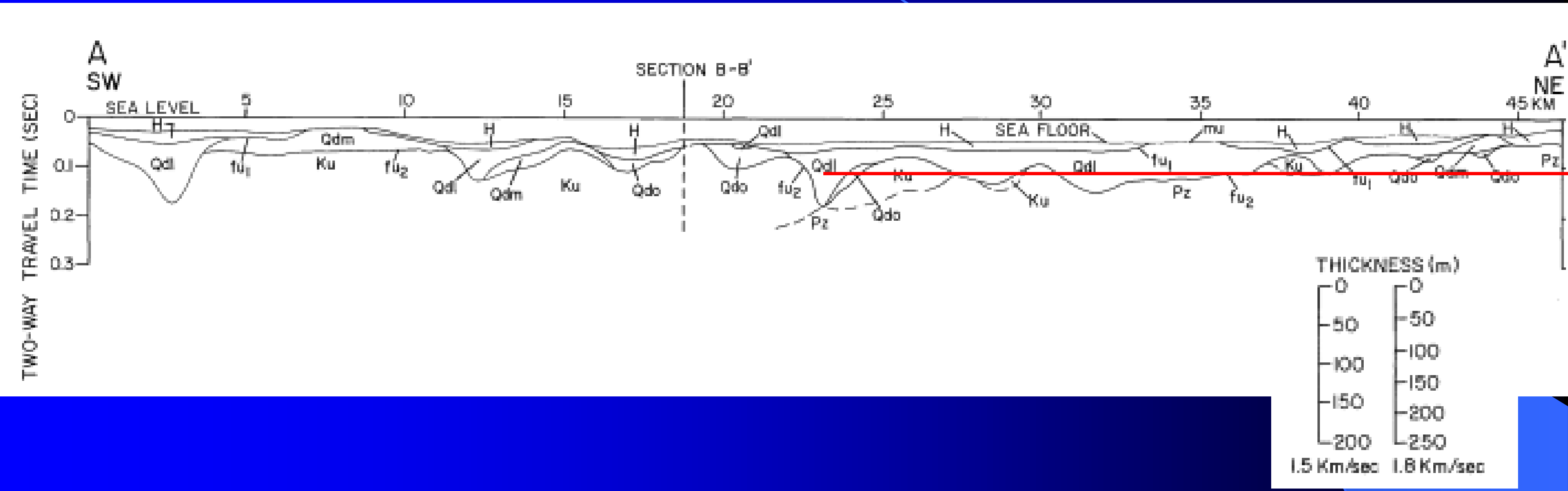
USGS Needell and Lewis Track lines and topography



Geologic Seismic Cross Section Lines (A-A’)



