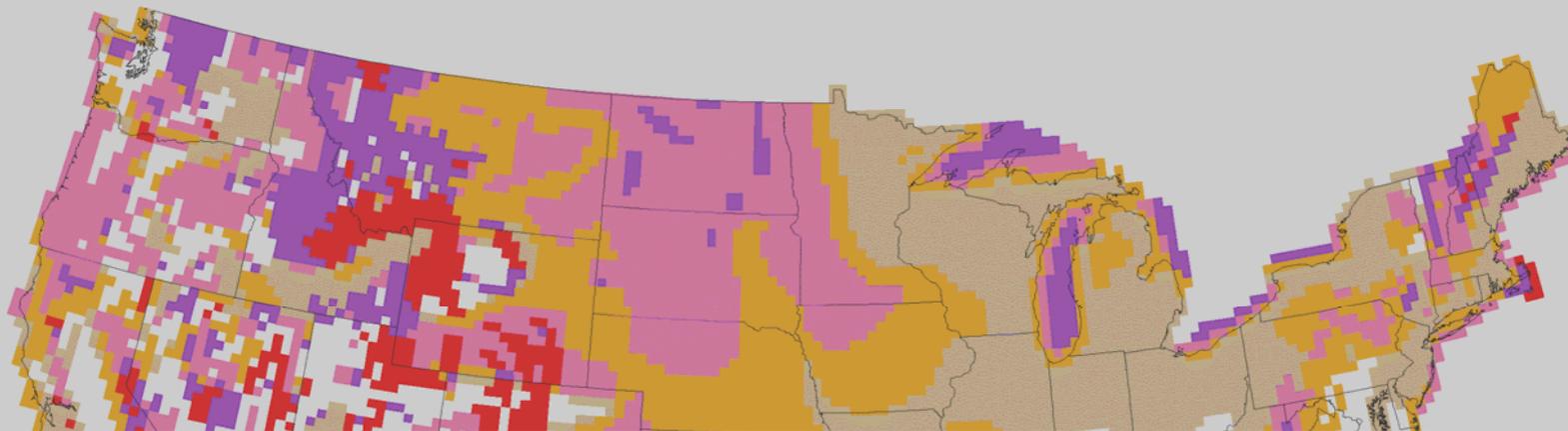


# Wind Resource Assessment and Mapping

Dennis Elliott, Marc Schwartz, George Scott,  
Steve Haymes, and Donna Heimiller

Wind for Schools Summit  
September 13-15, 2007  
NREL/NWTC Golden, Colorado

# United States - Wind Resource Map (1987)



## Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> 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

<sup>a</sup> Wind speeds are based on a Weibull k value of 2.0

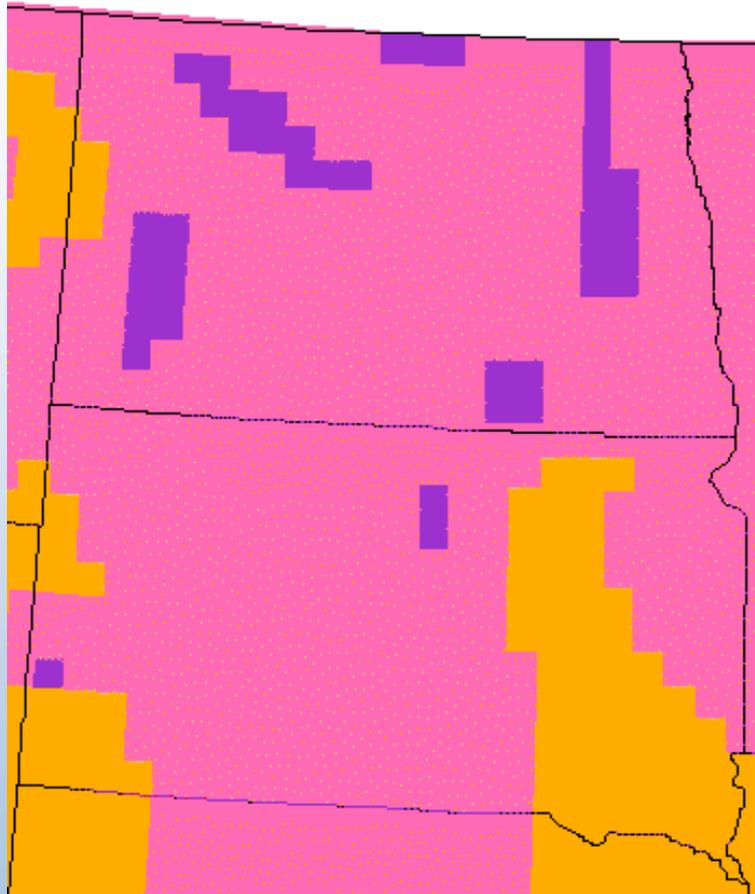
# Why Use Power Density Instead of Speed for Mapping Wind Resources?

## Comparison of Annual Average Wind Power at Four Sites with Identical Annual Average Wind Speeds at 10 m

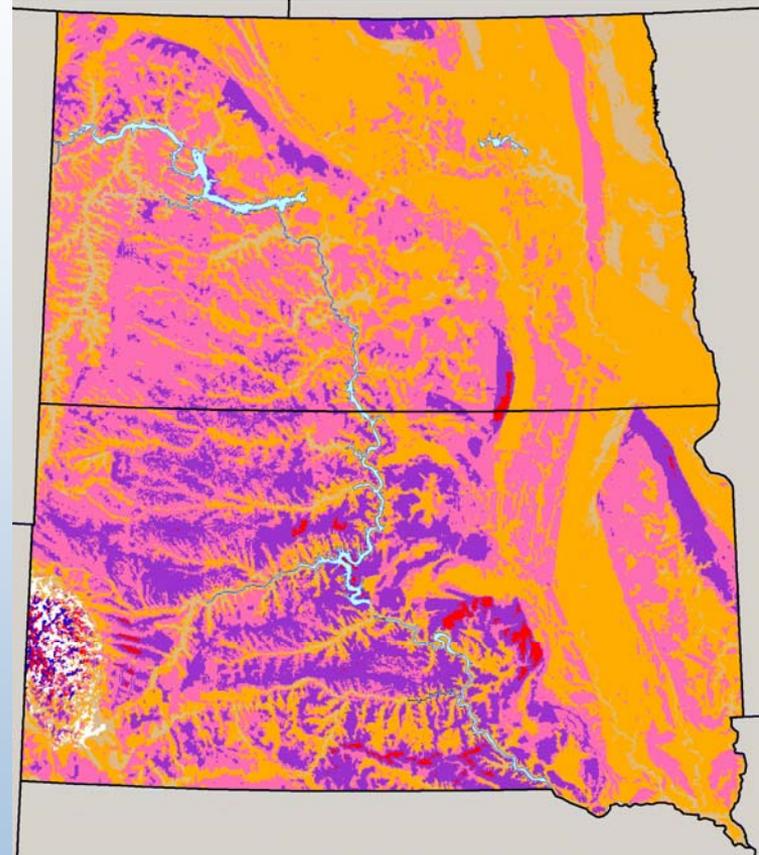
Site	Annual Average Wind Speed, m/s (mph)	Annual Average Wind Power Density, W/m <sup>2</sup>	Wind Power Power Class
Constant Wind Speed (hypothetical)	6.3 (14)	150	2-3
Culebra, Puerto Rico	6.3 (14)	220	4
Tiana Beach, New York	6.3 (14)	285	5
San Gorgonio, California	6.3 (14)	365	6

Wind power varies with distribution of wind speeds, and air density (elevation, air temperature and pressure)

# Comparison of Digital Wind Map from 1987 U.S. Wind Atlas and New (2000) High-Resolution (1-km<sup>2</sup>) Wind Map North and South Dakota



