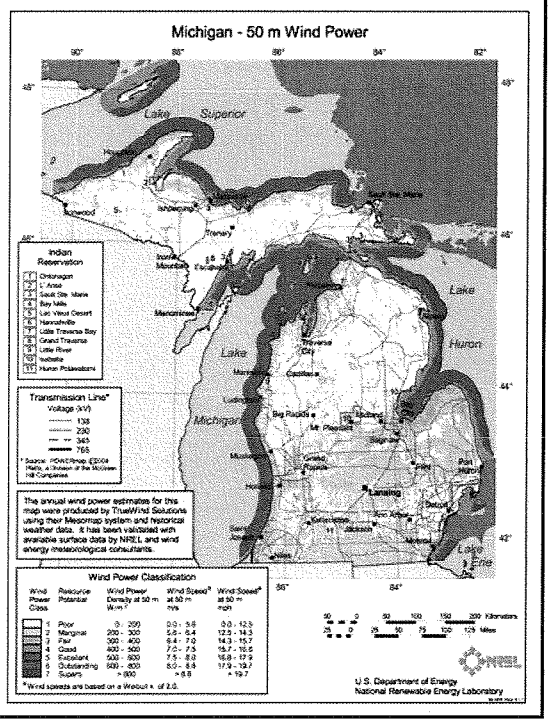
Michigan Wind Resources

Dennis Elliott
National Renewable Energy Laboratory
Golden, CO

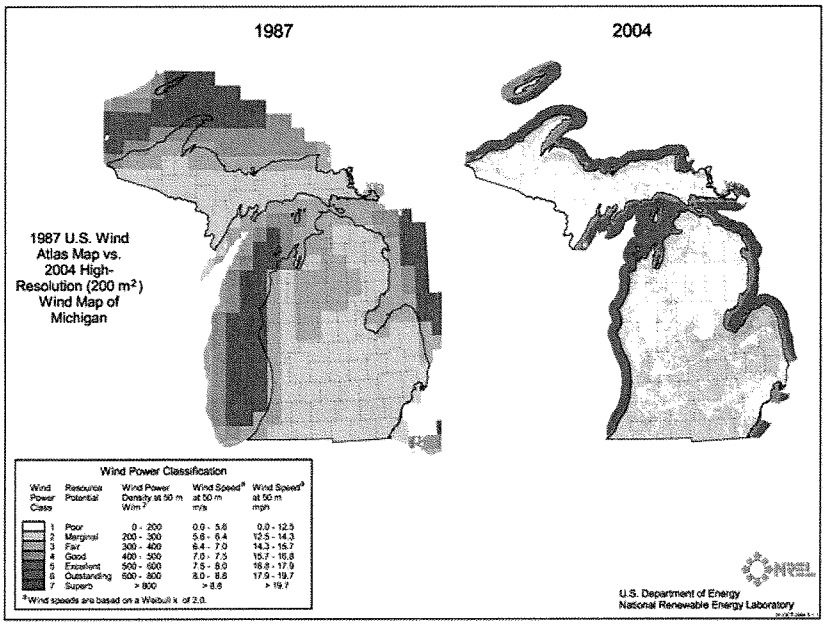
Michigan Wind Working Group Meeting
Lansing, Michigan
October 5, 2004

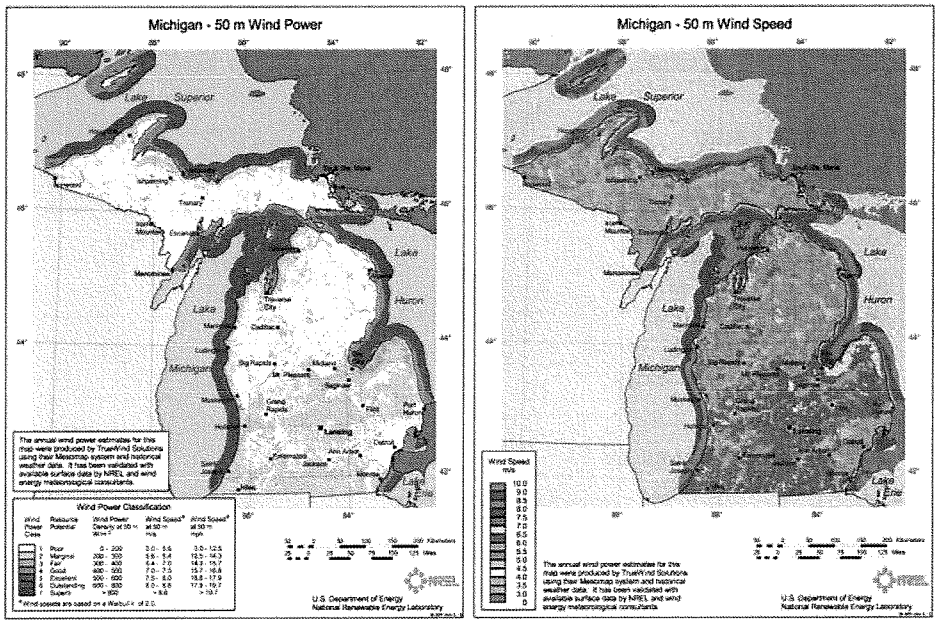
2004 Michigan Wind Power Map

- Preliminary map produced by AWS Truewind
- Preliminary maps of annual average 50-m wind power and wind speed validated by NREL and wind energy consultants
- Final maps produced by AWS Truewind with approval by NREL



"Old" vs. "New" Michigan Wind Maps



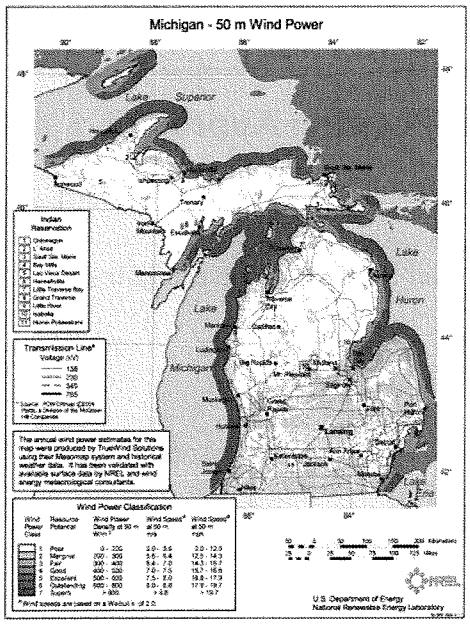


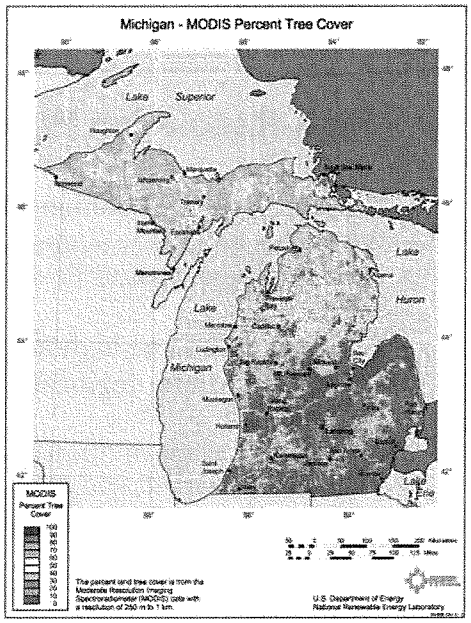
High-Resolution Wind Mapping Approach

- Produces 200 m resolution wind resource maps
- AWS Truewind uses a numerical weather model with climatic data and wind flow model to produce the preliminary maps
- Does not depend on high-quality surface wind data
- Maps designed for regional wind mapping and not micrositing
- Preliminary maps of 50-m annual average wind resource validated by NREL and meteorological consultants
- Final maps developed based on revision of preliminary maps from validation results

Validation Process

- NREL produced a spreadsheet used in the validation processed
  - Each measurement location
    - Site coordinates and elevation
    - Measurement heights and period of record
    - Measured speed and power
    - Adjusted speed and power to map height
    - Map estimates for speed and power
    - Qualitative comments
- NREL & AWS Truewind review validation results
- AWS Truewind adjusted preliminary maps based on quantitative and qualitative inputs

