WIND POWER IN OKLAHOMA:

A PRELIMINARY STUDY

By

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CHAPTER I

INTRODUCTION

Background

For thousands of years, wind has been harnessed for an energy source. Uses for such energy included pumping water, grinding of grain, and travel across the oceans. With the advent of steam engines and electricity from fossil fuels, many wind-driven machines fell into disuse (Street and Miles, 1996). In response to the oil crises in the 1970s, however, these traditional devices were looked to as an alternative energy source along with solar power (Sesto, 1999; Bourillon, 1999). Since then development of wind power has been on the increase, largely in response to government influence in many countries (Bourillon, 1999). Energy harnessed from the wind has become an economically viable alternative to increasing the use of an ever dwindling supply of fossil fuels (Wolsink, 2000; Street and Miles, 1996). California took up the wind power craze in the 1980s. Denmark, at present, is the leader in Europe producing up to 2% of the country's electricity through wind power (Street and Miles, 1996). Now much of the United States and other countries are increasingly developing the wind power opportunity.

The Pacific Northwest Laboratory (PNL) (1991) of the United States Department of Energy published a report stating that the United States had the potential to become a major wind power producer. A list in the 1991 report showed that among the top twenty potential power producing states Oklahoma ranked number eight (Table 1). Elliot and Swartz (1993) stated that the Great Plains states have enough wind energy to produce four times as much electricity as was used by the country in 1990. As recently as 1995, the Canadian Great Plains was also recognized as a potential source of wind power (Swanekamp, 1995). Even with a wind potential of 725 billion kilowatt hour annually, Oklahoma is one the last top ranking states to begin its preliminary studies of wind power (Pacific Northwest Laboratory, 1991).

Table 1. Potential Wind Energy in the United States

Rank	State	bkWh	Rank	State	bkWh
1	North Dakota	1,210	11	Colorado	481
2	Texas	1,190	12	New Mexico	435
3	Kansas	1,070	13	Idaho	73
4	South Dakota	1,030	14	Michigan	65
5	Montana	1,020	15	New York	62
6	Nebraska	868	16	Illinois	61
7	Wyoming	747	17	California	59
8	Oklahoma	725	18	Wisconsin	58
9	Minnesota	657	19	Maine	56
10	Iowa	551	20	Missouri	52

Source: An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States, Pacific Northwest Laboratory, 1991.

Objectives

Oklahoma has recently taken on the task of preliminary assessments of wind power across the state through the Oklahoma Wind Power Assessment Initiative (OWPAI) funded through the Departments of Energy and Commerce. This Master's thesis is part of the larger OWPAI study. There is one major objective: using the most extensive statewide weather system (Mesonetwork) and geographical information system

(GIS) techniques to determine how well a commercially available wind power model simulates wind speed and potential wind power density.

The objective will be evaluated by comparing model output to the observed data at the Mesonet sites. The assumed hypothesis is that there is no significant difference between the observed and simulated values.

Study Areas

The study area consists of three areas in Oklahoma (Figure 1). One is in the northwestern part of the state, the second is in the central part of the state, and third is in the southeastern part of the states. These areas represent a variety of land cover and elevation types. Chi-squared tests were used to test significance levels between model output and known data.

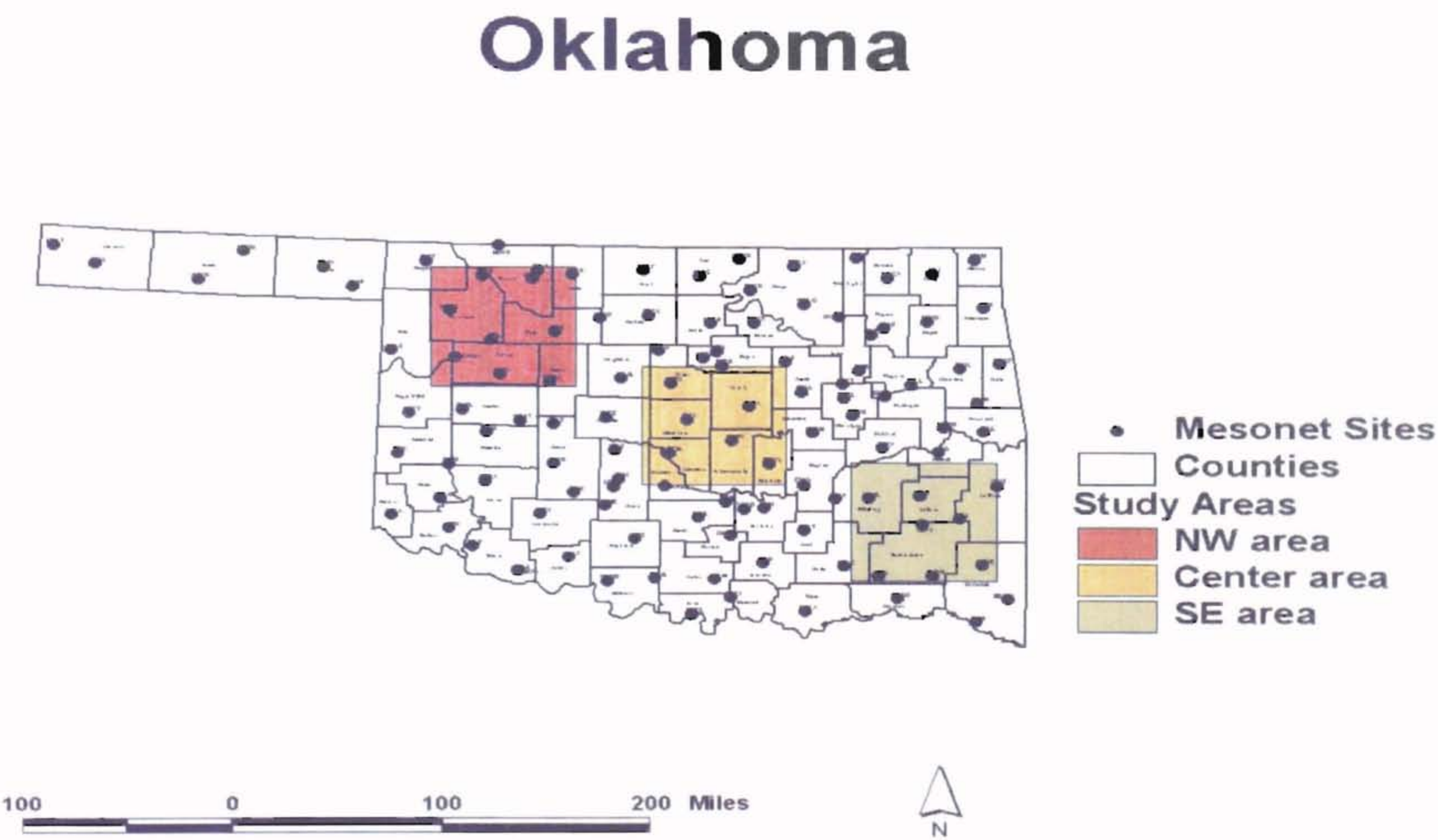

Figure 1. State map of Oklahoma showing study areas used in research.