1987



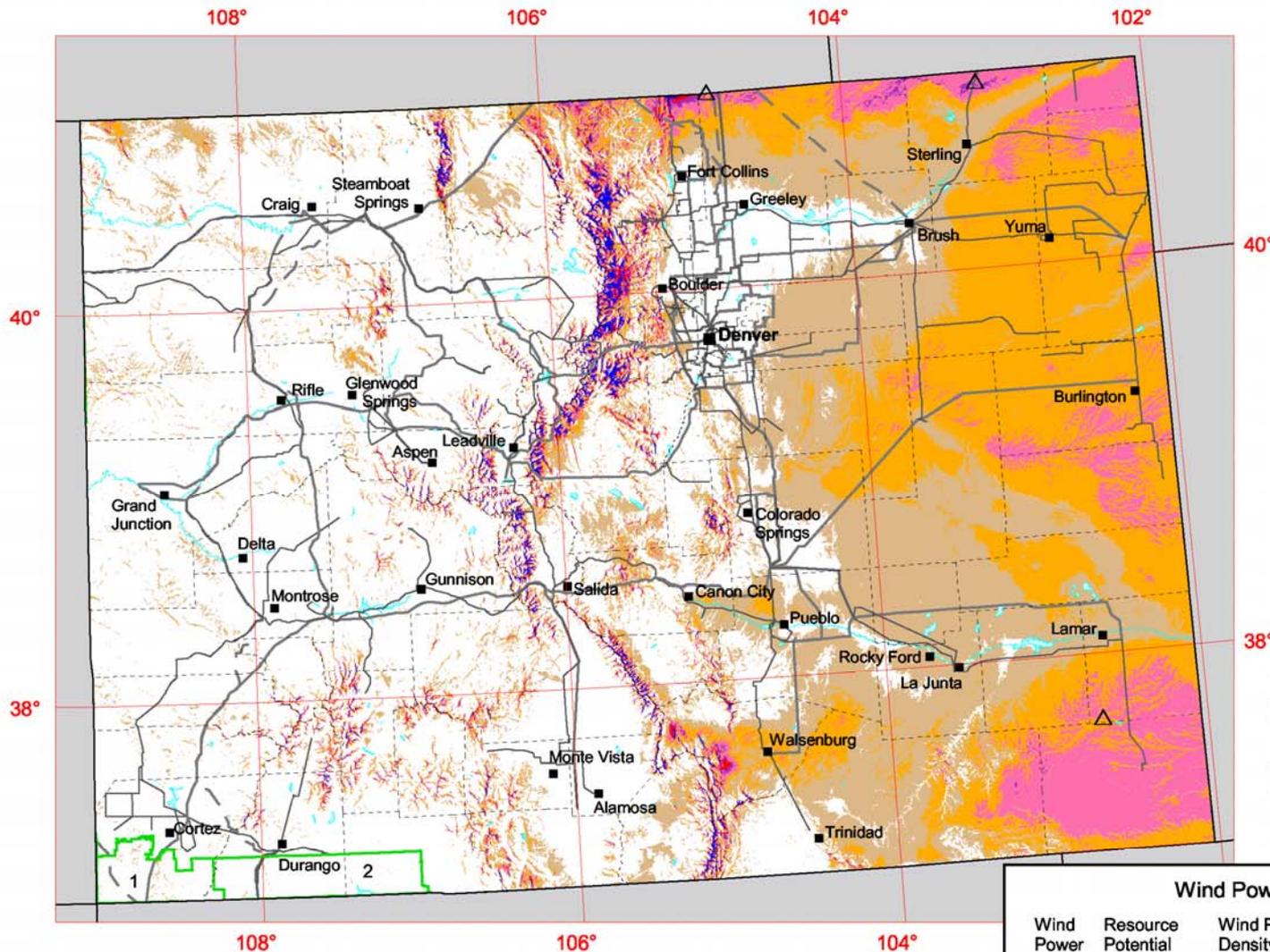
2000

Wind Power Classification				
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
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6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

<sup>a</sup> Wind speeds are based on a Weibull k value of 2.0

# Colorado

## 50 m Wind Power



**Transmission Line\***  
Voltage (kV)

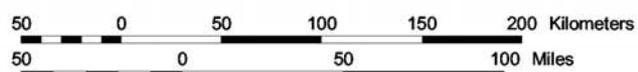
- 115 - 161
- 230
- - 345

\* Source: POWERmap, ©2003  
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.

Wind Power Classification				
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.7	13.2 - 15.0
3	Fair	300 - 400	6.7 - 7.4	15.0 - 16.6
4	Good	400 - 500	7.4 - 7.9	16.6 - 17.7
5	Excellent	500 - 600	7.9 - 8.4	17.7 - 18.8
6	Outstanding	600 - 800	8.4 - 9.3	18.8 - 20.8
7	Superb	> 800	> 9.3	> 20.8

<sup>a</sup> Wind speeds are based on a Weibull k of 2.0 at 1500 m elevation.



**Indian Reservation**

- 1 Ute Mountain
- 2 Southern Ute

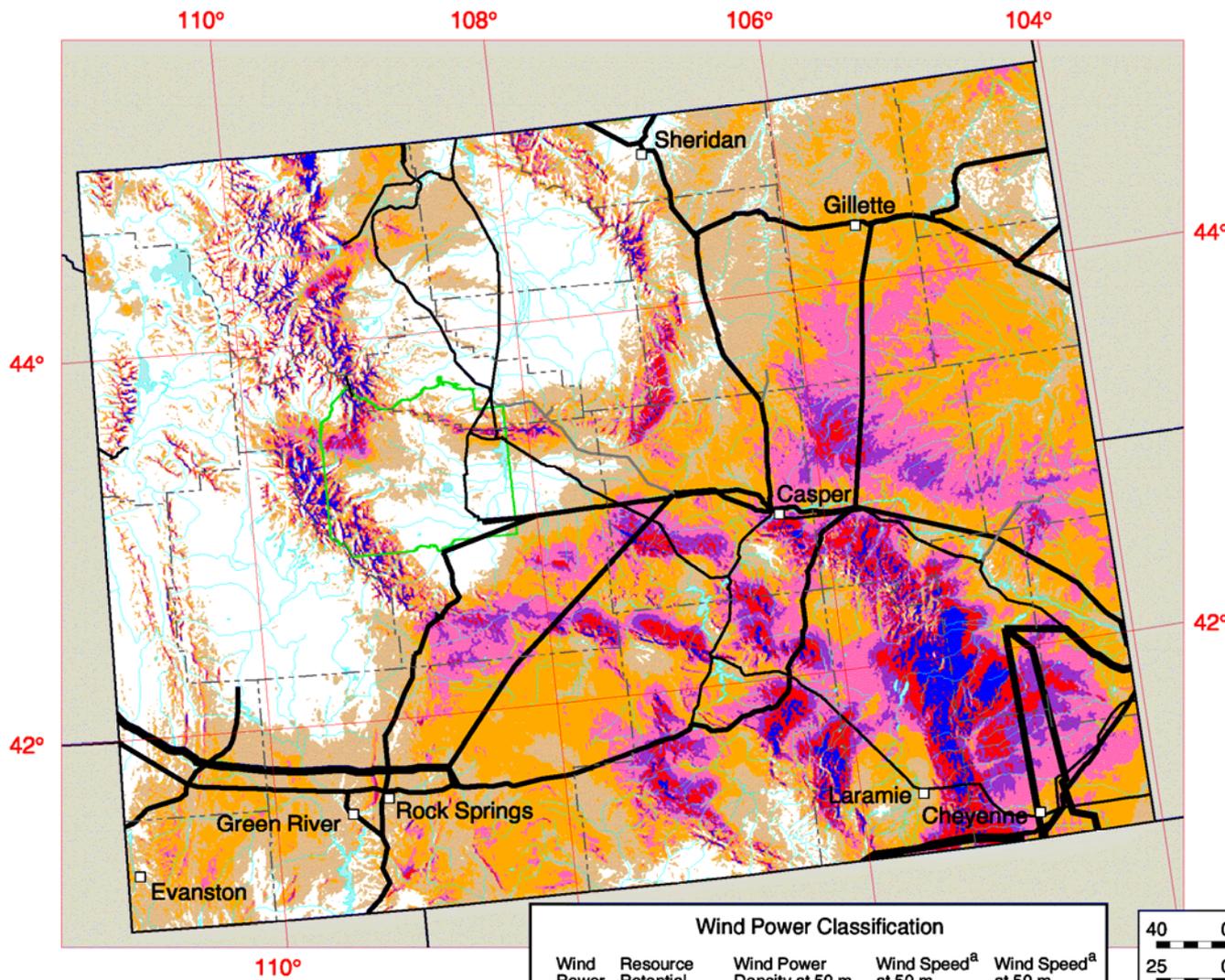


U.S. Department of Energy  
National Renewable Energy Laboratory



# Wyoming

## Wind Power Resource Estimates



 Wind River Indian Reservation

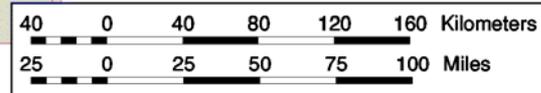
**Transmission Line\***  
Voltage (kV)