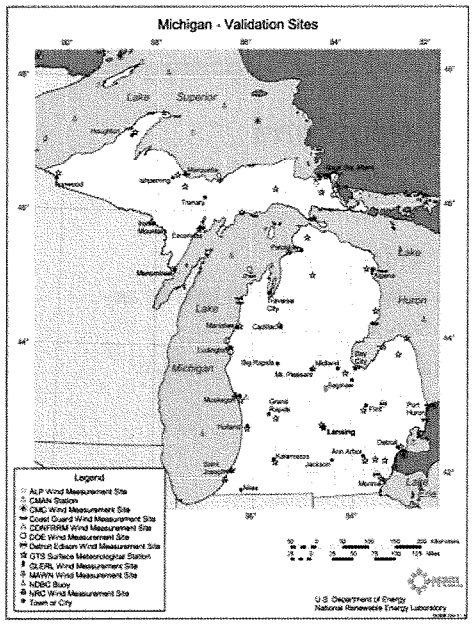


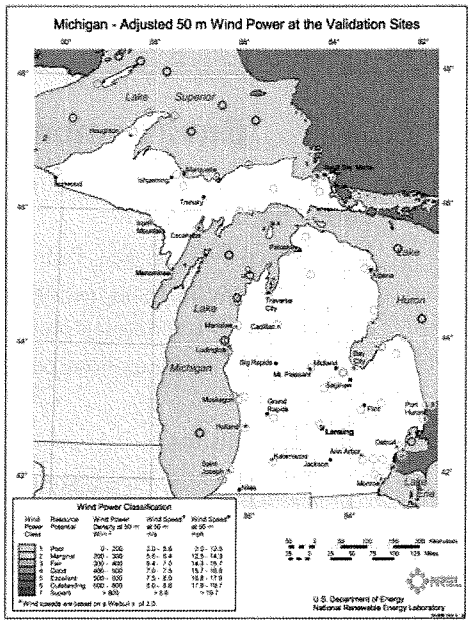


NREL

NREL's Michigan Validation

- Over 90 measurement stations used for validation
  - 57 GTS NOAA National Climatic Data Center (35Airport, 2 Non-Airport, 20 Coast Guard)
  - 11 NOAA National Data Buoy Center (4 Coastal Marine Automated Network, 7 Buoy)
  - 2 NOAA Great Lakes Environmental Research Laboratory
  - 4 DOE/NREL (2 Candidate Site, 1 CONFRRM, 1 ALP)
  - 2 Nuclear Regulatory Commission
  - 3 Detroit Edison
  - 2 Michigan Agricultural Weather Network
  - 5 GTS Canadian Meteorological Centre
  - 7 Proprietary
- Accuracy comparable to other updated state maps
  - Within 10% of annual speed and 20% of annual power at 80+% of individual sites





NREL

Quantifying Available Windy Lands and Electric Potential by DOE/NREL (2004)

- Class 4 and higher resource areas (good-to-excellent for utility-scale applications) used as base for available windy lands
- Environmental Exclusions
- Land-use Exclusions
- Other Factors

Environmental Exclusions

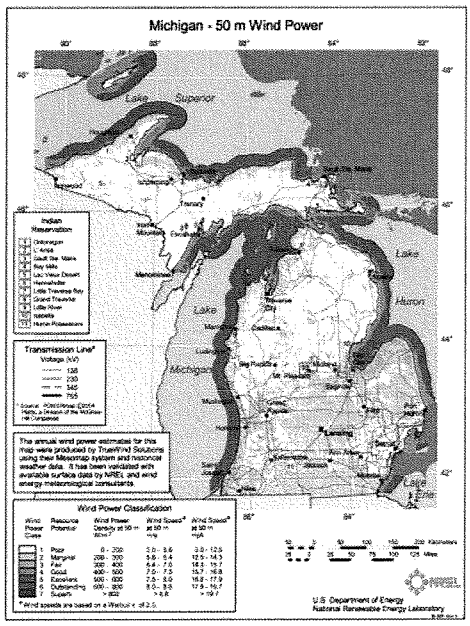
- 100% Exclusions
  - National Park Service, Fish and Wildlife Service
  - Wildlife, Wilderness, and Recreation Areas on federal land of any designation (predominately Forest Service lands)
  - State and private environmental lands (from the Michigan GAP data)
- 50% Exclusions
  - Remaining U.S. Forest Service and DOD lands

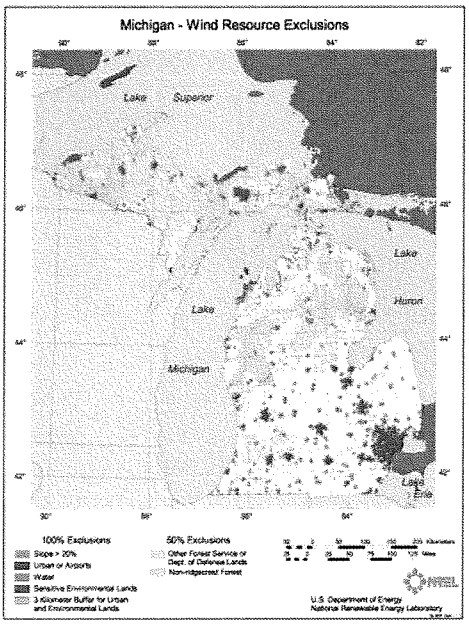
Land-Use Exclusions

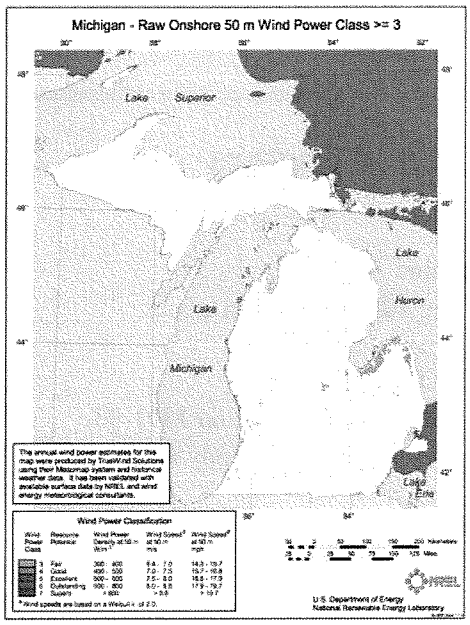
- 100% Exclusions
  - Urban areas and airports
  - Wetlands
  - Water bodies
- 50% Exclusions
  - Non ridge crest forest
- 0% Exclusions
  - Ridge crest forest
  - Agriculture lands

Additional Windy Land Factors

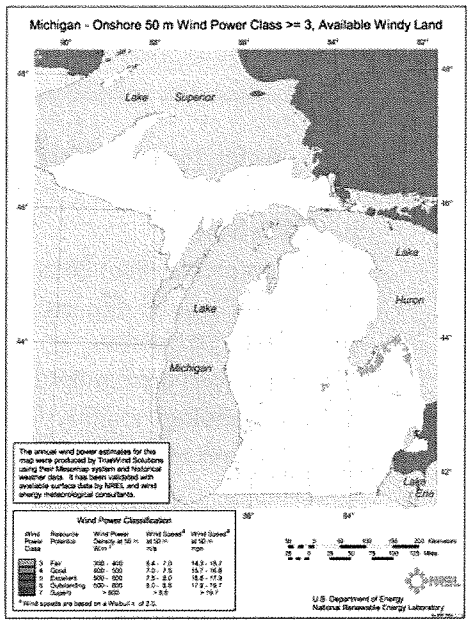
- Slope Exclusions
  - Slopes greater than 20% excluded
- 3 km buffer around airports and the 100% exclusion areas, except for water bodies
- Windy grid cell contiguity/density factor
- New methodology slightly less restrictive than used in 1991-93
- Distance from transmission lines not included in windy land calculations
- Windy land → electric potential
  - Direct conversion from sq. km to potential installed capacity- 5 MW per km^2 of available windy land