CHAPTER II

LITERATURE REVIEW

This chapter will review the literature pertaining to wind models and the required values of model parameters and input data. It will also encompass wind assessments conducted by several states.

Models and Parameters

The most prevalent type of model used to predict wind speeds and wind power density is known as a mass-consistent model. It uses wind observations to generate an initial wind field that shows how the wind would behave in the absence of terrain effects. Then it applies an adjustment to the initial wind field to conserve mass. The final wind field takes into account terrain (i.e., elevation and surface roughness) changes so the adjustment makes the final wind field conform more to the initial guess while conserving mass (Sherman, 1978; Barnard, 1991). The model does this so that the output reflects more accurately what is happening in the real world. This type of model requires two main types of data: wind observations as the input variable and terrain (topography and surface roughness) as model parameters.

Wind observations that consist of point measurements at weather stations are recorded at certain times. These observations are generally wind speed, wind direction, and frequency measurements where frequency is the percent of time the wind is blowing in a particular direction at a particular time. Frequencies are used as a weighting factor used to adjust the final simulated wind field (Barnard, 1991; Dear et al, 1991).

Katsoulis and Metaxas (1992), in western Greece, looked at the parameter of wind observations. Specifically looking at the number of observations via the number of stations in a given study area. Researchers concluded that the number of stations did indeed matter if the area was convoluted much like the coastline of Greece. They found that increasing the number of stations (i.e., increasing the number of wind observations) did have an influence on the final simulated wind field if the perimeter of a given study area had a tendency to be highly convoluted. Otherwise the number did not dramatically increase the result of the final wind field. Chen et al (1990) confirmed the need for more stations when dealing with a convoluted area such as in Jamaica.

Terrain is characterized by the elevation of an area and surface roughness (Dear et al, 1991; Sherman, 1978). Surface roughness refers to the obstacles that are present on the earth surface that interfere with the flow of wind. These obstacles can be anything from trees, buildings, and/or mountains. Surface roughness is measured as a length above ground. For example, a smooth surface like water would have a roughness length of 0.0001-0.001m whereas crops such as wheat have roughness lengths of 0.0002-0.05m (Geiger, 1957; Lowry, 1969). The elevation component of this parameter is the elevation above mean sea level of the wind observation station.

State Wind Assessments

Several states have commissioned assessments of the potential for wind power development. Several have taken a GIS approach: Colorado (Brower et al, 1996), New Mexico (Brower 1997(b)), Iowa (Brower, 1997(a)), and Minnesota (Artig 1994). They have all used a GIS-based wind model developed by Brower (2001) to simulate annual winds as well as seasonal winds. Brower's model is a mass-consistent model or, as he calls it, a mass-conserving model. It takes into account wind observations and terrain data. Brower used regressions against GIS derived parameters (i.e., surface roughness and elevation) to produce smooth and consistent maps of the states. The number of stations, however, has little effect on model performance. Each state used a different number of stations: 4 stations were used in Minnesota, 8 in Colorado, 13 in Iowa, and 67 in New Mexico. Model techniques were the same for all four states. This difference in station number had little or no effect on the outcomes because all the maps produced confirmed the general wind distribution set out by the *Wind Energy Resource Atlas of the United States* (the Atlas) (Elliot, 1987). These results call into question the earlier arguments that suggest that the more stations used the better the outcome (Barnard, 1991; Dear et al, 1991). These four states have a somewhat convoluted terrain with mountains, hills, and flat plains. Yet the 13 stations used in the Iowa study seemed to make no real difference as compared to the four used in the Minnesota study. They both showed the same general power distribution that the Wind Atlas showed.

CHAPTER III

DESCRIPTION OF THE MODEL

The model used in this research is called WindMap™ version 2.21which was developed by Brower (1999). This model is a mass-conserving model developed after the NOABL model used by the U.S. Department of Energy (Brower, 1999). WindMap™ works to create a divergence free wind field in two ways. First, it calculates an initial wind field. From that wind field small adjustments are made to create the final wind field. Like other mass-consistent models, it requires wind observations and terrain data. The wind observations come from point data observed at the weather stations. Two GIS data layers of elevation and surface roughness characterize the terrain. Both layers are cell-based or raster meaning that each cell has a specific spatial dimension and one value (elevation or roughness) assigned to it. From these data, the model creates a series of maps of wind speed, wind power density, and turbine power output.

The first step in the creation of these maps is the initial wind field. WindMap™ allows the user to define the "background velocity" of a given area. The stations used for this initialization process should be those stations that are a good representation of the area. If the whole study area is more hills and slight elevation changes then those stations that show that type of change should be used in the initialization because that is condition of the area. For instance, if a study area were in virtually a plain such as in a desert, the user would choose those stations where the local elevation closely matched the area as a whole. Stations that have terrain effects that are not prevalent in the area, as a whole should not be used for initialization. It should be kept in mind that the initial wind field is the field that the model will try to match in its final calculations, so the choosing of stations for initialization should be done carefully.

Frequencies of wind direction also need be considered. This is done through the choosing of the reference station. Some thought should be given to this reference station for it should be a station where the winds come in all directions. These frequencies provide the weight that makes the final calculated wind field conform to the initial field keeping the divergence to a minimum; they provide the adjustments needed by the model to achieve minimum divergence in an area. Once the initial wind field is created, WindMap™ goes through a series of iterative steps to create the final wind field of least divergence (mass-conservation) and reflects terrain characteristics. The result of the process is final average weighted wind field. The weights applied to the field are the frequencies that a reference station supplies.

The final wind field that the model creates is the field with the minimum divergence. This field is then used to create the, final wind speeds, wind power density, and turbine power output across a region from the initial point data of wind observations.

Limitations

WindMap™ is limited in four ways. The first is by the amount of data that can be inputted into the model. The model only allows for a 300x300 cell layer for each of the roughness and elevation layers. So if the user were to do a larger area such as an entire state, the area would have to be divided into several smaller areas, modeled, and then mosaicked together. Second, it allows for only one station's frequencies to be used in the final calculation. It may be more beneficial to use more than one set or even an average for the region instead of frequencies for only one station.

The third limitation is poor documentation for users especially pertaining to model runs and errors encountered. Without the proper documentation of reporting errors, the user has no way of knowing if the errors affect the final outcome and if so to what extent. The user documentation is also lacking in it poor description of certain functions that the model uses and its defaults. It is not always clear how the user should go about choosing reference stations or initialization stations.

The third and perhaps the most obvious is user expertise. Brower (1999) states that the user does not need experience with GIS or wind-related information, but it seems clear that this is not the case. The user needs to be able to understand how to generate the GIS data layers to for the model and it is very necessary to understand how the wind in a given area is behaving to able to make informed decisions about reference stations and the initialization process.