-  69
-  115
-  230
-  345

\* Source: POWERmap, ©2002 Platts, A Division of the McGraw-Hill Companies

Wind Power Classification				
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
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	7 Superb	> 800	> 8.8	> 19.7

<sup>a</sup>Wind speeds are based on a Weibull k value of 2.0



The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.

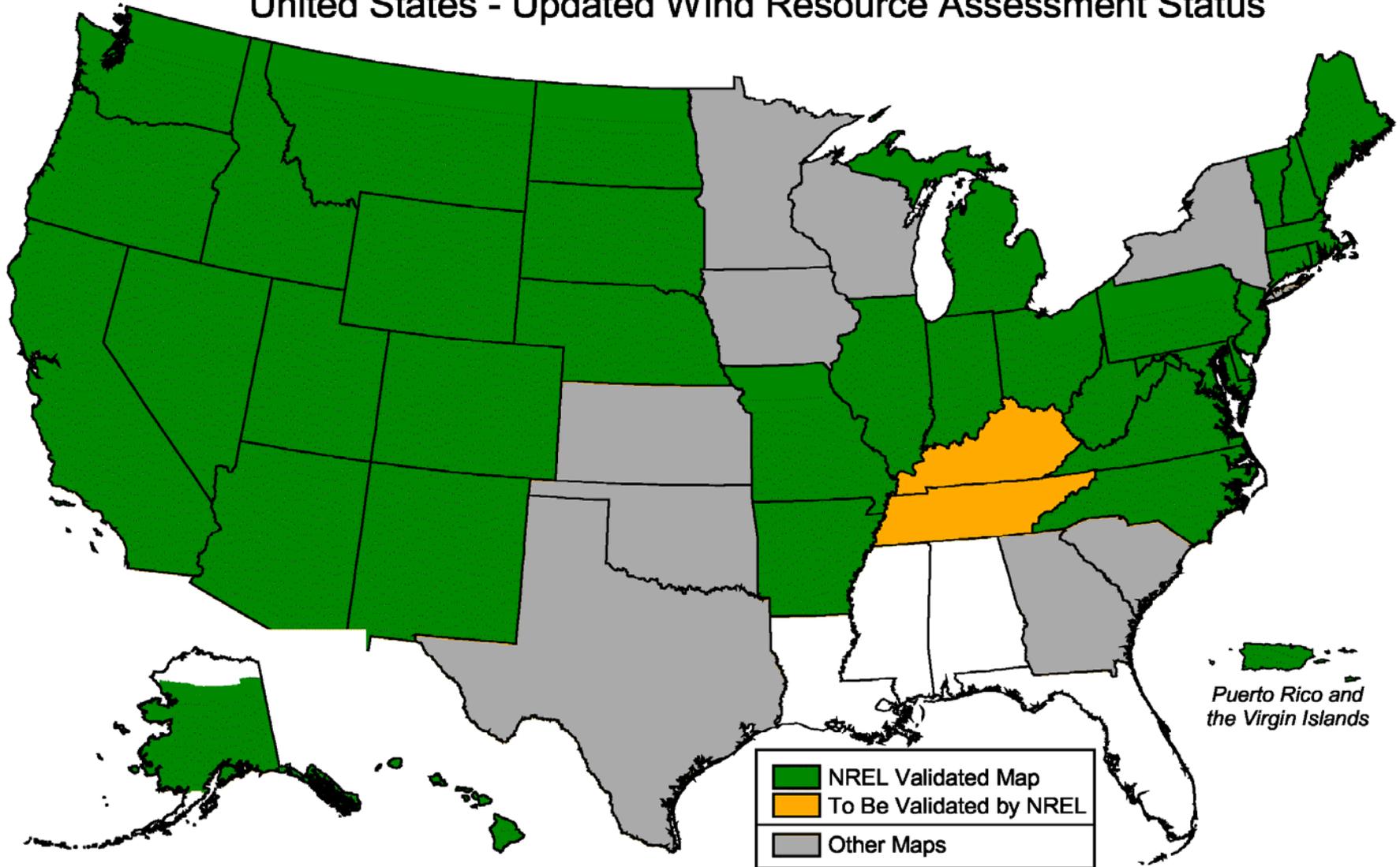
U.S. Department of Energy  
National Renewable Energy Laboratory



# High-Resolution Wind Mapping Approach

- Produces finer than 1 km<sup>2</sup> horizontal resolution wind resource maps
- Combination of numerical (AWS Truewind), empirical and analytical methods (NREL validation)
- Does not depend on high-quality surface wind data
- Preliminary maps are validated and modified
  - Formal validations limited to 50 m speed and power maps
- Many states re-mapped as part of Wind Powering America