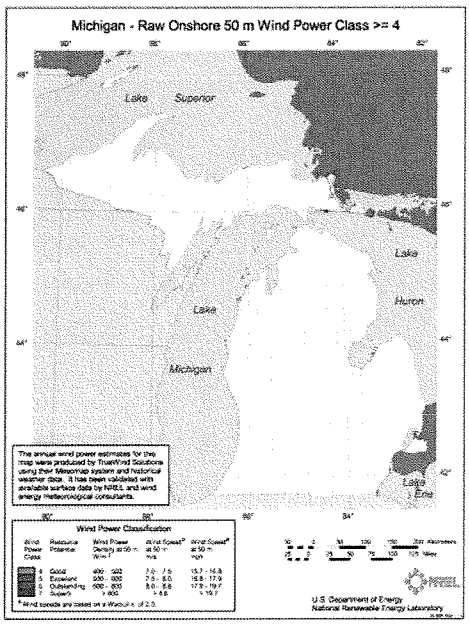




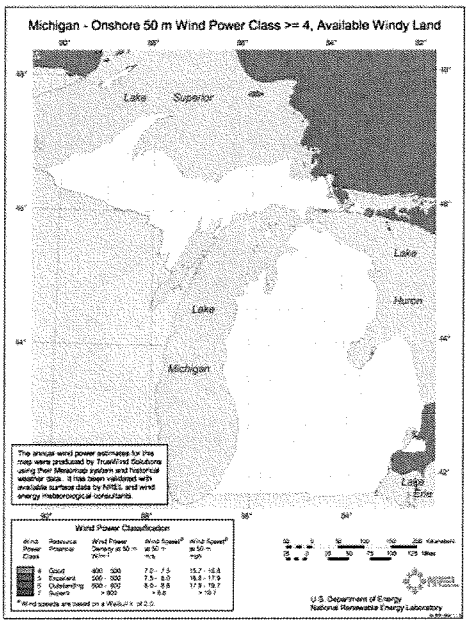
4,905 km² (24,530 MW) Raw Class 3+



3,313 km² (16,560 MW) Class 3+
After Exclusions



413 km² (2,070 MW) Raw Class 4+

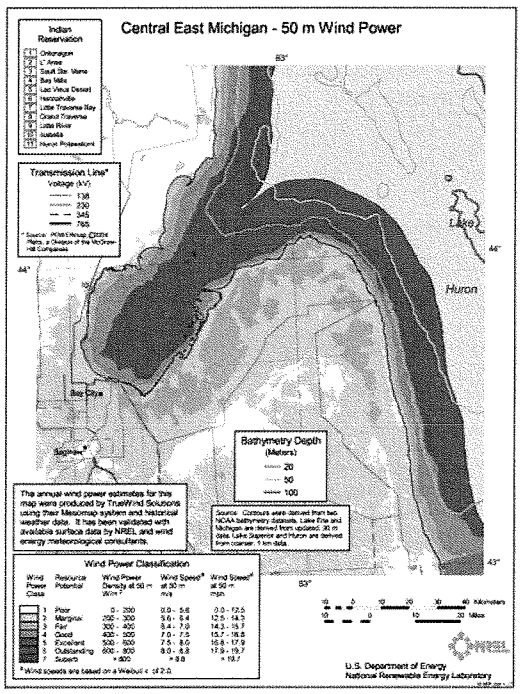


166 km² (830 MW) Class 4+
After Exclusions

Michigan Wind Electric Potential (Installed Capacity)

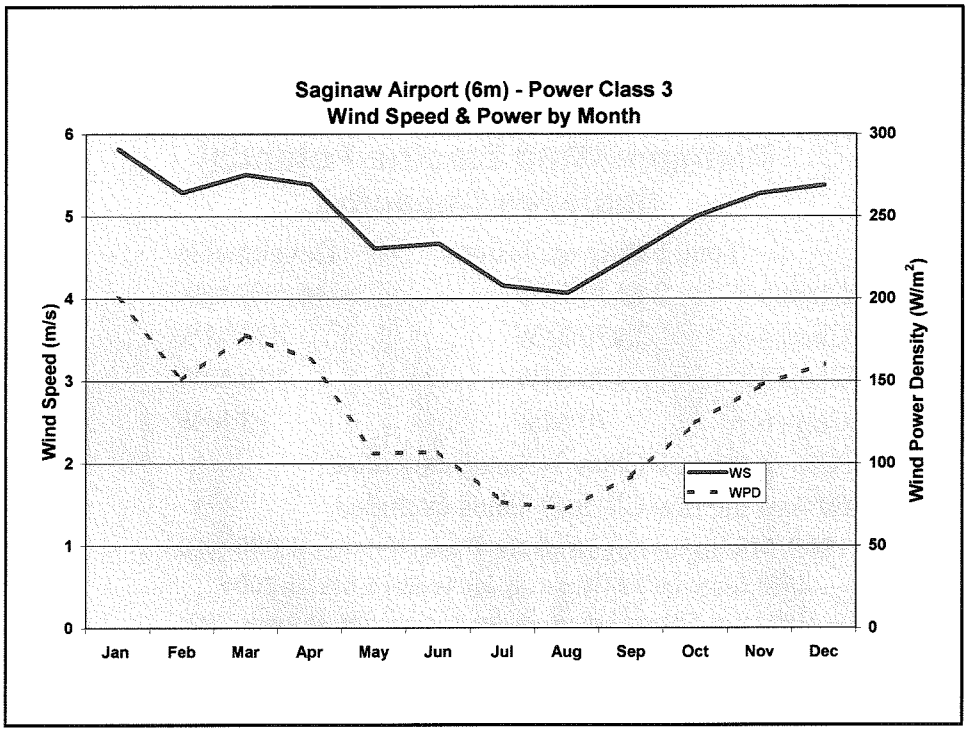
	Total before exclusions	Developable
• Class 3 +	24,530 MW	16,560 MW
• Class 4 +	2,070 MW	830 MW
• Class 5 +	390 MW	110 MW
• Class 6 +	70 MW	13 MW

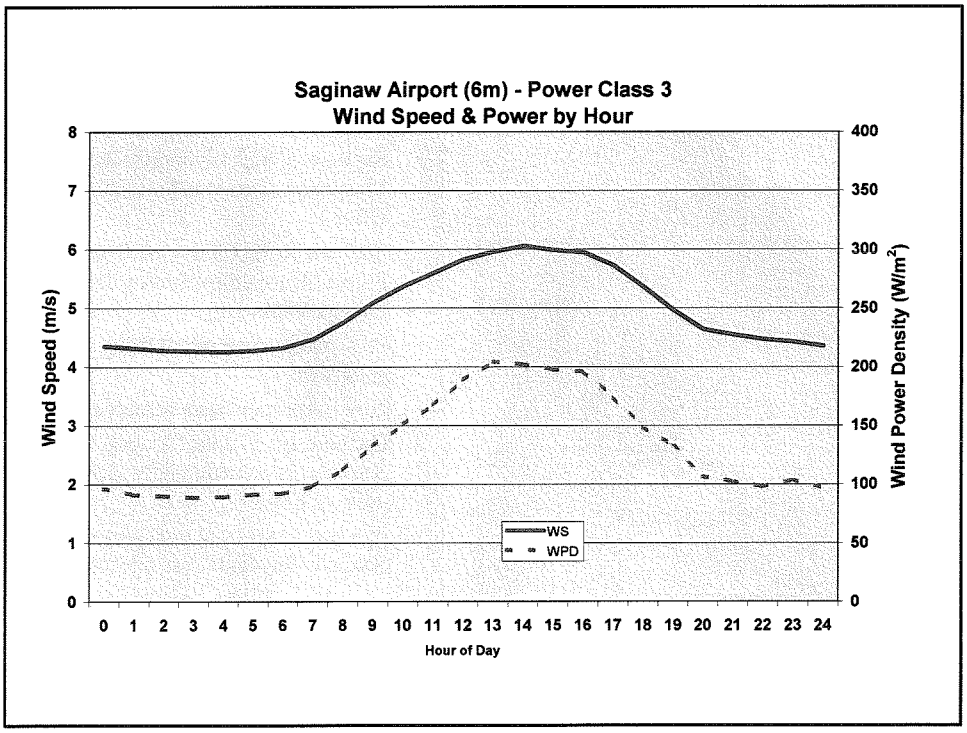
- 32% of the raw Class 3+ lands excluded
- 60% of the raw Class 4+ lands excluded
- 1993 Michigan potential for Class 4+ was 4,070 MW
  - 1993 based on 7 MW per sq. km versus 5 MW in 2004
  - 1993 was 581 sq. km windy land versus 166 sq km in 2004

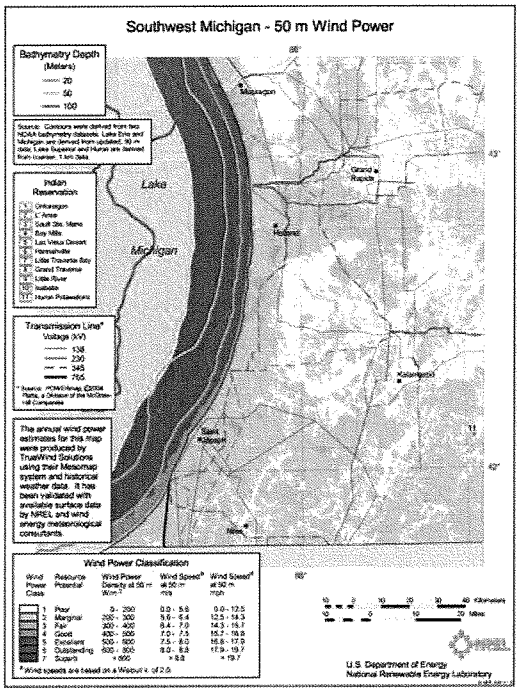


Central East Michigan

- Saginaw airport is windiest (tied with Muskegon airport) in Michigan – Class 3
- Saginaw River Coast Guard and Pigeon Agricultural Station data also indicate Class 3
- Prevailing strong winds from southwest
- Nov – Apr maximum resource
- Onshore areas of the "Thumb" east of Saginaw estimated to have significant areas of Class 3
- Shallow water (<20 m depth) in Saginaw Bay and Class 5 resource