CHAPTER IV

METHODOLOGY

This chapter describes the various data needed to run the model as well as the preparation of the model output. It also explains the experimental setup and statistical analysis, which were used to determine the how well the model worked.

Data Description

A large amount of data was used for this study. First, the wind observations came from the Oklahoma Mesonetwork system (Oklahoma Mesonet, 2001). This is a network of 115 stations that take various weather related readings such as temperature, wind speed and direction, relative humidity, pressure, rainfall, and other readings. The stations collect data every five minutes and relay data every fifteen minutes to a central processor. The central processor collects the data allowing it to be used for computations to produce annual data: average wind speed, average direction, and many other variables for 10-meter heights. This research utilized the wind speeds, frequencies, directions as well as local elevations, and geographic coordinates for the stations in the study areas for the years 1994-1999.

Elevation data came in the form of Digital Elevation Models (DEMs) available for download from the USGS mapping center (USGS, 2001(a)). For this study, the 1:250,000 meter DEMs were obtained for the state.

Surface roughness was obtained from an examination of the Oklahoma GAP project vegetation layer. The Gap Analysis Program (GAP) was created to provide regional assessments of vegetation, species, and habitat types for study of conservation (USGS, 2001(b)). The GAP data provided the most current vegetation cover of Oklahoma. For that reason, it was chosen as the basis for the creation of a roughness layer. It also came in raster format at 30-meter resolution for convenient use in the wind model.

Data Preparation

The data obtained for this research came in a variety of forms. The wind observations came in non-GIS format of text files. The elevation and GAP came in ready to use GIS formats. Before input into the model, all of the data had to be pre-processed.

The elevation data had to be converted from geographic coordinates (not projected) into Albers (the same projection as the GAP data). Once projected, all of the digital quadrangle maps for the state were merged to form one contiguous, seamless DEM for the state of Oklahoma. Next the DEM was resampled to a specified resolution of 372 x 372 meter grid cells using ARC/INFO™ (ESRI, 2000). Once resampled, the DEM was clipped to 300 x 300 grid cells in the northwest, central, and southeastern parts of the states (Figure 1) using ARC/INFO™ (ESRI, 2000).

The GAP data was used to create the roughness layer by adding a roughness value field to the attribute table of the GAP data. The roughness values correspond to the categories of the GAP data. Those categories define the vegetation found in a particular pixel in the data. Various categories include Western Crosstimbers, tallgrass prairie, mixed grass prairie, etc. Using various research on surface roughness, a roughness values was attributed to each category and added to the attribute table. Once the values were added, the roughness layer was resampled to the 372-meter grid cells and then clipped to the same areas as the DEMs using ARC/INFO™ (ESRI, 2000).

Both elevation and roughness layers were prepared in ARC/INFO™ (ESRI, 2000). Before input into WindMap™, the roughness and elevation layers for each site had to be exported from ARC/INFO™ into ASCII format, and the headers had to stripped off. Once this was done then they were ready to be put into WindMap™.

Before the wind observations were added to the model, the Mesonet coordinates were converted to Albers coordinates. This was done in ArcView™ (ESRI, 2000), and then recorded on paper. Next the local roughness had to be found for each of the stations. This was done by overlaying the new Albers coordinates of the stations on the GAP data. Each station was in one cell that had one value and it was recorded as well.

Experimental Setup

Once all of the data were entered into the wind model, the reference station and stations to be used the initialization process were selected in the three study sites. Each site was done the same way. Only those stations that were found in the 300x300 cell area were used in the run. For each site, the one station that showed the most omni-directional wind pattern was used as the reference station. The Mesonet Web site has site photographs of each station (Oklahoma Mesonet, 2001). Those photographs helped to determine what the representative area was like. Those stations that showed the best representation of the region were chosen for the initialization process. To be chosen as the best representation of the area, the stations needed to be similar in elevation, surrounding structures, height of vegetation, etc to the study area. Tables 2-4 shows the stations in the study areas, those used for initialization, and the reference stations. For all the sites, the model was run four times in each site, each with a different set of initialization stations (See Tables 2-4). For each run, wind speed and wind power density were simulated for 10- and 50-meter heights.

Statistical Analyses

Statistical analyses were performed using chi-squared tests comparing the measured values at the Mesonet stations to the simulated values of wind speed and wind power density. The chi-squared statistic allows for the determination of significant difference between the measured values taken at the Mesonet sites and the simulated values generated by the model. This statistical test provides a goodness-of-fit measurement.

The formula for the chi-squared is:

$$\chi^2 = \Sigma(O_i - E_i)^2 / E_i$$

where O_i = the observed or measured values

E_i = the expected or simulated values

TABLE 2

NW Area Stations

Station Name	Initialization	Reference Station
Run 1		
FREE	no	yes
WOOD	no	
CAMA	no	
SEIL	no	
PUTN	no	
WATO	no	
FAIR	yes	
ALVA	yes	
CHER	yes	
Run 2		
FREE	no	yes
WOOD	no	
CAMA	yes	
SEIL	no	
PUTN	no	
WATO	no	
FAIR	yes	
ALVA	yes	
CHER	yes	
Run 3		
FREE	no	yes
WOOD	yes	
CAMA	yes	
SEIL	no	
PUTN	no	
WATO	no	
FAIR	yes	
ALVA	yes	
CHER	yes	
Run 4		
FREE	no	yes
WOOD	yes	
CAMA	yes	
SEIL	yes	
PUTN	yes	
WATO	yes	
FAIR	yes	
ALVA	yes	
CHER	yes	

TABLE 3

Center Area Stations

Station Name	Initialization	Reference Station
Run 1		
CHAN	no	
BOWL	no	
GUTH	yes	
NORM	no	
PERK	no	yes
SHAW	yes	
SPEN	no	
Run 2		
CHAN	no	
BOWL	no	
GUTH	yes	
NORM	no	
PERK	yes	yes
SHAW	yes	
SPEN	no	
Run 3		
CHAN	no	
BOWL	yes	
GUTH	no	
NORM	yes	
PERK	no	yes
SHAW	no	
SPEN	yes	
Run 4		
CHAN	no	
BOWL	no	
GUTH	yes	
NORM	yes	
PERK	yes	yes
SHAW	yes	
SPEN	no	

TABLE 4

SE Area Stations

Station Name	Initialization	Reference Station
Run 1		
ANTL	no	
CLOU	no	
MCAL	no	yes
MTHE	no	
TALI	yes	
WILB	yes	
CLAY	no	
Run 2		
ANTL	no	
CLOU	no	
MCAL	yes	yes
MTHE	no	
TALI	yes	
WILB	yes	
CLAY	no	
Run 3		
ANTL	no	
CLOU	no	
MCAL	yes	
MTHE	no	
TALI	yes	
WILB	no	yes
CLAY	no	
Run 4		
ANTL	no	
CLOU	no	
MCAL	yes	
MTHE	no	
TALI	yes	
WILB	yes	yes
CLAY	no	

The null hypothesis tested in this research was the simulated values generated by the model are not significantly different from that of the measured values taken at the Mesonet sites. The alternative hypothesis was these values are significantly different. When the values are similar, the chi-squared will be small and the goodness of fit is strong, thus the null hypothesis cannot be rejected at the selected significance level of 0.05. When the p-values are close to one and are greater than the significance level, then the simulated values and measured values are close since the p-value measures the probability that the simulated values match the measured values. When the opposite is true, the null hypothesis is rejected. Chi-squared results and associated p-values are found in Tables 5-7.