## United States - Updated Wind Resource Assessment Status

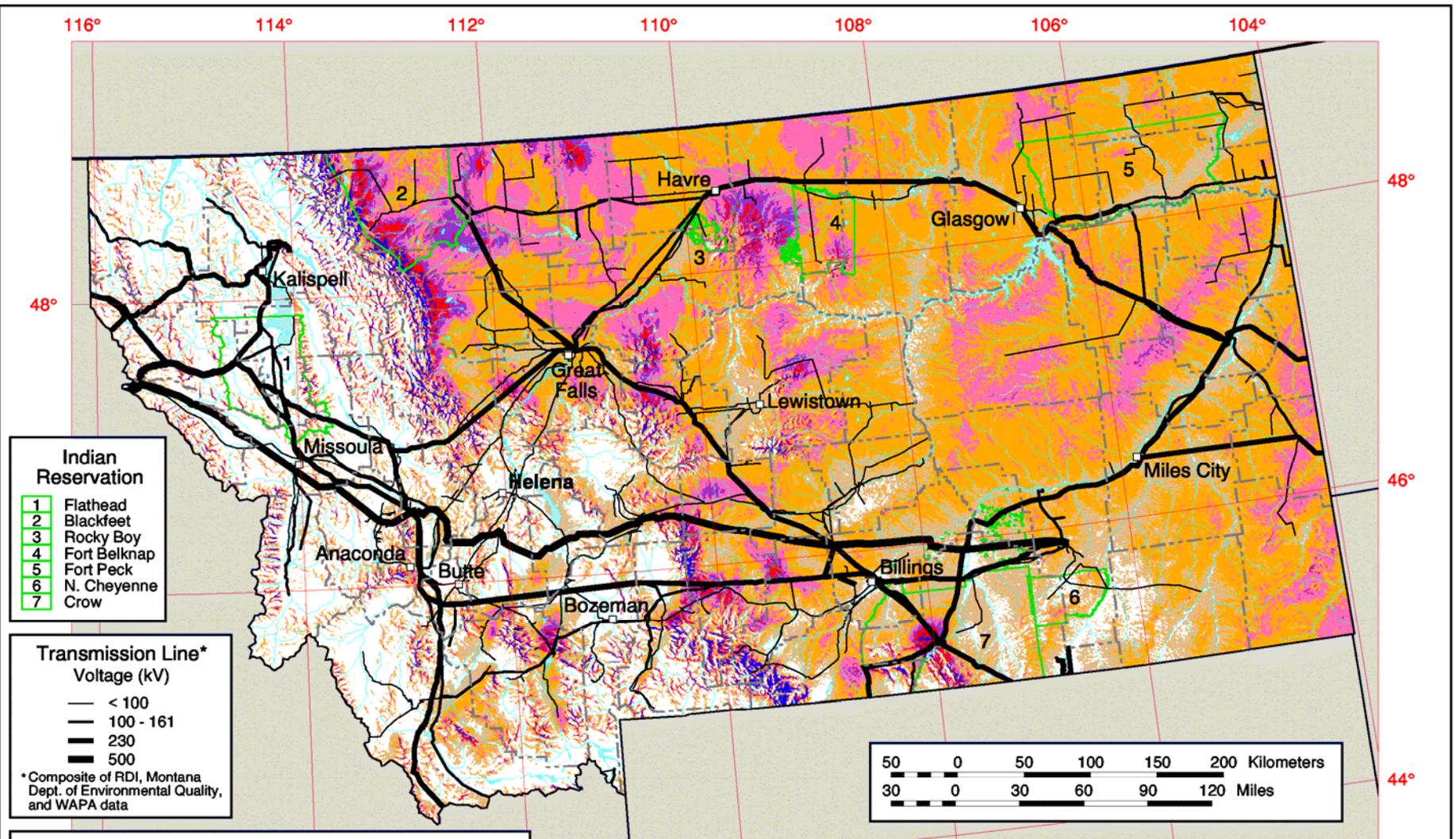


[http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind\\_maps.asp](http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp)

# Status of State Wind Mapping and Validation (August 2007)

- 50-m maps for 36 states and territories have been validated by NREL for Wind Powering America (WPA)
  - FY07 maps validated include Arkansas and Puerto Rico/Virgin Islands
- Methodology is being developed to validate 70 m to 100 m (modern turbine hub-heights) wind resource maps
  - “Available” measurements from these heights are uncommon and not likely to substantially increase in near future
- First two states for 70 m to 100 m map validation are Indiana and Ohio





**Indian Reservation**

1	Flathead
2	Blackfeet
3	Rocky Boy
4	Fort Belknap
5	Fort Peck
6	N. Cheyenne
7	Crow

**Transmission Line\*  
Voltage (kV)**

—	< 100
—	100 - 161
—	230
—	500

\* Composite of RDI, Montana Dept. of Environmental Quality, and WAPA data

**Wind Power Classification**

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
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6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

<sup>a</sup> Wind speeds are approximate and based on a Weibull k value of 2.0

## Montana Wind Power Resource Estimates

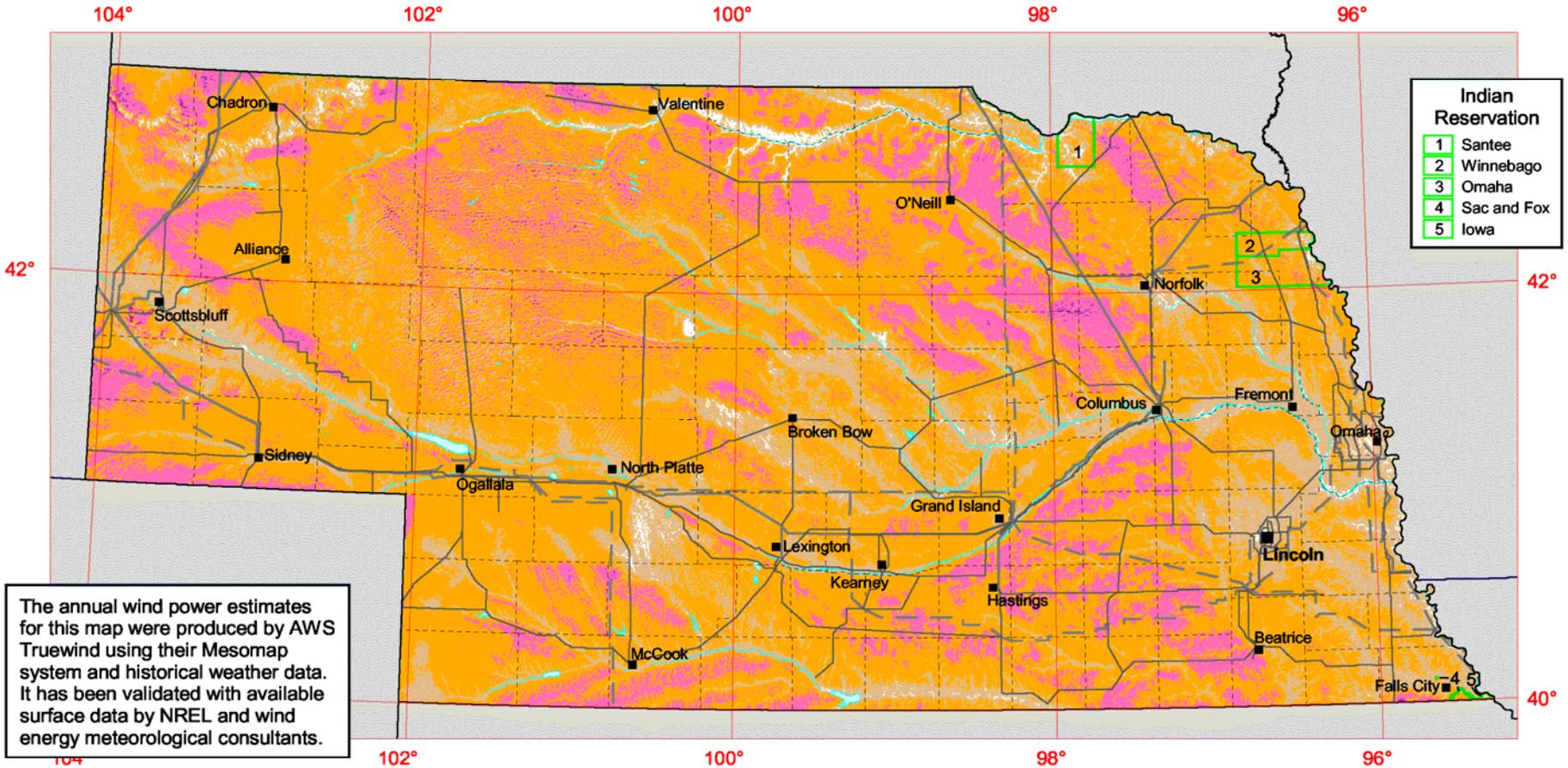
The wind power resource estimates were produced by TrueWind Solutions using their Mesomap system and historical weather data. This map has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.

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National Renewable Energy Laboratory



15-MAR-2002 1.1.1

# Nebraska - 50 m Wind Power



- Indian Reservation**
- 1 Santee
  - 2 Winnebago
  - 3 Omaha
  - 4 Sac and Fox
  - 5 Iowa

The annual wind power estimates for this map were produced by AWS Truewind using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.

Wind Power Classification				
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
1	Poor	0 - 200	0.0 - 5.7	0.0 - 12.8
2	Marginal	200 - 300	5.7 - 6.5	12.8 - 14.6
3	Fair	300 - 400	6.5 - 7.2	14.6 - 16.1
4	Good	400 - 500	7.2 - 7.8	16.1 - 17.5
5	Excellent	500 - 600	7.8 - 8.2	17.5 - 18.4
6	Outstanding	600 - 800	8.2 - 9.0	18.4 - 20.2
7	Superb	> 800	> 9.0	> 20.2

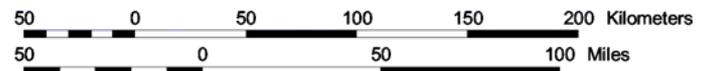
<sup>a</sup>Wind speeds are based on a Weibull k of 2.0 at 800 m elevation.