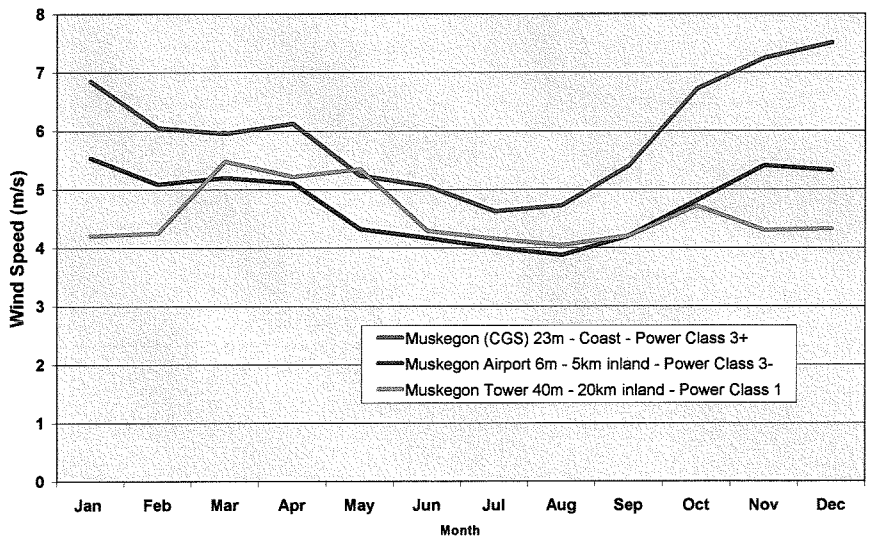

Saginaw Airport (6m) - Power Class 3
Wind Speed & Power by Month
Wind Speed (m/s)
Wind Power Density (W/m²)
0
1
2
3
4
5
6
0
50
100
150
200
250
300
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
WS
WPD

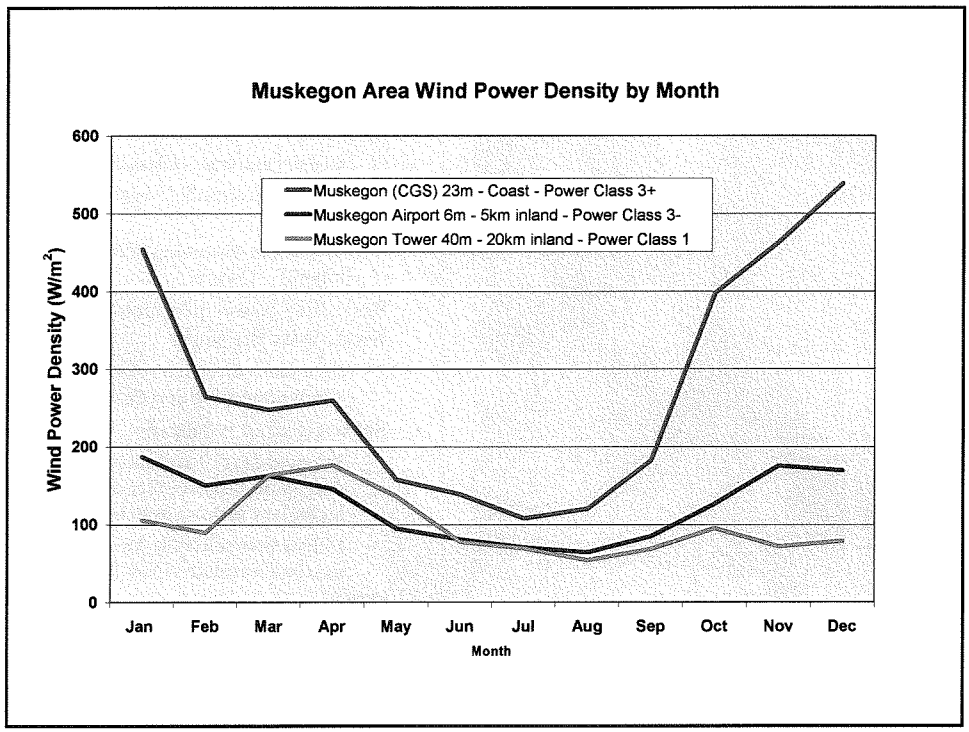

Saginaw Airport (6m) - Power Class 3
Wind Speed & Power by Hour
Wind Speed (m/s)
Wind Power Density (W/m²)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
300
350
400
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day
WS
WPD