CHAPTER V

RESULTS AND DISCUSSION

Statistics

The statistical analysis for the NW area shows p-values, very near 1 (Table 5a). That means that there is no significant difference between the measured speeds and simulated speeds. Because four runs were completed in each site, to determine which run was more successful, an average difference between the measured and predicted speeds was taken. Even though the differences were very small (almost negligible in each study area) there was one run that was better than the others. It was found that WindMap™ predicted a little more than 0.2 meter/second higher for wind speeds. However, for prediction of WPD, WindMap™ seems to predict about 30 Watts/meter^2 higher for both 10- and 50-meter heights still there is no significant difference between the measured and predicted wind power densities (Table 5b). The higher average difference could be due to the relationship between wind speed and power density. Wind power density (WPD) is usually calculated using one of the following equations:

Where $WPD = \frac{1}{2} * \rho * V^3$,

V = velocity,

$\rho = 1.225\ kg/m^3$ or

$\rho = 1.225 - (1.194 * 10\text{-}4) *$ local elevation in meters

TABLE 5a

Summary of Chi-Squared for the NW Area

Run #	χ^2	p - value	Ave. Diff.
Run 1	0.9999	0.9982	0.0231 *
Run 2	0.9999	0.9982	0.2003
Run 3	0.9999	0.9982	0.1493
Run 4	0.9999	0.9982	0.0434

*Denotes run used to compare predicted Wind Power Density values with the measured for the area.

TABLE 5b

Summary of Chi-Squared Wind Power Density for the NW Area

Run #1	χ^2	p - value	Ave. Diff.
WPD 10m	4.95E-26	1	30.25
WPD 50m	1.38E-28	1	34.15

Because WPD is related to the third power of wind speed, a small difference in the wind speed results in a larger difference in WPD. However, the documentation for WindMap™ does not state how wind power density is calculated, so it cannot be said why there is such a large difference (Hughes, 2000).

The Center area shows much the same result (Table 6a). The p-values are very near 1 meaning that there is no significant difference in the measured speeds and predicted speeds. Again an average difference was taken for each run to determine which run was more successful. In predicting the wind speed for this region, WindMap™ predicts almost 0.5 meter/second more at the highest wind speed and 0.01 meter/second difference at the lowest for wind speeds. It is overestimating the 50-meter height for WPD more than the 10-meter. At the 10-meter height, wind power density is overestimated by about 12 Watts/meter^2 and at the 50-meter it is overestimated by 21 Watts/meter^2 (Table 6b). Again this could be due to how WindMap™ is calculating this variable.

The SE area shows the same trend of no significant difference in the measured and predicted values of either the wind speed and wind power density (Table7a). In this site, WindMap™ is more consistent in it average differences finding an average difference of about 0.1 meter/second for wind speeds. The wind power density is slightly overestimated at the 10-meter height by 4 Watts/meter^2 and at the 50-meter height by 21 Watts/meter^2 (Table 7b). Here again, the model seems to be overestimating more on the 50-meter height for wind power density as well.

TABLE 6a

Summary of Chi-Squared for the Center Area

Run #	χ^2	p - value	Ave. Diff.
Run 1	0.9999	0.9856	0.4557
Run 2	0.9999	0.9856	0.1328
Run 3	0.9999	0.9856	0.0432
Run 4	0.9999	0.9856	0.0167 *

*Denotes run used to compare predicted Wind Power Density values with the measured for the area.

TABLE 6b

Summary of Chi-Squared Wind Power Density for the Center Area

Run #4	χ^2	p - value	Ave. Diff.
WPD10m	3.67E-09	1	12.85
WPD50m	6.68E-15	1	21.32

TABLE 7a

Summary of Chi-Squared for the SE Area

Run #	χ^2	p - value	Ave. Diff.
Run 1	0.9996	0.9856	0.0778 *
Run 2	0.9996	0.9856	0.1295
Run 3	0.9996	0.9856	0.1024
Run 4	0.9996	0.9856	0.1417

*Denotes run used to compare predicted Wind Power Density values with the measured for the area.

TABLE 7b

Summary of Chi-Squared Wind Power Density for the SE Area

Run #1	χ^2	p - value	Ave. Diff.
WPD10m	7.48E-09	1	4.66
WPD50M	6.94E-41	1	21.06

Comparing the results for the three study sites, the model does tend to overestimate, but not to the extent that one would disregard the results entirely. The overestimations were significant at the significance level of 0.05. Also, the overestimation decreases from the northwest to the southeast. That could be because of the slower wind speed there, the terrain in the area (mountainous, etc), or error in input values into the model. Also the observation of the discrepancy between the values of wind power density at the two different heights is a bit puzzling. Since the 50-meter data are simply extrapolated values, one would tend to think that the differences would not be that far off from the 10-meter data, however the results show this is not the case. This result could be impart due to how the model performs those extrapolations and the data itself. Whatever the reason, the model does seem to perform well enough to be confident in the results.

Classification of sites

In order to classify the sites as a wind class, Table 8 was utilized along with the wind speed and wind power density maps produced by WindMap™. The NW area (Figures 2 - 5) is showing at 10-meter a class of 1 and very small areas of class 2. At 50-meter, the NW area is showing class 1 and 2. The Center area is showing at 10-meter and 50-meter classes 1 and 2 (Figures 6 - 9). The SE area is also showing class 1 at both 10-meter and 50-meter (Figures 10 - 13). To have a viable wind farm, wind density and wind speed needs to be at least at a class 4 level (Hughes, 2000). Now that is not to say that this area is totally unsuitable for wind turbines. Individual turbines could very well be quite beneficial in this area.