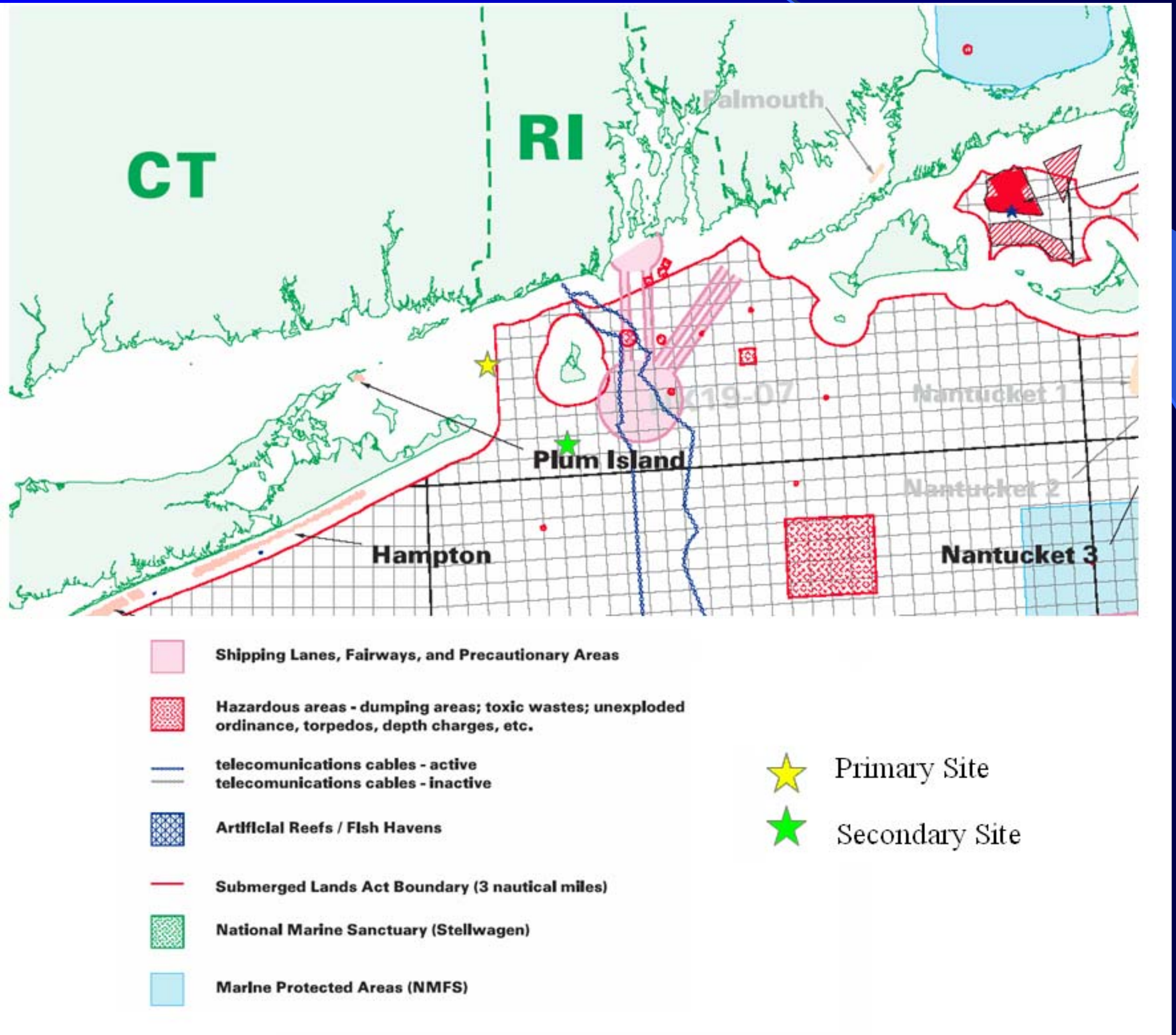
A-A' Cross Section



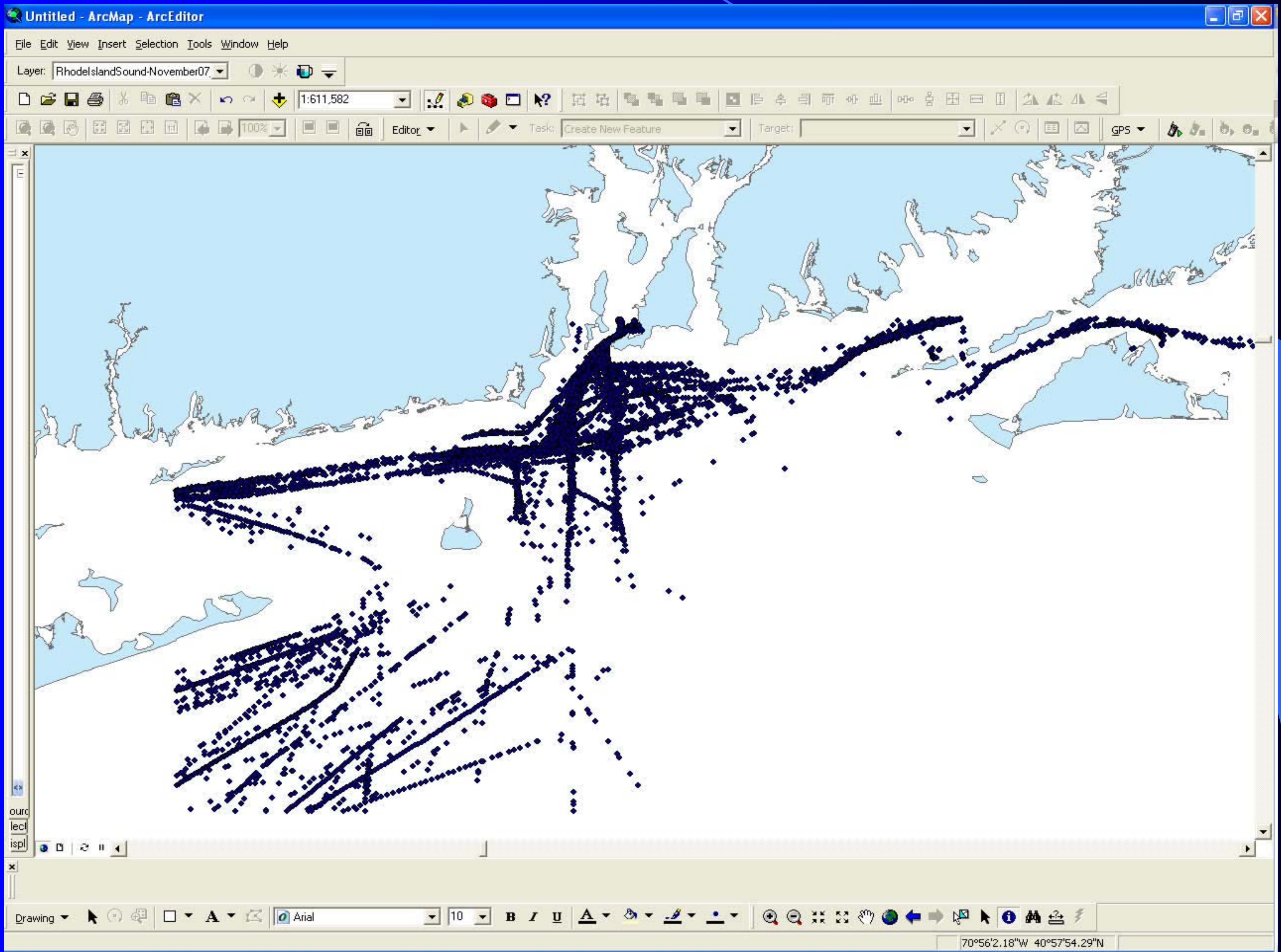
Bedrock is located approx 35 meters below seafloor

(Needell and Lewis, 1984)