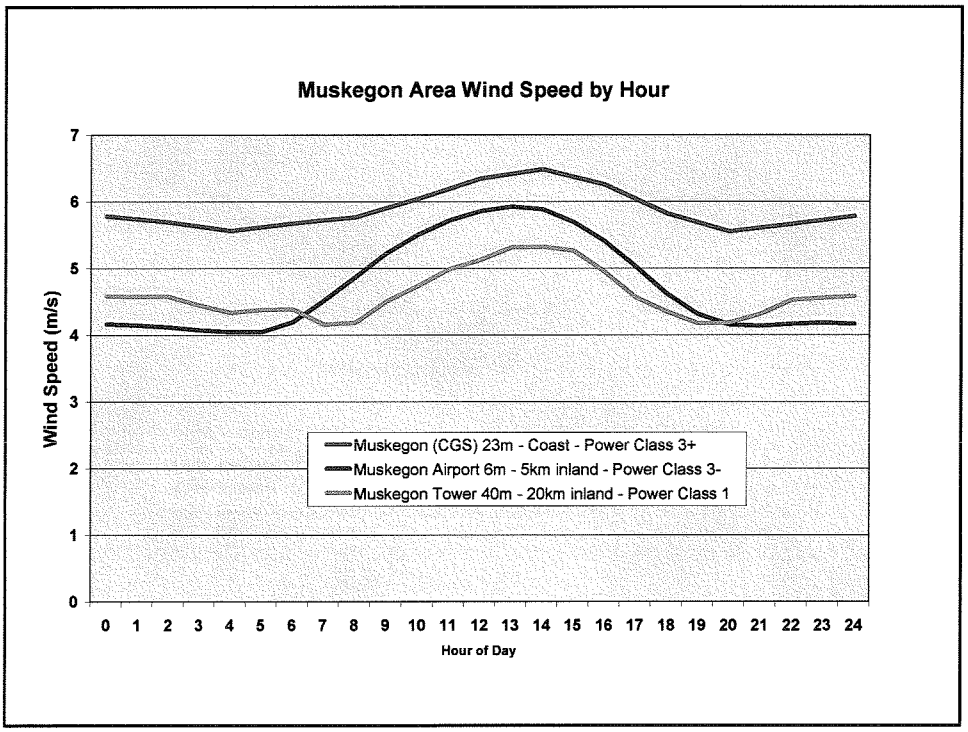


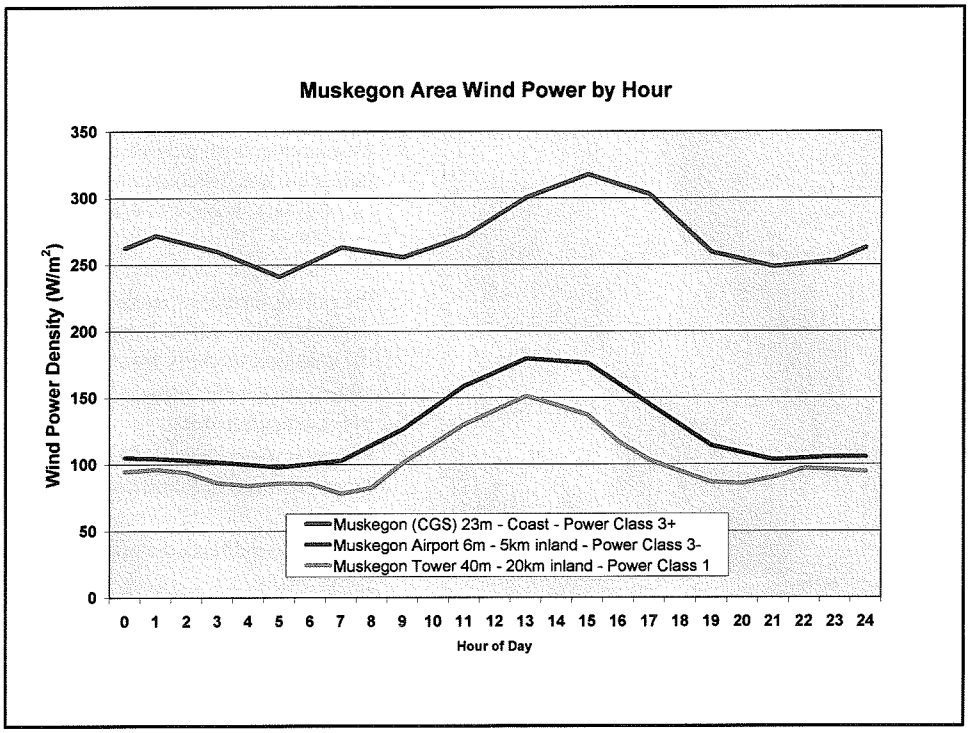
Southwest Michigan

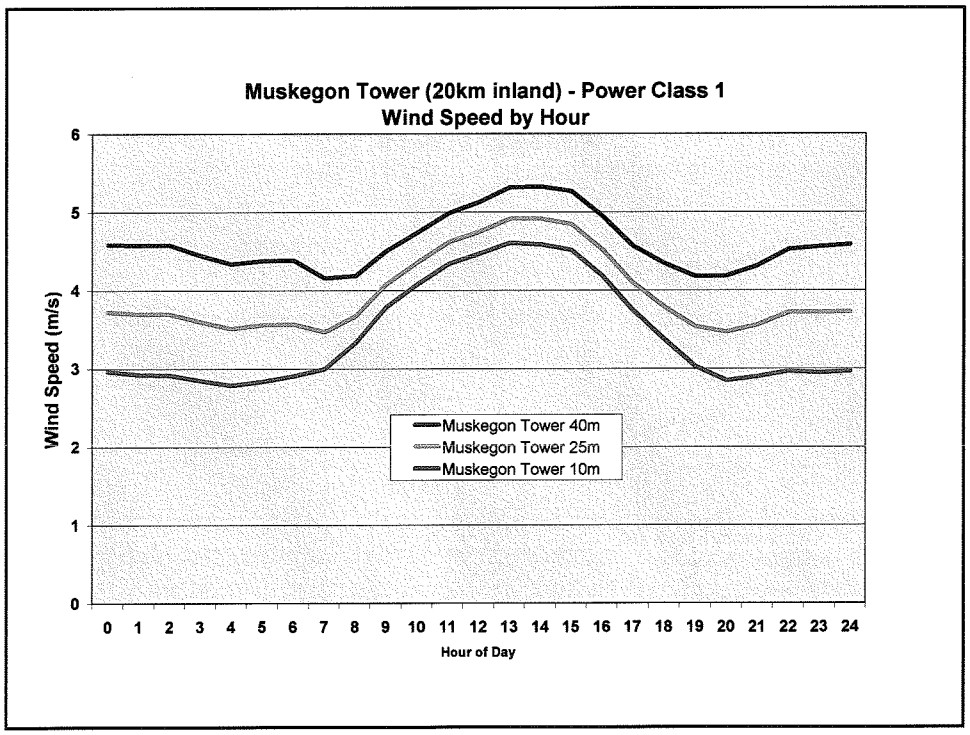
- **Muskegon area measurements verify strong resource gradients in the coastal-onshore area**
  - **Coastal stations – Class 3+**
  - **Muskegon airport (5 km) inland) – Class 3**
  - **Muskegon 40-m tower (20 km inland) – Class 1**
- **Prevailing power producing winds winds from the south**
  - **Secondary directions of strong winds from west-northwest**
- **Seasonal wind resources**
  - **Exposed coastal areas have strong maximum resource Oct-Jan and secondary maximum Feb-Apr**
  - **Inland sites generally have a broad maximum resource Nov-Apr**
- **Offshore resource**
  - **Strong gradients in near offshore areas with resource increasing to class 5-6 within 5-10 km of coast**

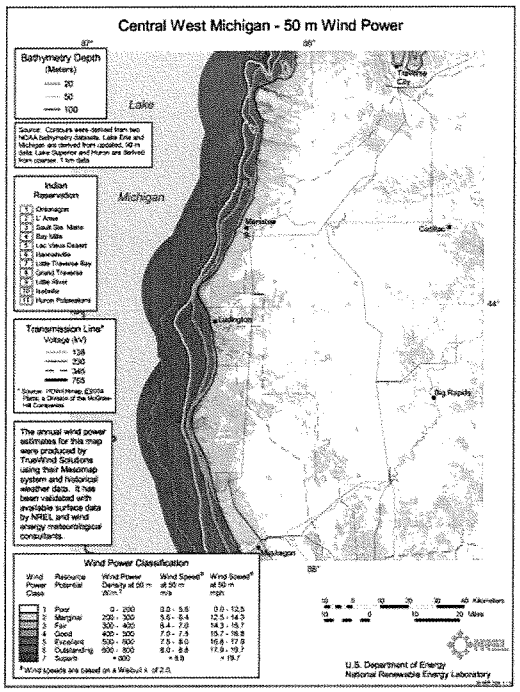



Muskegon Area Wind Power Density by Month
Wind Power Density (W/m²)
600
500
400
300
200
100
0
Muskegon (CGS) 23m - Coast - Power Class 3+
Muskegon Airport 6m - 5km inland - Power Class 3-
Muskegon Tower 40m - 20km inland - Power Class 1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Muskegon Area Wind Speed by Hour
Wind Speed (m/s)
7
6
5
4
3
2
1
0
Muskegon (CGS) 23m - Coast - Power Class 3+
Muskegon Airport 6m - 5km inland - Power Class 3-
Muskegon Tower 40m - 20km inland - Power Class 1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

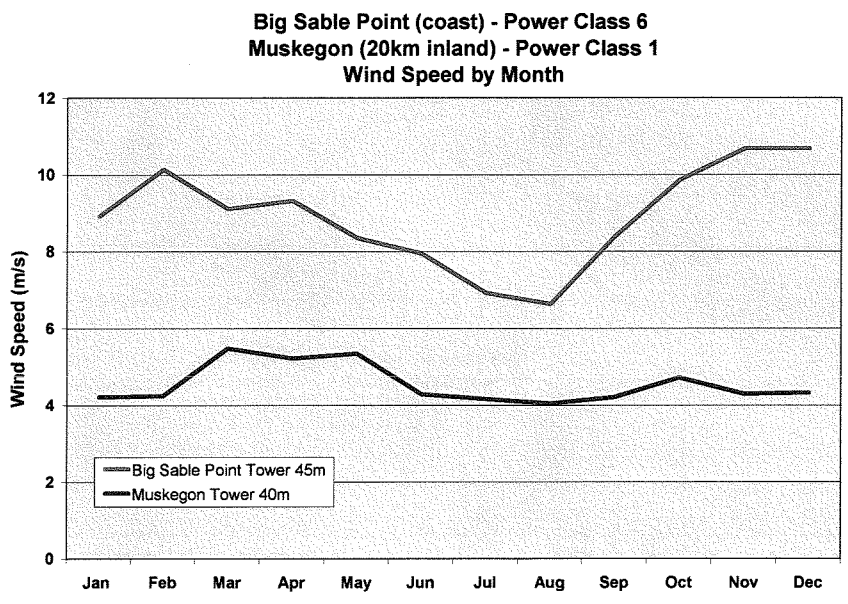

Muskegon Area Wind Power by Hour
Wind Power Density (W/m²)
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day
Muskegon (CGS) 23m - Coast - Power Class 3+
Muskegon Airport 6m - 5km inland - Power Class 3-
Muskegon Tower 40m - 20km inland - Power Class 1

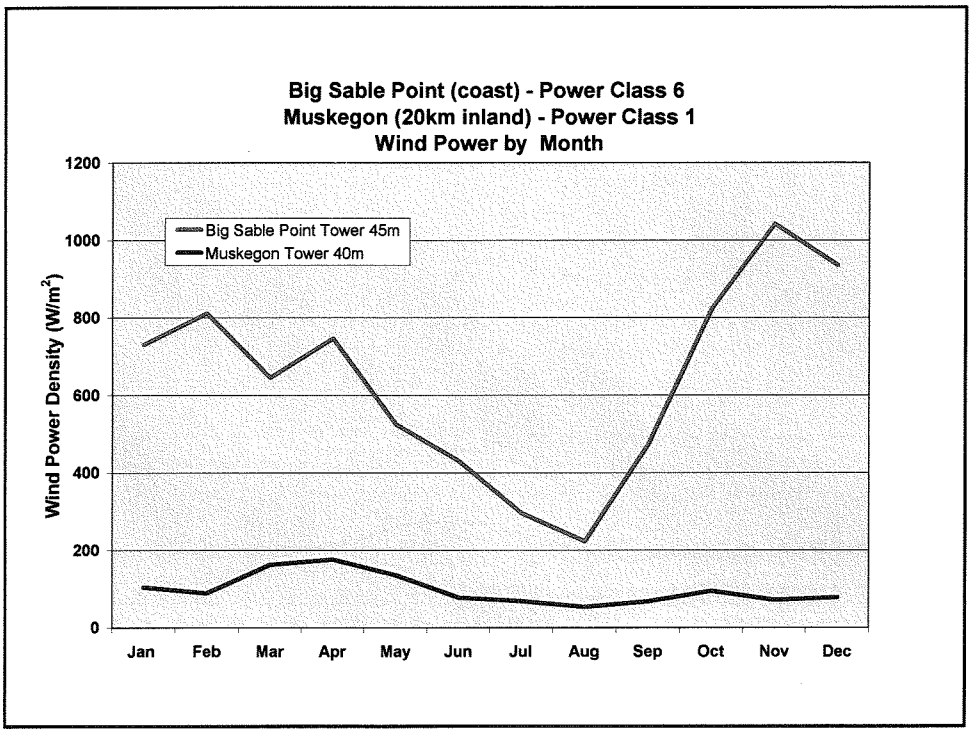

Muskegon Tower (20km inland) - Power Class 1
Wind Speed by Hour
Wind Speed (m/s)
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day
Muskegon Tower 40m
Muskegon Tower 25m
Muskegon Tower 10m