TABLE 8

Summary of Wind Power Classes

	10 m		50m	
Class	WPD W/m^2	Wind Speed m/s	WPD W/m^2	Wind Speed m/s
1	<100	<4.4	<200	<5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4-7.0
4	200-250	5.6-6.0	400-500	7.0-7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-700	8.0-8.8
7	>400	>7.0	>800	>8.8

Table found at the website of the American Wind Energy Association (www.awea.org/faq/basicwr.html)

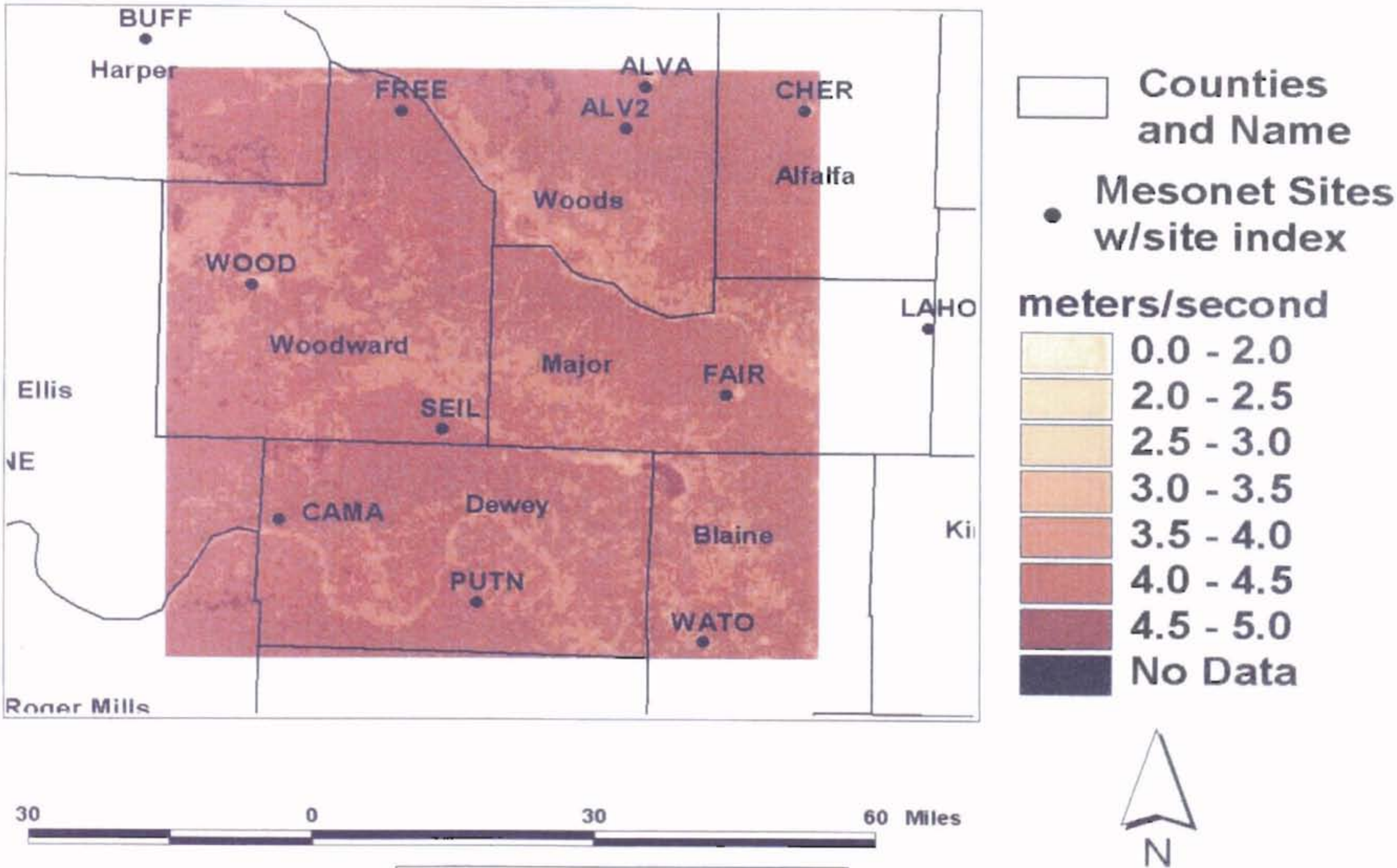

Figure 2. NW area wind speed at 10m