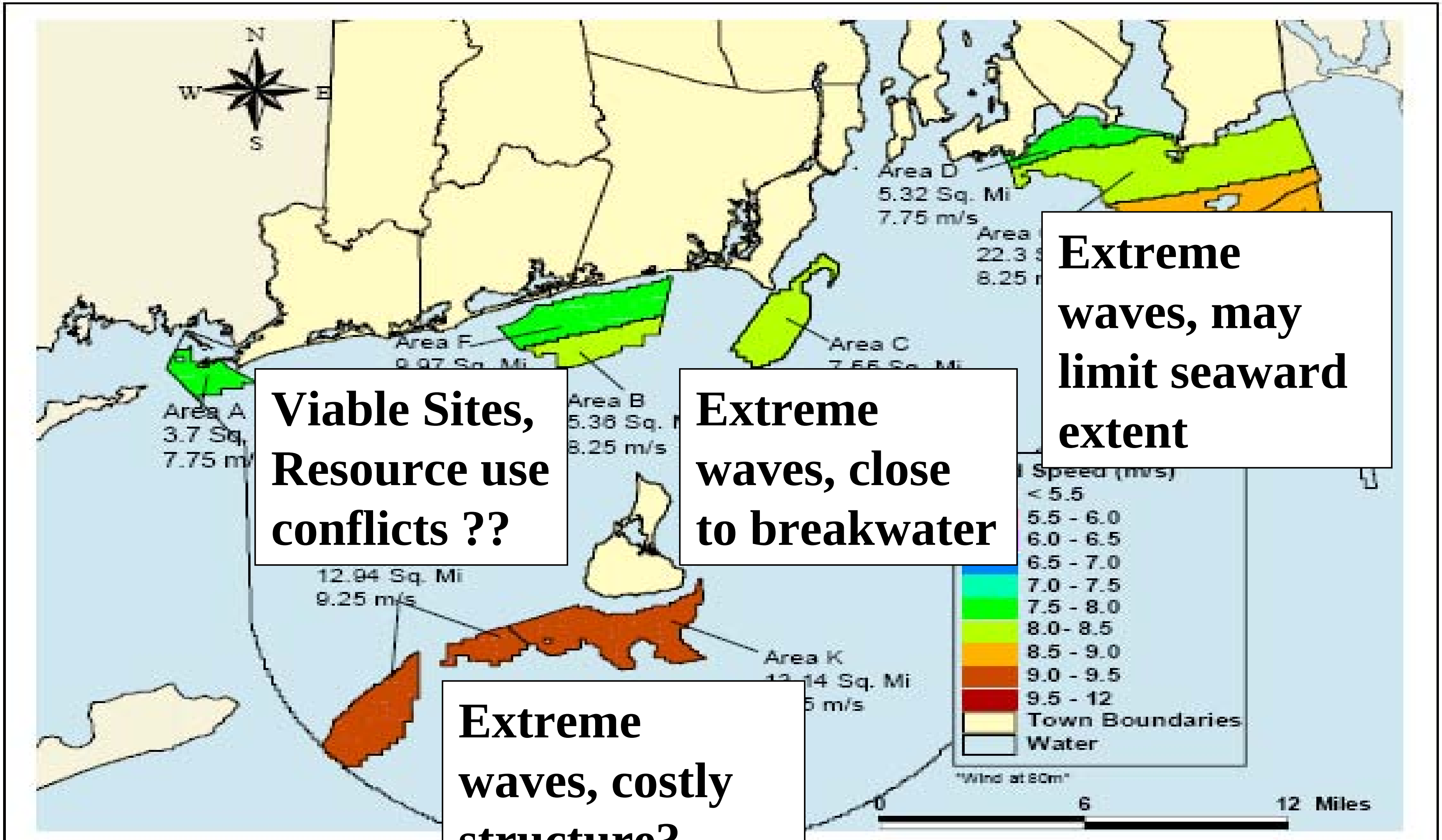
MMS Use Summary



AIS Tracks Oct 31 to Nov 26, 2007 (ASA)



SUMMARY FINDINGS



Viable Sites, Resource use conflicts ??