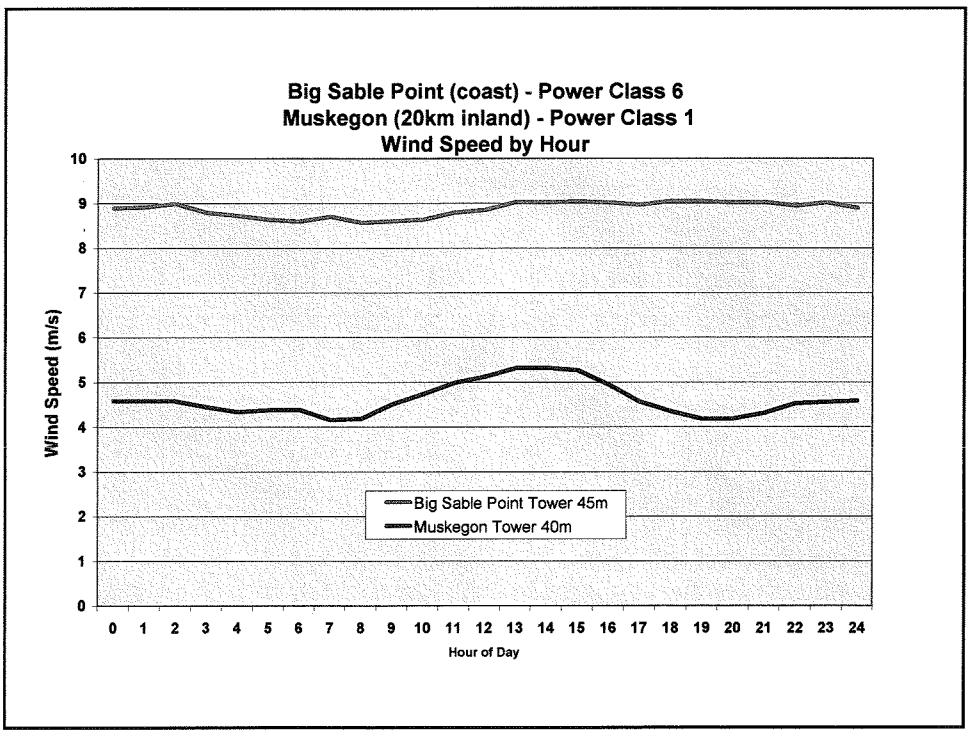


Central West Michigan

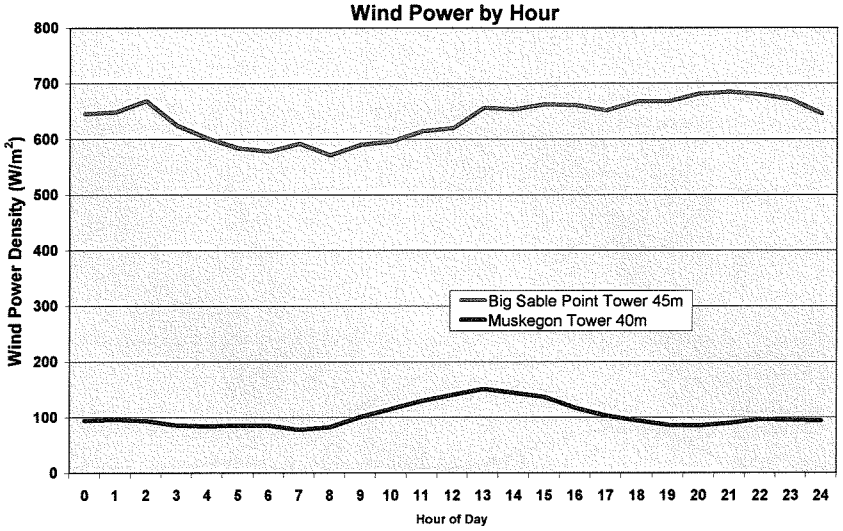
- Measurements at exposed capes indicate Class 6 resource
  - Big Sable Point (45.7 m tower) – Class 6
  - Point Betsie Lighthouse – Class 6
- Prevailing wind directions at exposed capes tend to be parallel to the coast, particularly from Mar-Sep
- Other coastal sites measured Class 3-4 (Ludington area)
- Seasonal wind patterns similar to those observed in Southwest Michigan
- Offshore wind resource generally Class 5-6.




Big Sable Point (coast) - Power Class 6
Muskegon (20km inland) - Power Class 1
Wind Power by Month
Wind Power Density (W/m²)
1200
1000
800
600
400
200
0
Big Sable Point Tower 45m
Muskegon Tower 40m
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

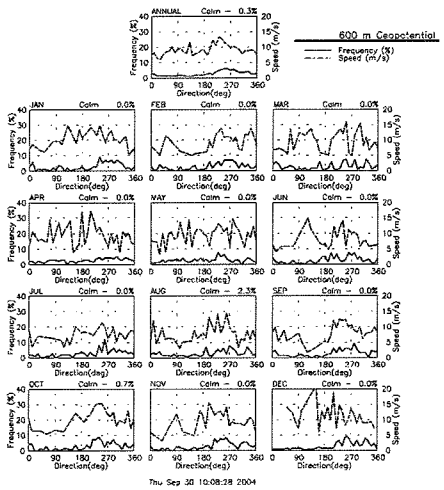

Big Sable Point (coast) - Power Class 6
Muskegon (20km inland) - Power Class 1
Wind Speed by Hour
Wind Speed (m/s)
10
9
8
7
6
5
4
3
2
1
0
Big Sable Point Tower 45m
Muskegon Tower 40m
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

Big Sable Point (coast) - Power Class 6
Muskegon (20km inland) - Power Class 1
Wind Power by Hour



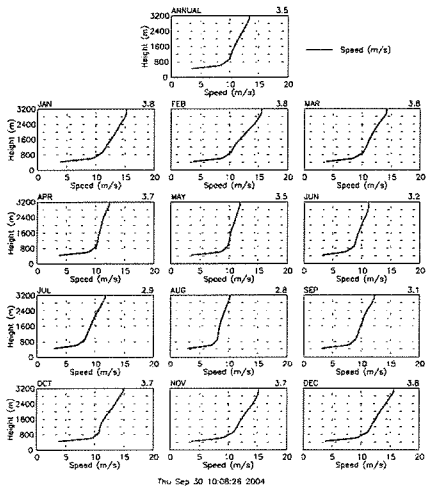
FREQUENCY & SPEED BY DIRECTION

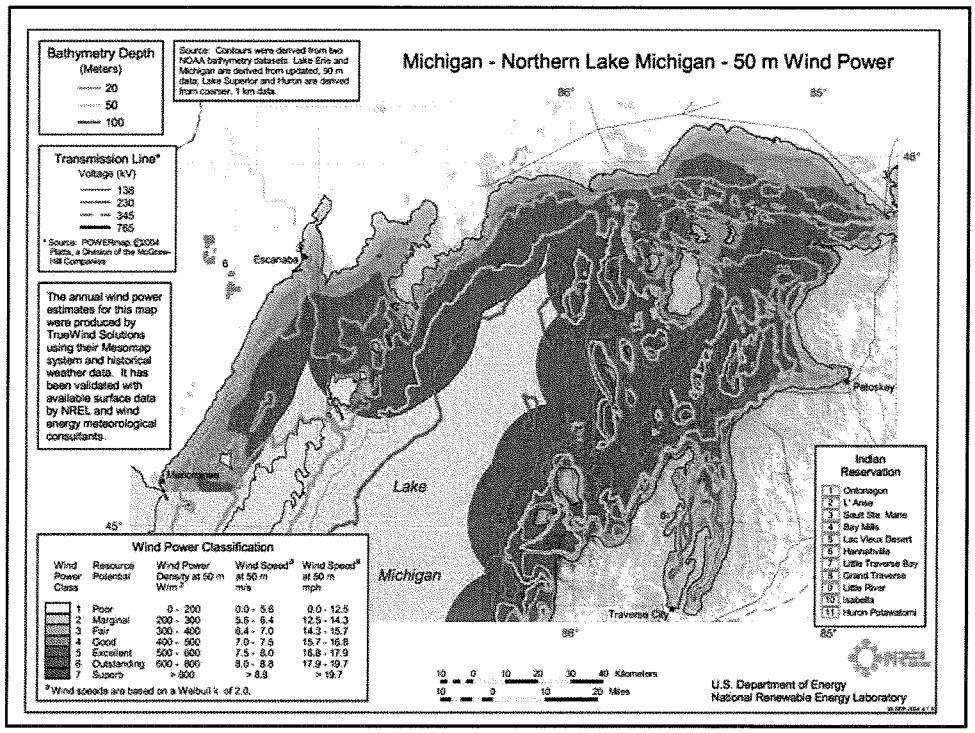
Gaylord - /2634 - 0/00 LST
44° 55' N 84° 43' W - Elev 446m
05/96-05/02