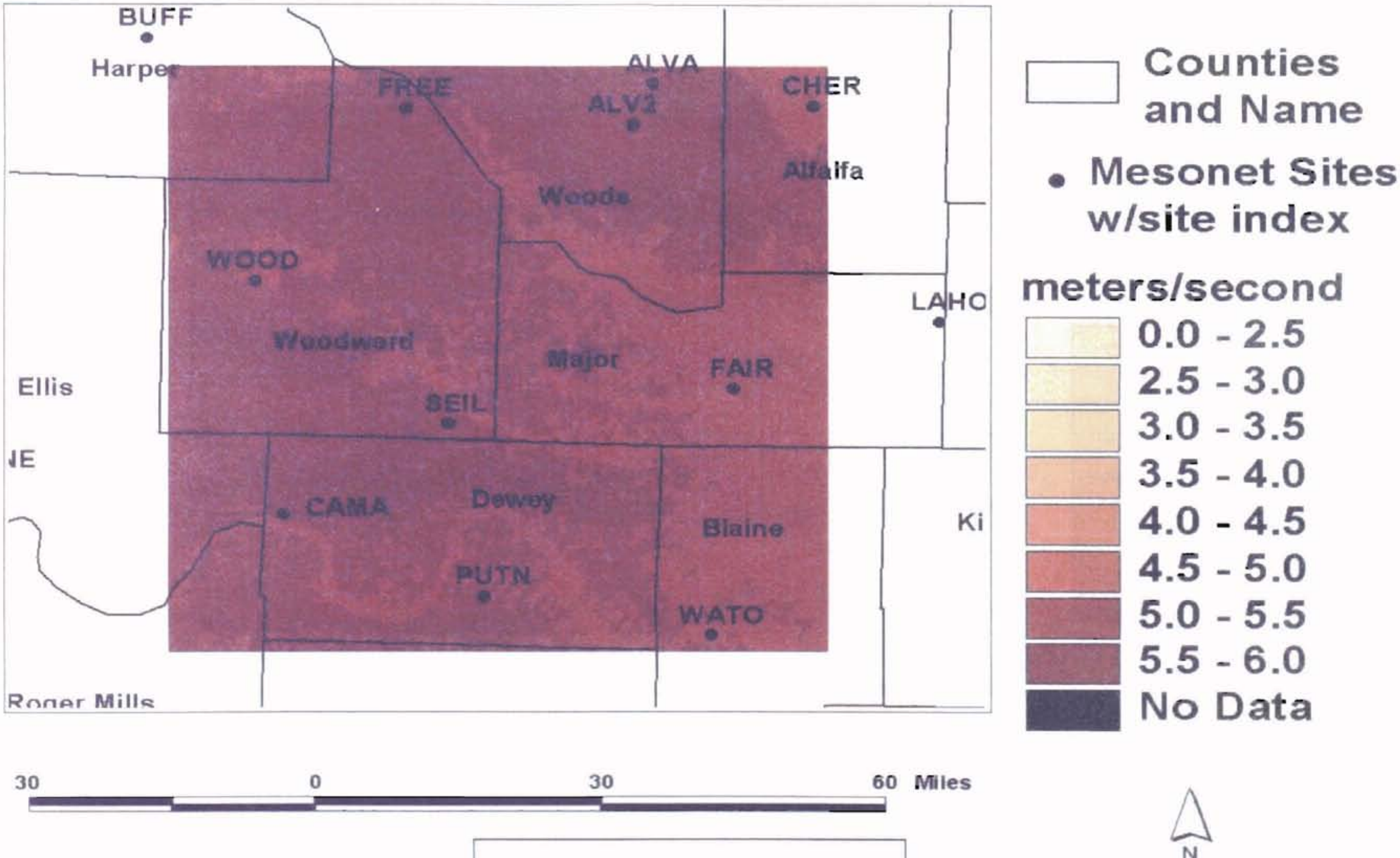

Figure 3. NW area wind speed at 50m

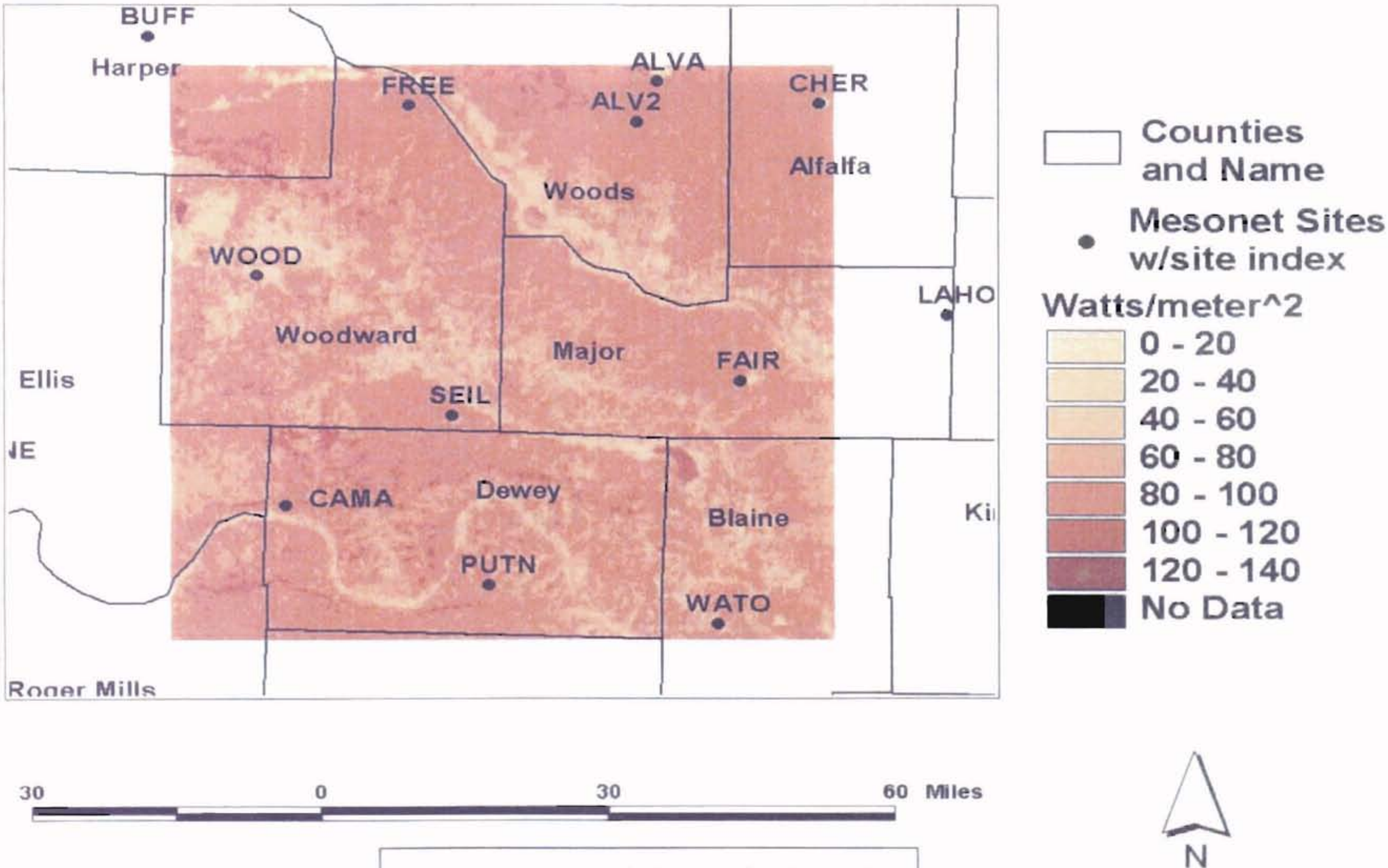

Figure 4. NW area wind power density at 10m

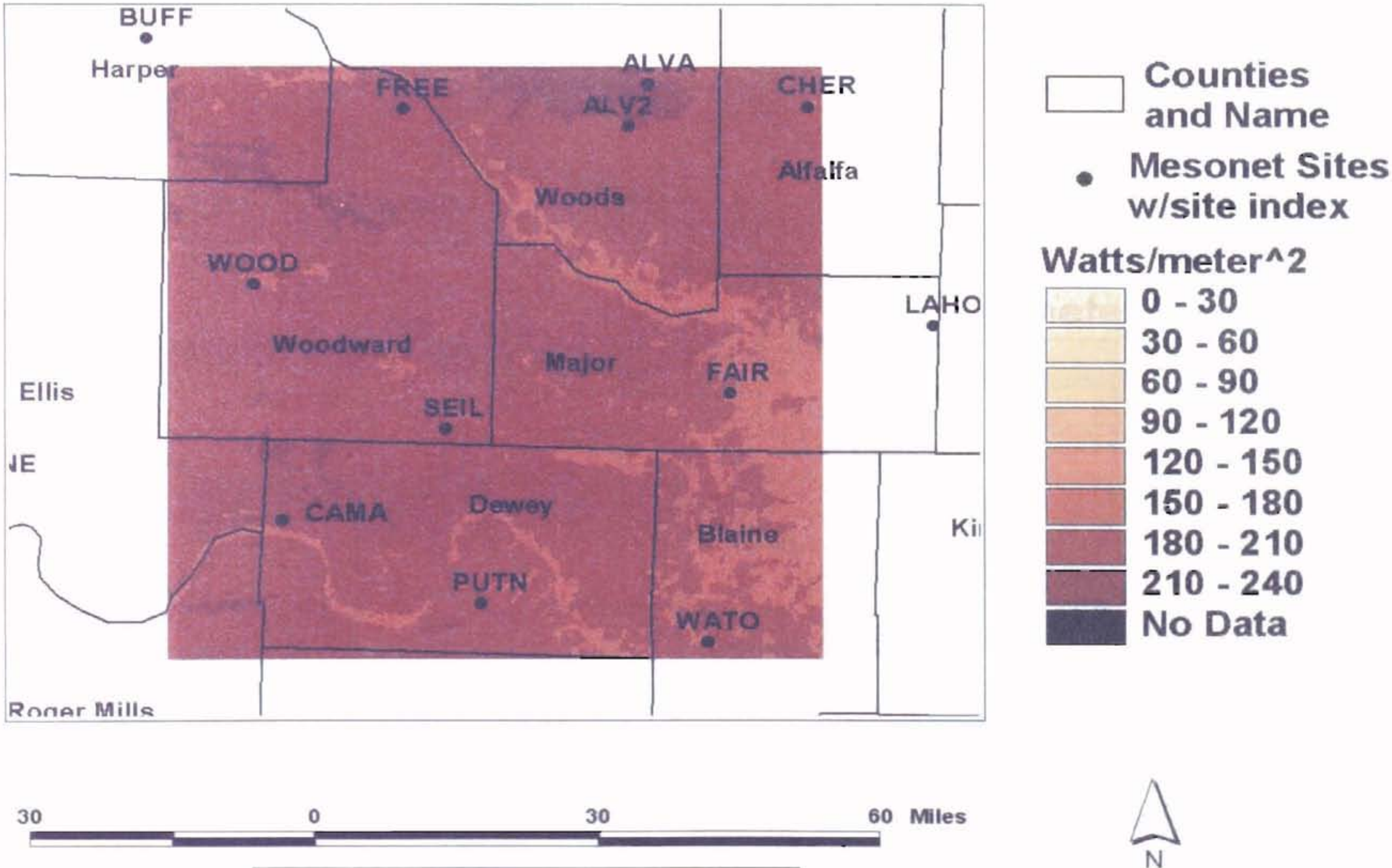

Figure 5. NW area wind power density at 50m