**Transmission Line\***

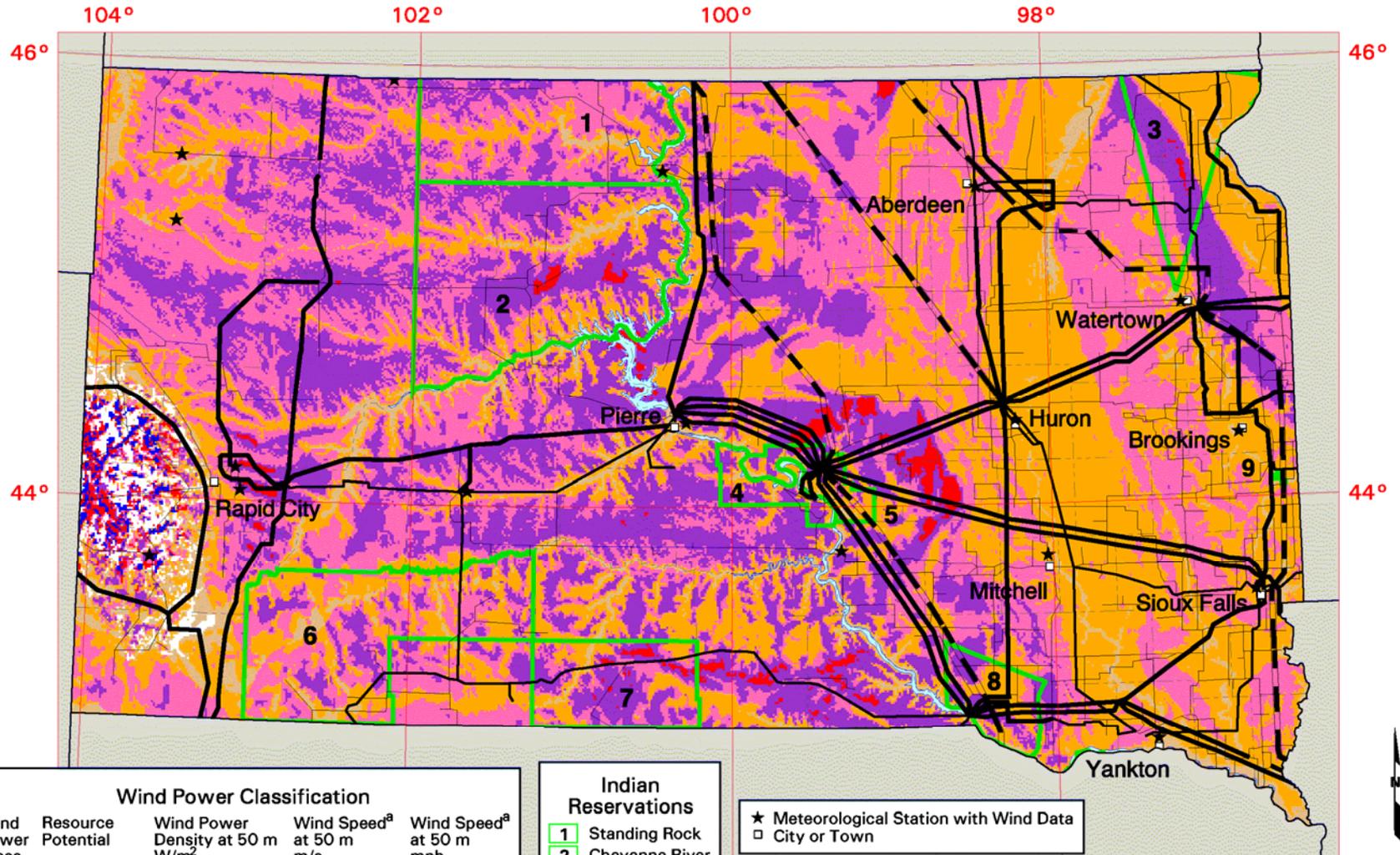
Voltage (kV)

- 35
- 115 - 161
- 230
- 345

\* Source: POWERmap, ©2005  
Platts, a Division of the McGraw-Hill Companies



# South Dakota - Wind Resource Map



## Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m <sup>2</sup>	Wind Speed <sup>a</sup> at 50 m m/s	Wind Speed <sup>a</sup> at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
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7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

<sup>a</sup>Wind speeds are based on a Weibull k value of 2.0

## Indian Reservations

- 1 Standing Rock
- 2 Cheyenne River
- 3 Lake Traverse
- 4 Lower Brule
- 5 Crow Creek
- 6 Pine Ridge
- 7 Rosebud
- 8 Yankton
- 9 Flandreau

★ Meteorological Station with Wind Data  
 □ City or Town

## Transmission Line Voltage

- 69 Kilovolts
- 115 Kilovolts
- 230 Kilovolts
- 345 Kilovolts

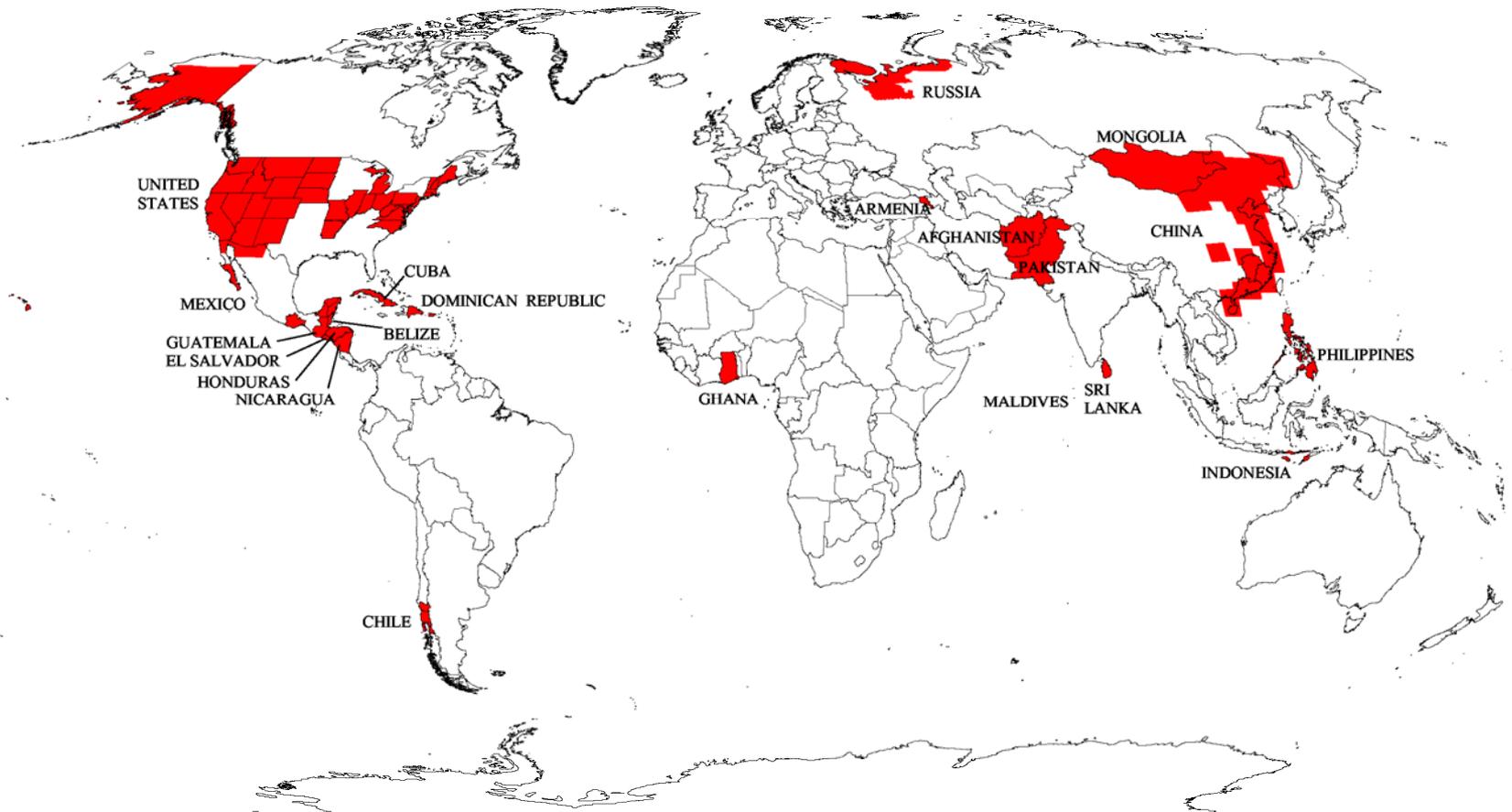
50 0 50 100 Kilometers

25 0 25 50 75 Miles



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 National Renewable Energy Laboratory