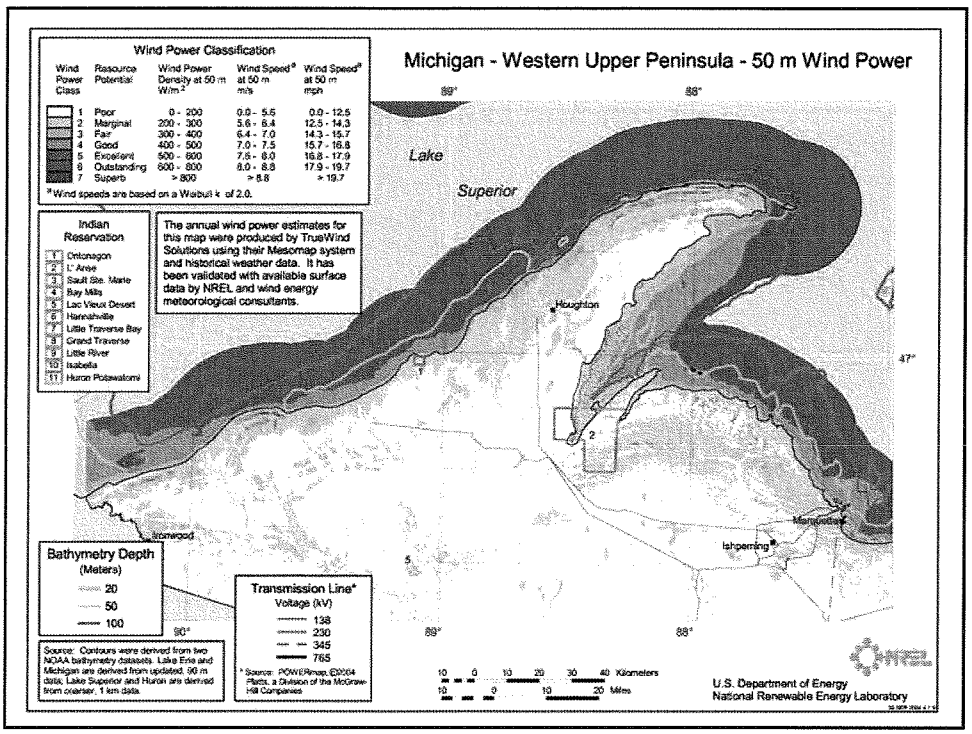


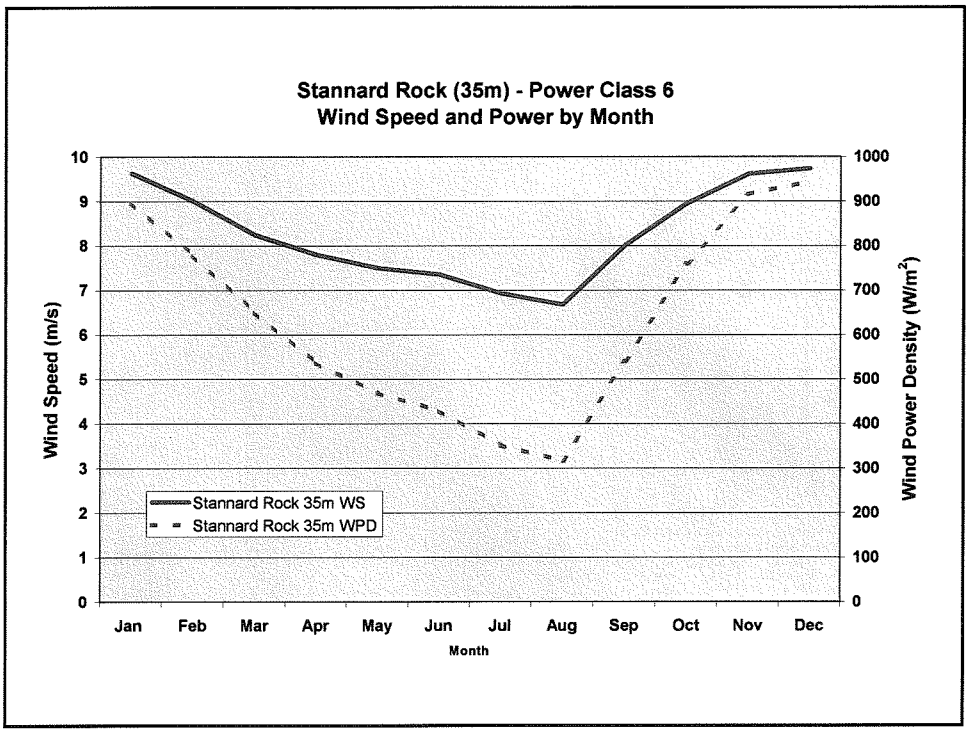
VERTICAL WIND SPEED PROFILE BY HEIGHT

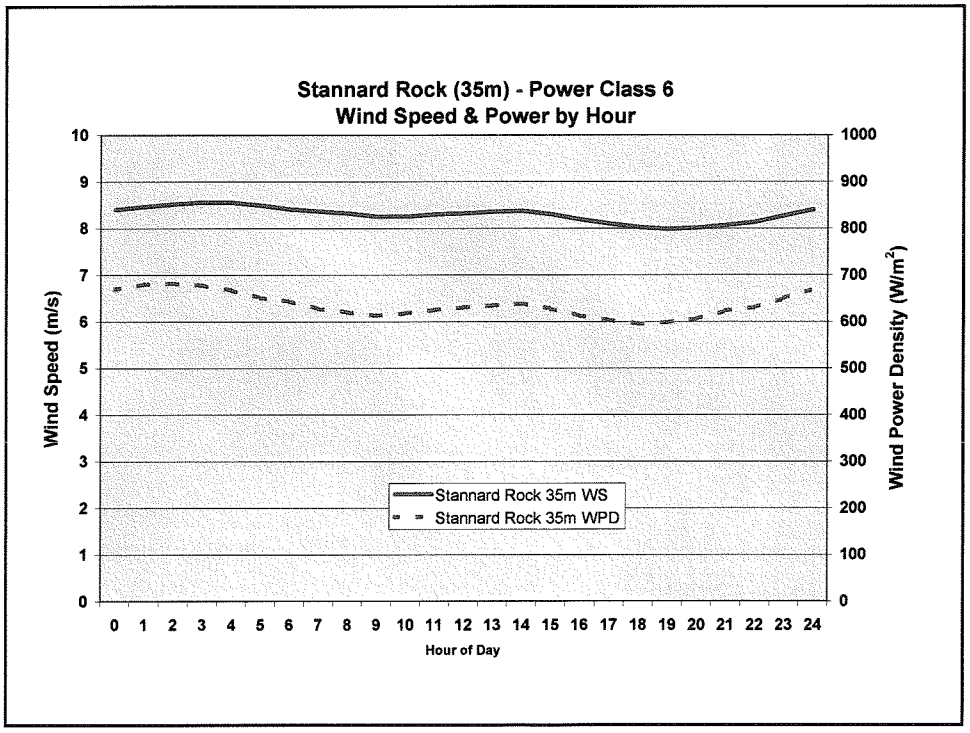
Gaylord - /2634 - 0/00 LST
44° 55' N 84° 43' W - Elev 446m
05/96-05/02