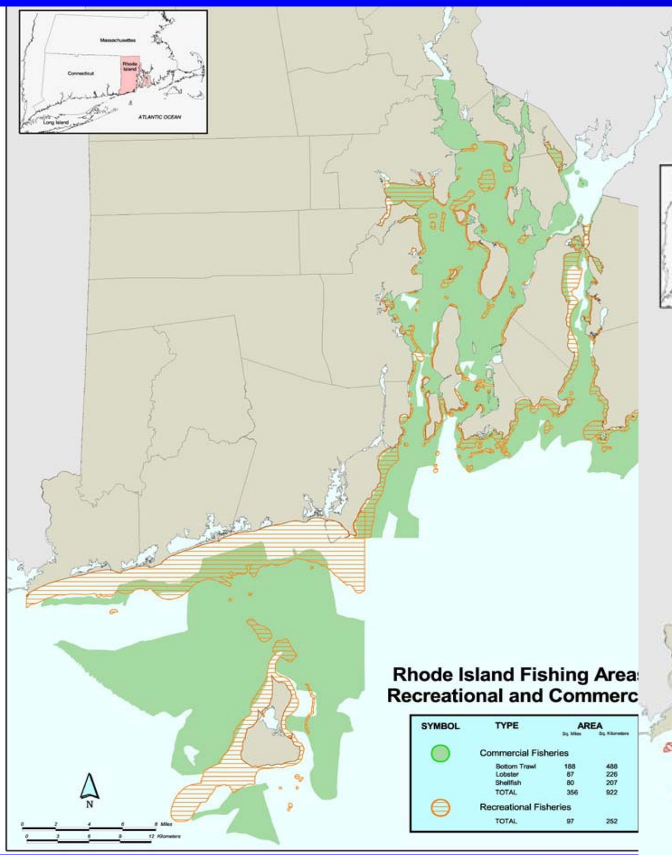
Extreme waves, close to breakwater

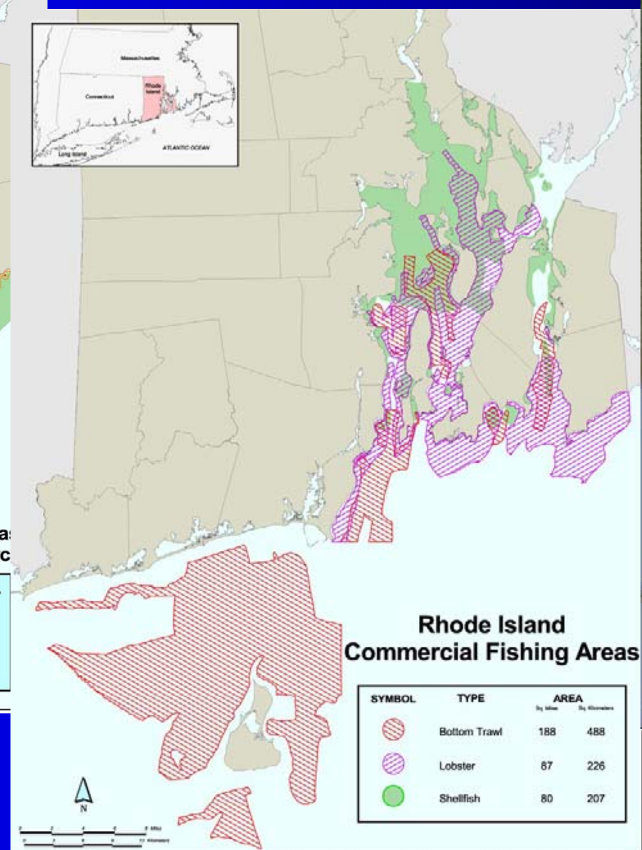
Extreme waves, may limit seaward extent

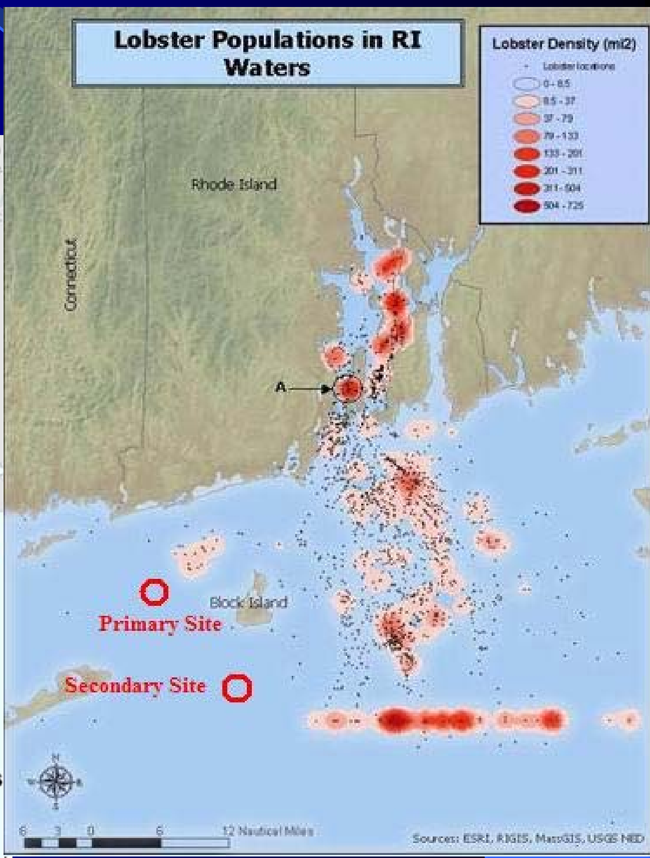
Extreme waves, costly structure?

Figure 1 - RIWINDS Report Figure 3.20: Map Showing Post Level 2 Screening Areas Separated by Wind Speed and Final Area Designation

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