# NREL's High Resolution Wind Mapping and Validation Projects



High-resolution (1 km<sup>2</sup> or finer) regional or national wind resource maps have been produced or are in progress for:

Afghanistan  
 Armenia  
 Belize  
 Chile - specific areas  
 China - specific areas  
 Cuba  
 Dominican Republic

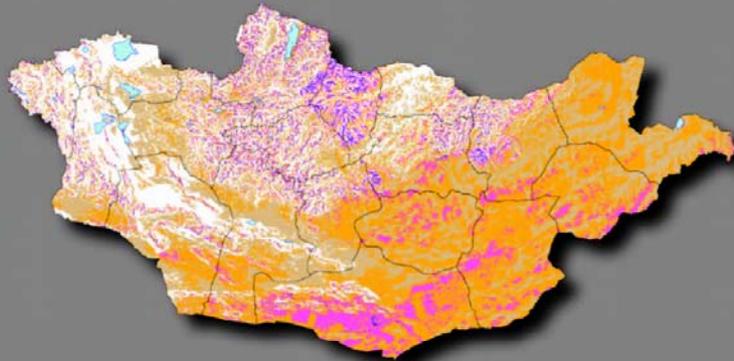
El Salvador  
 Ghana  
 Guatemala  
 Honduras  
 Indonesia - specific areas  
 Maldives  
 Mexico - specific areas

Mongolia  
 Nicaragua  
 Pakistan  
 Philippines  
 Russia - specific areas  
 Sri Lanka  
 United States - specific areas

U.S. Department of Energy  
 National Renewable Energy Laboratory



# Wind Energy Resource Atlas of Mongolia



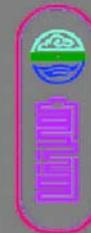
Prepared for  
U.S. Department of Energy



U.S. Agency for International Development



in cooperation with  
Renewable Energy Corporation of Mongolia



Institute of Meteorology and Hydrology



Prepared by  
National Renewable Energy Laboratory  
1617 Cole Boulevard • Golden, Colorado 80401-3393  
A national laboratory of the U.S. Department of Energy  
Managed by Midwest Research Institute • Battelle • Bechtel  
for the U.S. Department of Energy under Contract No. DE-AC36-98-GO10337  
NREL/TP-500-28972 • August 2001

D. Elliott, M. Schwartz, G. Scott, S. Haymes, D. Heimiller, R. George  
National Renewable Energy Laboratory

# Validation Process

- Collaborative process among AWS Truewind, NREL, and private consultants
- Validators -- NREL and expert consultants
  - consultants have access to proprietary data
  - use own methods and data
  - provide both quantitative scores via a spread sheet and qualitative comments
  - provide validation results to NREL/AWS Truewind
- AWS Truewind
  - produces preliminary map
  - reviews validation results to improve map
  - produces final validated map

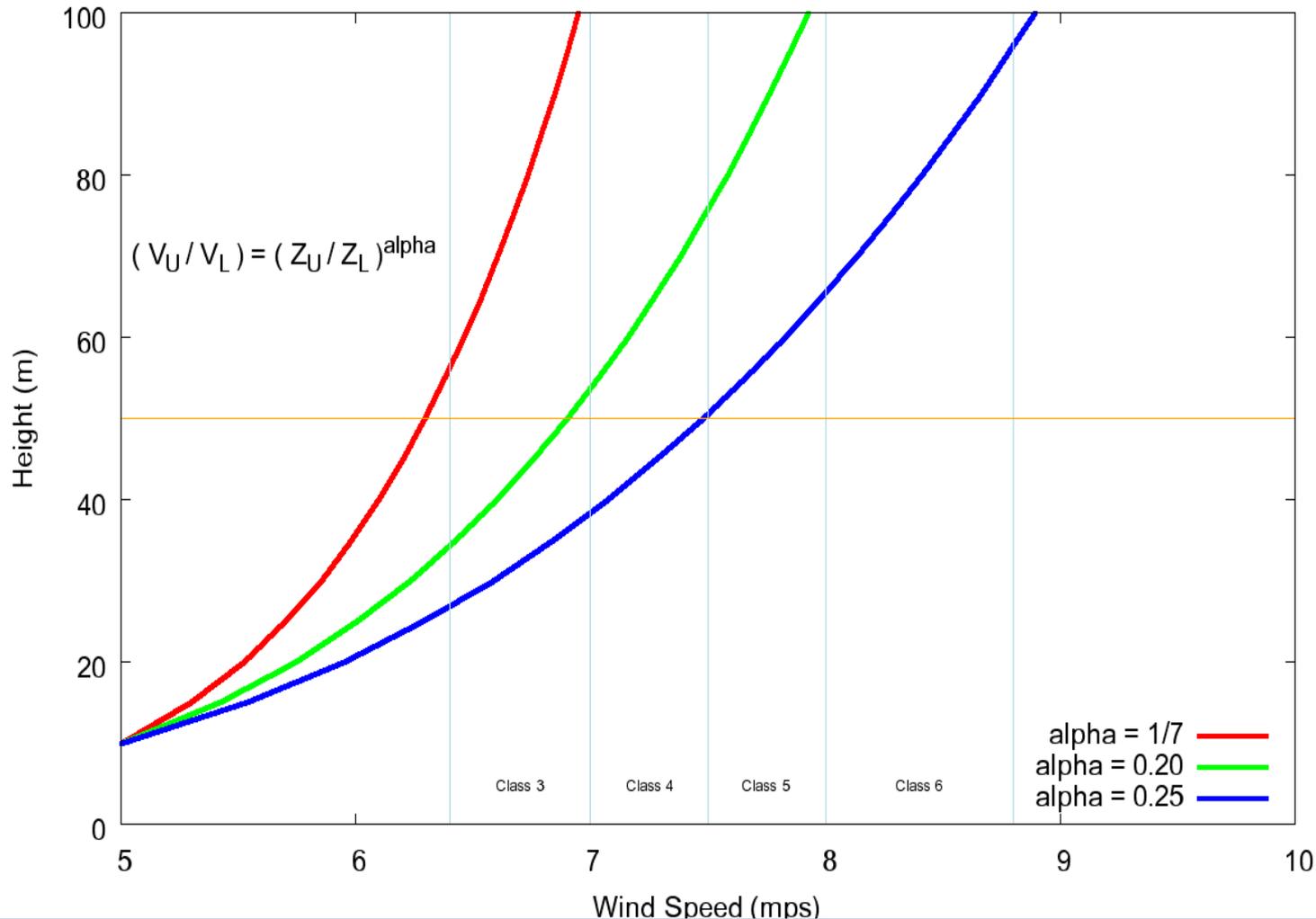
# Major Data Sets Used in Validation

- Federal, state, and utility wind measurement programs
- Developer wind data (proprietary sources)
- Meteorological station data from NOAA/NCDC
  - Airports and military bases
  - Coast guard stations, lighthouses, buoys
- Other wind data
  - Highway (State DOT)
  - Forest Service (RAWS)
  - Anemometer loan programs