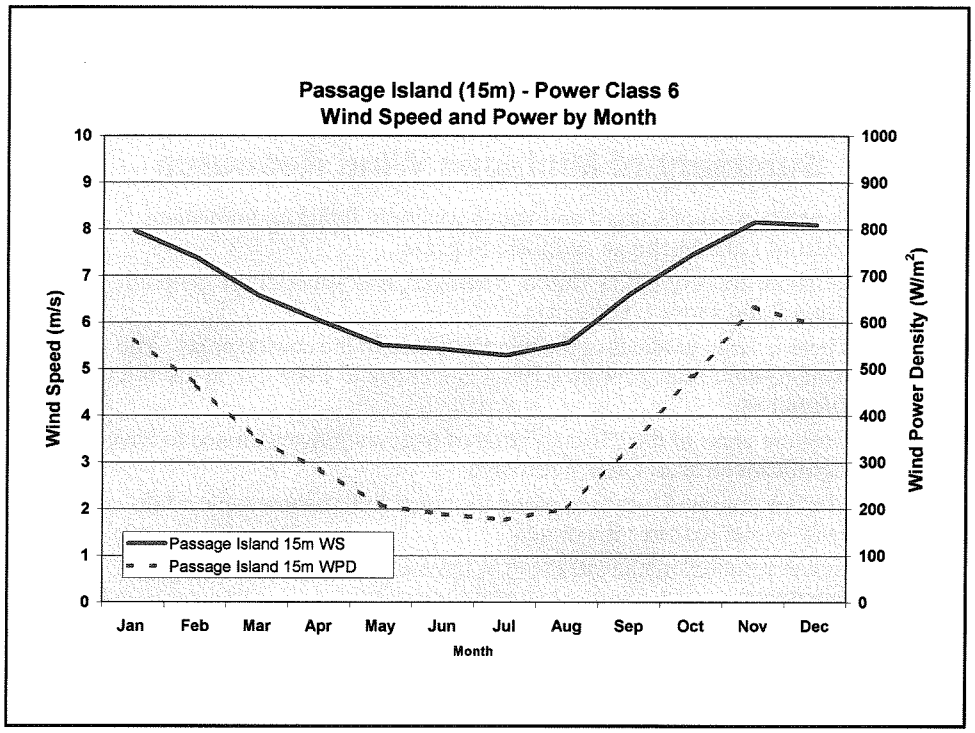


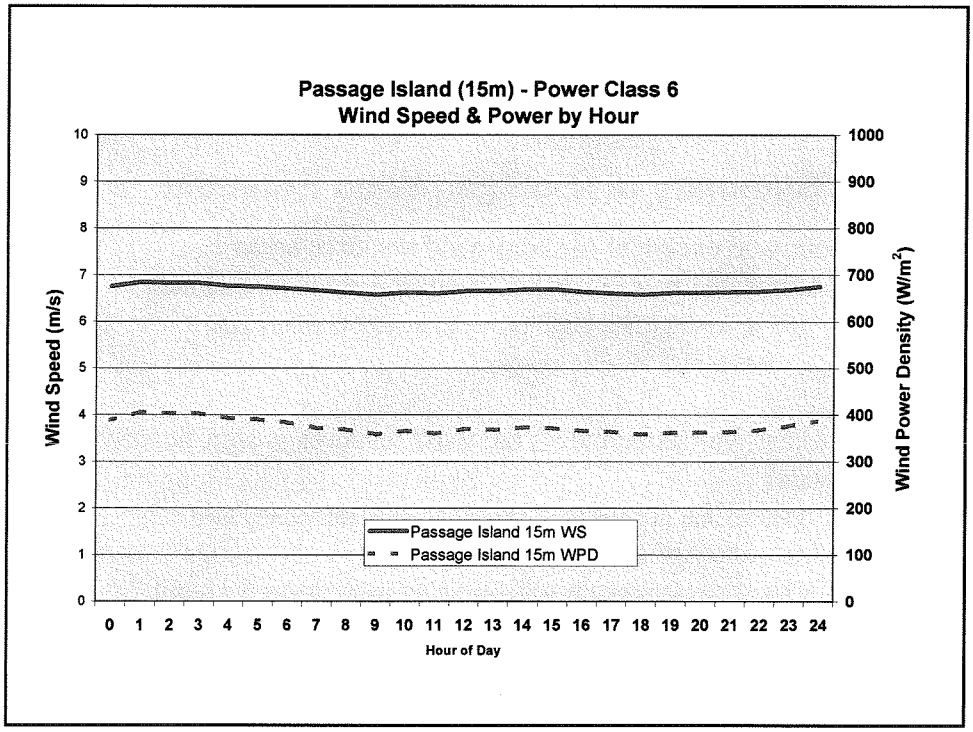

Michigan - Northern Lake Michigan - 50 m Wind Power
Bathymetry Depth (Meters)
20
50
100
Source: Contours were derived from two NOAA bathymetry datasets. Lake Erie and Michigan are derived from updated, 90 m data; Lake Superior and Huron are derived from coarser, 1 km data.
Transmission Line*
Voltage (kV)
138
230
345
765
* Source: POWERmap, ©2004 Platts, a Division of the McGraw-Hill Companies
The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.
Escanaba
Manistique
Petoskey
Traverse City
Lake
Michigan
Indian Reservation
1 Ontonagon
2 L' Anse
3 Sault Ste. Marie
4 Bay Mills
5 Lac Vieux Desert
6 Hannahville
7 Little Traverse Bay
8 Grand Traverse
9 Little River
10 Isabella
11 Huron Potawatomi
Wind Power Classification
Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m² | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph
1 Poor 0 - 200 0.0 - 5.6 0.0 - 12.5
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb > 800 > 8.8 > 19.7
[a] Wind speeds are based on a Weibull k of 2.0.
86°
85°
45°
10 0 10 20 30 40 Kilometers
10 0 10 20 Miles
U.S. Department of Energy
National Renewable Energy Laboratory


Michigan - Western Upper Peninsula - 50 m Wind Power
Wind Power Classification
Wind Power Class | Resource Potential | Wind Power Density at 50 m W/m² | Wind Speed[a] at 50 m m/s | Wind Speed[a] at 50 m mph
1 Poor 0 - 200 0.0 - 5.6 0.0 - 12.5
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb > 800 > 8.8 > 19.7
[a] Wind speeds are based on a Weibull k of 2.0.
Indian Reservation
1 Ontonagon
2 L' Anse
3 Sault Ste. Marie
4 Bay Mills
5 Lac Vieux Desert
6 Hannahville
7 Little Traverse Bay
8 Grand Traverse
9 Little River
10 Isabella
11 Huron Potawatomi
The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.
Lake
Superior
Houghton
Ironwood
Ishpeming
Marquette
Bathymetry Depth (Meters)
20
50
100
Source: Contours were derived from two NOAA bathymetry datasets. Lake Erie and Michigan are derived from updated, 90 m data; Lake Superior and Huron are derived from coarser, 1 km data.
Transmission Line*
Voltage (kV)
138
230
345
765
* Source: POWERmap, ©2004 Platts, a Division of the McGraw-Hill Companies
89°
88°
90°
47°
10 0 10 20 30 40 Kilometers
10 0 10 20 Miles
U.S. Department of Energy
National Renewable Energy Laboratory


Stannard Rock (35m) - Power Class 6
Wind Speed and Power by Month
Wind Speed (m/s)
Wind Power Density (W/m²)
Stannard Rock 35m WS
Stannard Rock 35m WPD
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Stannard Rock (35m) - Power Class 6
Wind Speed & Power by Hour
Wind Speed (m/s)
Wind Power Density (W/m²)
Stannard Rock 35m WS
Stannard Rock 35m WPD
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


Passage Island (15m) - Power Class 6
Wind Speed and Power by Month
Wind Speed (m/s)
Wind Power Density (W/m²)
Passage Island 15m WS
Passage Island 15m WPD
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Passage Island (15m) - Power Class 6
Wind Speed & Power by Hour
Wind Speed (m/s)
Wind Power Density (W/m²)
Passage Island 15m WS
Passage Island 15m WPD
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

Summary of Michigan Wind Resource

- Onshore areas of Class 4 and above generally found on immediate coast of Lake Michigan and Lake Superior
- Offshore areas of Lakes Huron, Michigan, and Superior are generally Class 5 and above (excellent)
- There is large gradient of the wind resource in the coastal areas. The wind resource can go from Class 4 and above to Class 1-2 in just a few kilometers.
- Onshore areas of the "Thumb" east of Saginaw Bay estimated to have significant areas of Class 3 resource
- The best exposed locations along the coast and offshore have a fall-early winter resource maximum
- Lower resource inland sites tend to have a winter-spring resource maximum
- The power producing winds tend to be from the south to the west-northwest.

Summary of Michigan Wind Potential

- Good and excellent onshore wind resource areas concentrated in a few exposed coastal areas and islands
  - 166 sq. km of Class 4 and higher of available windy land
    - 830 MW of installed capacity
- If Class 3 areas included, the wind resource is significantly greater
  - 3313 sq. km of Class 3 and higher of available windy land
    - 16,560 MW of installed capacity
  - Class 3 area potentially suitable for advanced low wind speed turbine technology