# Accuracy Issues with Wind Measurement Data

- Surface meteorological station wind data issues
  - Surface wind speeds (at or near 10-m height above ground) may be obstructed by nearby buildings, trees, or obstacles
  - A particular station's wind climate may not represent the wind climate at a turbine site
  - Changes in anemometer location, surroundings, or equipment can cause the wind speeds to change over time
    - For example, at airport stations, discontinuities in annual average wind speeds due to changes in equipment have occurred since 1992
    - Lack of metadata (such as exact locations and long-term history of measurement equipment) for many locations complicate the issue
- Tower wind data issues
  - Wind data collected on towers at heights of 20m to 50m+ for wind energy prospecting may be available for some locations
  - Flow around the tower may effect the wind speed and direction measurements
  - Missing and questionable quality data may make it difficult to obtain accurate estimates of the annual average wind speed
    - Questionable data can be due to icing, weather conditions, and sensor problems

## Wind Speed vs. Height for Different Shear Exponents



**Annual average shear exponents can vary from 1/7 to 0.25, causing considerable uncertainty in vertical extrapolations of wind resource**



# Online Wind Information Availability

- High resolution mapping status and static maps
  - Wind Powering America web site
- Interactive map server
  - U.S. Renewable Energy Atlas
  - Non-NREL state and regional applications are also available (New England, Northwest, Texas, etc.)
- GIS wind resource map data
- Wind measurement data
  - Various sources

Address [http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind\\_maps.asp](http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp)

U.S. Department of Energy  
**Energy Efficiency and Renewable Energy** *Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable*

**Wind & Hydropower Technologies Program**

About the Program | Program Areas | Information Resources | Financial Opportunities | Technologies | Deployment | Home

**Wind Powering America** Search

State Wind Resource Maps

One of Wind Powering America's key activities for states is to provide validated state wind maps. Below is a color-coded map, which indicates which states have validated wind resource maps, which states are planned, and other wind maps that have not been validated. Click on a state to go to its wind resource map or you can use the drop down lists below to get to state wind resource maps.

United States - Updated Wind Resource Assessment Status

View an enlarged map (not clickable)

# Online Maps

- WPA site shows current high resolution maps
- Links provided to NREL validated and other (non-validated) wind maps



# Wind & Hydropower Technologies Program

- About the Program
- Program Areas
- Information Resources
- Financial Opportunities
- Technologies
- Deployment
- Home

## Wind Powering America

Search  
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  - Economic Development
  - Policy
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- Resources & Tools
  - Wind Maps
  - Software
  - Publications
  - News

### Colorado Wind Resource Map

The Department of Energy's Wind Program and the National Renewable Energy Laboratory (NREL) recently published a new wind resource map for the state of Colorado. This resource map shows wind speed estimates at 50 meters above the ground and depicts the resource that could be used for utility-scale wind development. Future plans are to provide wind speed estimates at 30 meters, which are useful for identifying small wind turbine opportunities.

As a renewable resource, wind is classified according to wind power classes, which are based on typical wind speeds. These classes range from class 1 (the lowest) to class 7 (the highest). In general, wind power class 4 or higher can be useful for generating wind power with large turbines. Class 4 and above are considered good resources.

This map indicates that Colorado has wind resources consistent with utility-scale production. Significant contiguous areas of good



This map of Colorado shows the wind resource at 50 meters.

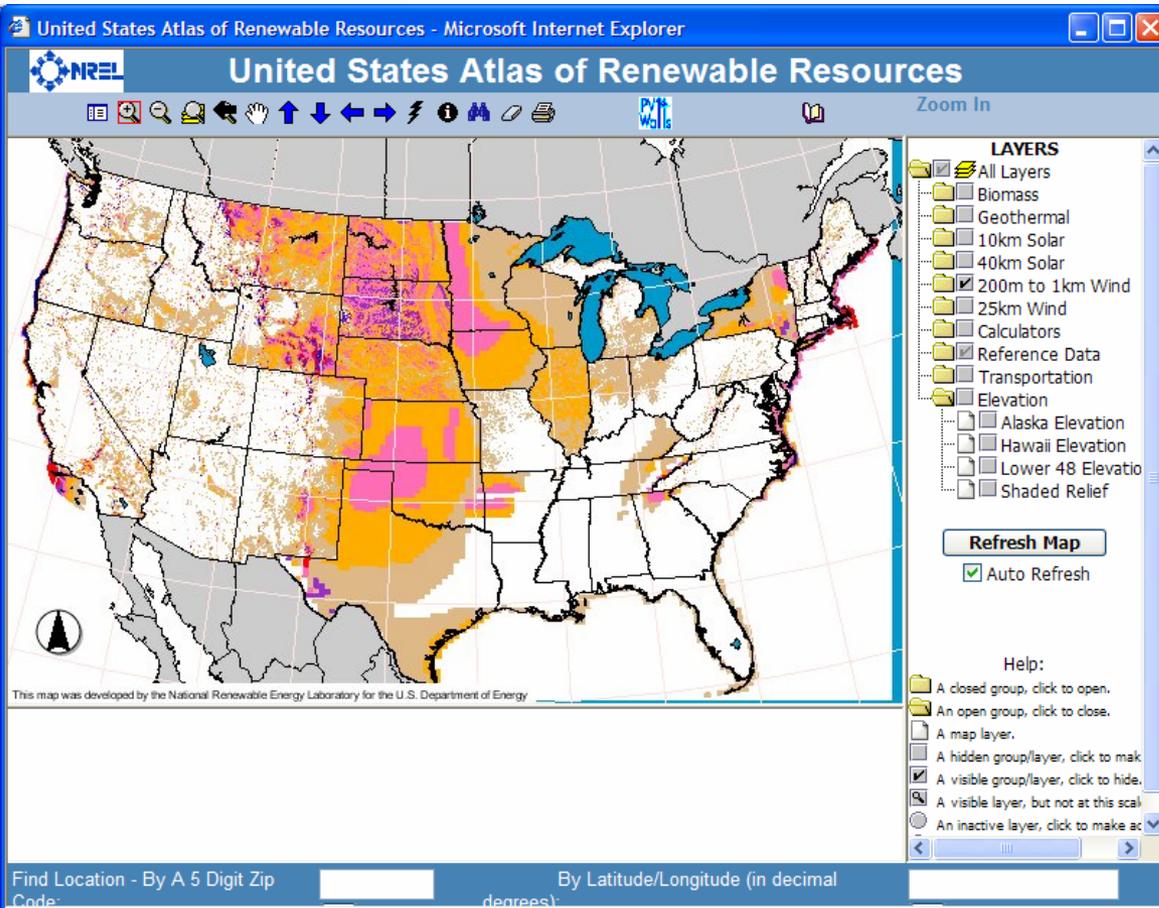
- Viewing Options**  
Larger Jpeg: [Click Map](#)  
Printable: [\(PDF 5.0 MB\)](#)  
[Download Acrobat Reader](#)  
[Interactive Map](#)

Link to Detailed PDF

Link to interactive map

# Interactive Maps Online

- Allows users to:
  - Zoom in to area of interest
  - Turn on/off map layers (county bounds, roads, zip code, etc.)
- Full U.S. including Alaska and Hawaii
- Other interactive maps are available for specific areas



<http://www.nrel.gov/gis>  
- Interactive zoom tool

# GIS Wind Resource Map Data

- NREL validated wind data only
- Geographic shapefiles of annual wind power class
- ESRI ArcGIS and ArcView format
- Importable to many other GIS packages

NREL: Dynamic Maps, GIS Data, and Analysis Tools - Data and Analysis Tools - Microsoft Internet Explorer

Address [http://www.nrel.gov/gis/data\\_analysis.html](http://www.nrel.gov/gis/data_analysis.html)

**NREL National Renewable Energy Laboratory**

ABOUT NREL | SCIENCE & TECHNOLOGY | TECHNOLOGY TRANSFER | APPLYING TECHNOLOGIES | LEARNING ABOUT RENEWABLES

## Dynamic Maps, GIS Data, & Analysis Tools

← NREL GIS Home

About NREL GIS

Maps

**Data & Analysis Tools**

### Data and Analysis Tools

NREL's GIS Team develops technology-specific GIS data maps for a variety of areas, including biomass, geothermal, solar, wind, and renewable hydrogen. Maps for these technology-specific areas are available in either high resolution or low resolution in most cases. High-resolution maps are available for specific states. Low-resolution maps are available for Alaska, Hawaii, and the lower 48 states.

NREL's GIS Team provides an analysis tool, the Geospatial Toolkit, a map-based software application with predefined queries that can be used for decision-making and policy analysis in addition to planning for future renewable energy projects. The Geospatial Toolkit is available for select countries.

The process for [downloading data and tools](#) from the GIS server is to first fill out a form with contact information, then read and accept a disclaimer statement before proceeding to download data.

### National Wind Resource

This data provides an estimate of the annual average wind resource for the conterminous United States, with a resolution of 1/3 degree of latitude by 1/4 degree of longitude. For more information, please refer to the [Wind Energy Resource Atlas of the United States](#).

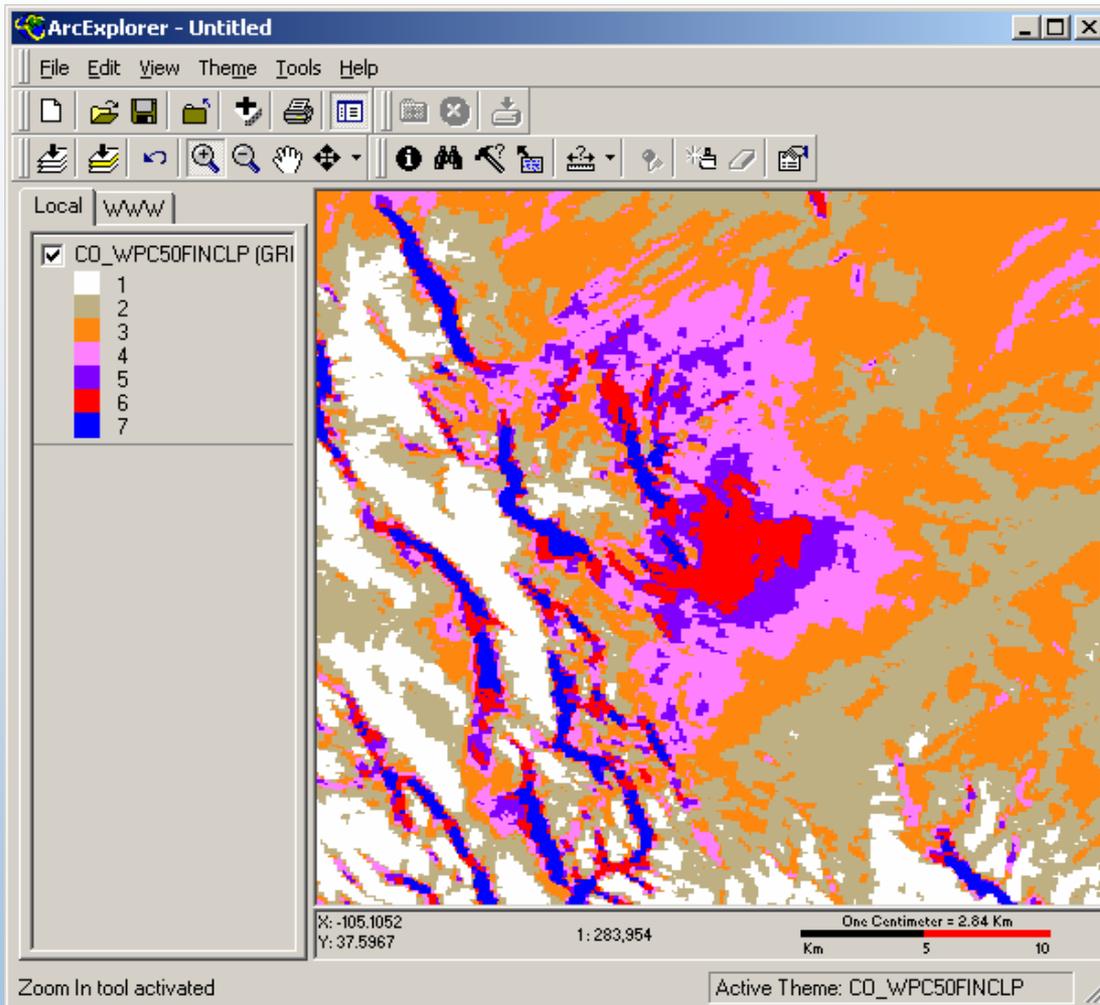
### High Resolution Wind Data

These datasets are geographic shapefiles generated from the original raster data. The original raster data varied in resolution from 200 m to 1000 m cell sizes. The data provides an estimate of annual average wind resource for specific states or regions. The data are separated into two distinct groups: NREL produced, and TrueWind produced/NREL validated.

The NREL-produced map data only applies to areas of low surface roughness (i.e.

[http://www.nrel.gov/gis/data\\_analysis.html](http://www.nrel.gov/gis/data_analysis.html)

# GIS Data Viewer - ArcExplorer



- Free from ESRI
- Allows you to view and query shapefile data
- Will not come with any reference data (roads, cities, etc)
- Displaying scale bar will show latitude/longitude coordinates

# Wind Measurement Data

- EERC web site data shown here
- NREL has select data sets available on request
- Datasets are also available from other sources

**Killdeer Wind Monitoring Site**  
(Data available from 1/3/2001 to 5/31/2004)

Latitude: N47 27.193' Longitude: W102 27.106' Elevation(ft): 2430 [Back to ND Wind Site](#)

The Killdeer monitoring site is operated and maintained by the Dunn County Jobs Development Authority. The North Dakota Division of Community Services provided partial funding for this effort.

**Select a Date Range**  
(Start date and Stop date defaults to the Earliest and Latest dates available)

Start date (mm/dd/yyyy)   
Stop date (mm/dd/yyyy)

**Select Parameter**

Wind Speed sensor height	Wind Direction sensor height	Air Temperature sensor height
<input checked="" type="checkbox"/> 40 meters	<input type="checkbox"/> 40 meters	<input type="checkbox"/> 3 meters
<input type="checkbox"/> 30 meters	<input type="checkbox"/> 10 meters	
<input type="checkbox"/> 10 meters		

**Select Units (wind speed and temperature)**

English  Metric

**Data Display**

include [Standard Deviation](#) fields  
 include [Data Quality Information](#)

**Graph Data**

Time Series (for wind speed, direction, and temperature graphs)  
 Polar (for wind direction graphs only)

Include Suspect Data

**Wind Speed Statistics: 1/3/2001 - 4/3/2001**

Description	WS40 m/s
Average	7.31
Max   Min	22.27   0.40

**Killdeer Hourly 1/3/2001**

Wind Speed (m/s)

<http://www.undeerc.org/wind/>

# Wind Resource Assessment Handbook

## ***WIND RESOURCE ASSESSMENT HANDBOOK***

*Fundamentals for Conducting  
a Successful Monitoring  
Program*



*Prepared By:*  
*AWS Scientific, Inc.*  
*CESTM, 251 Fuller Road*  
*Albany, NY 12203*  
*April 1997*

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NREL Subcontract No. TAT-5-15283-01

*Prepared for:*  
*National Renewable Energy Laboratory*  
*1617 Cole Boulevard*  
*Golden, CO 80401*

- Handbook provides guidelines for planning and conducting a wind resource measurement program

## Web Site

- [http://www.nrel.gov/wind/wind\\_pubs.html](http://www.nrel.gov/wind/wind_pubs.html)