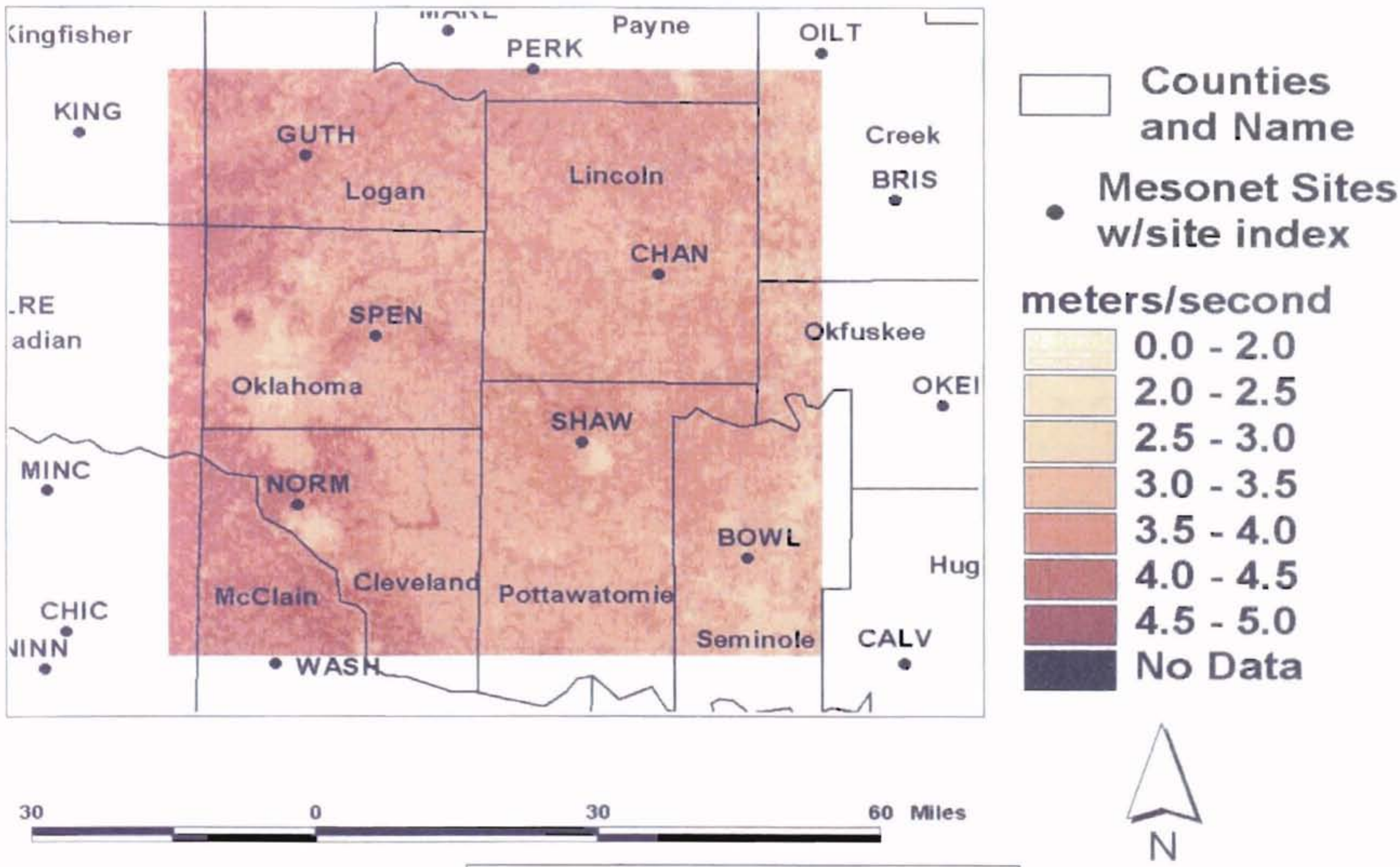

Figure 6. Center area wind speed at 10m

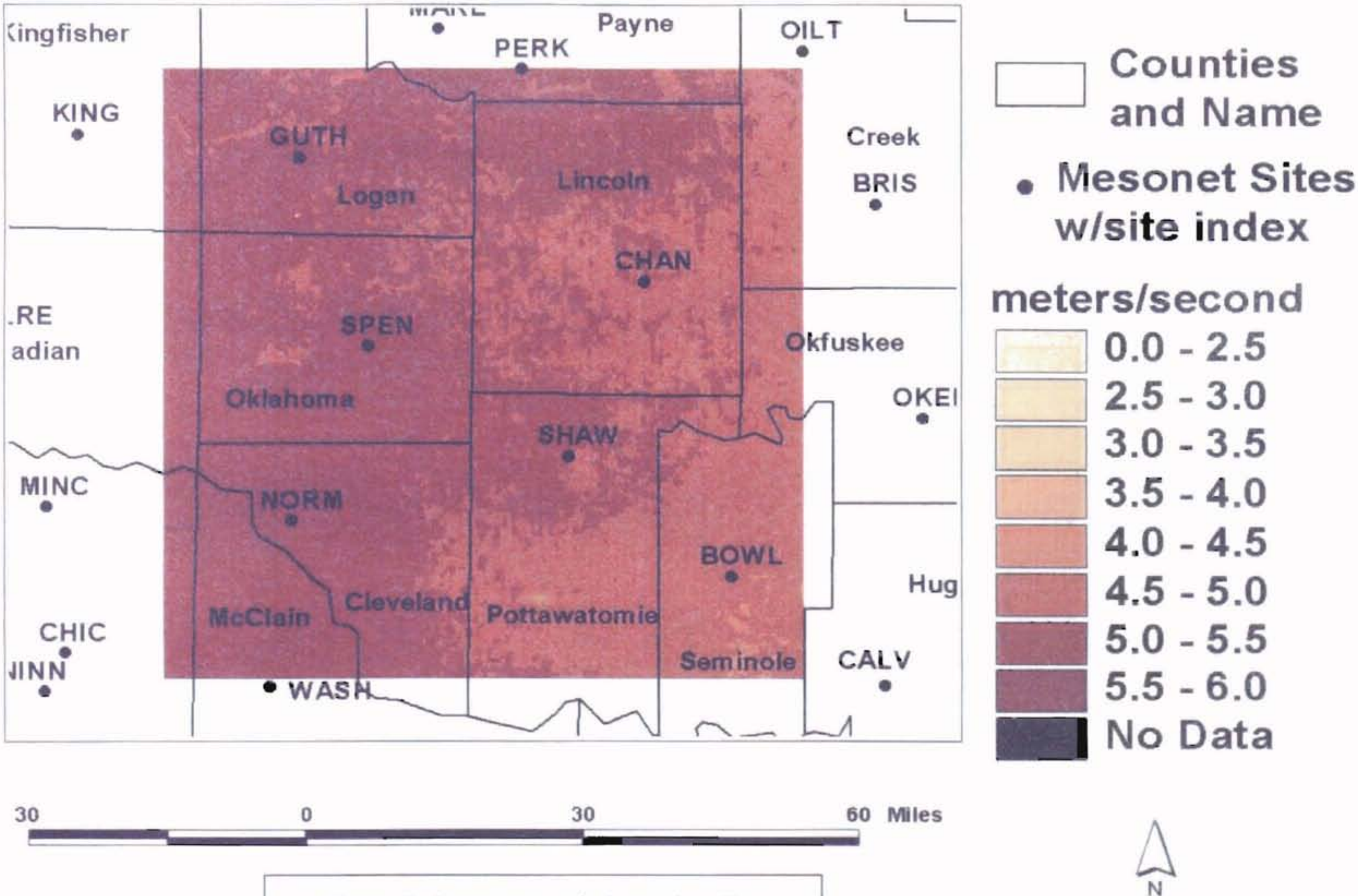

Figure 7. Center area wind speed at 50m

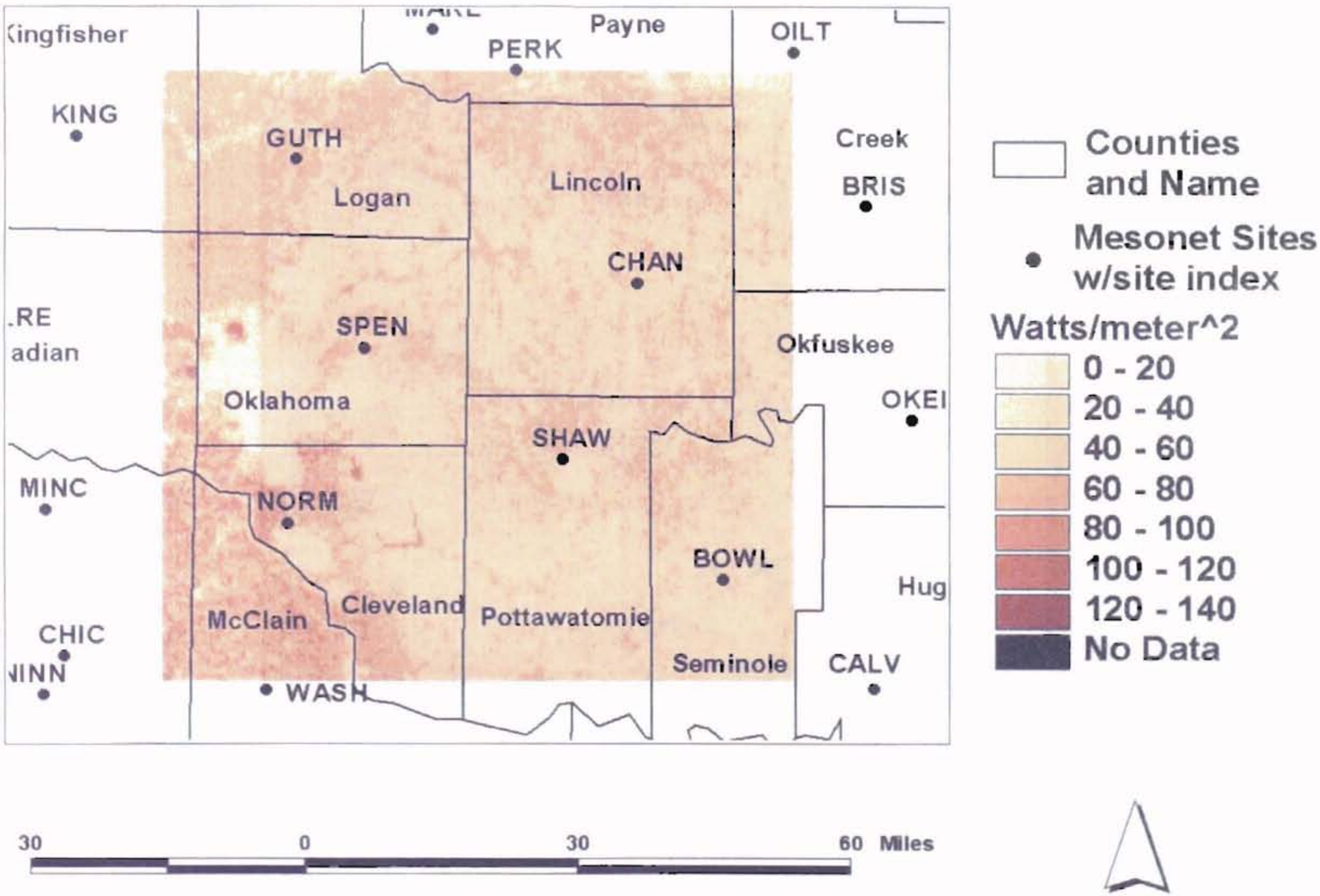

Figure 8. Center area wind power density at 10m

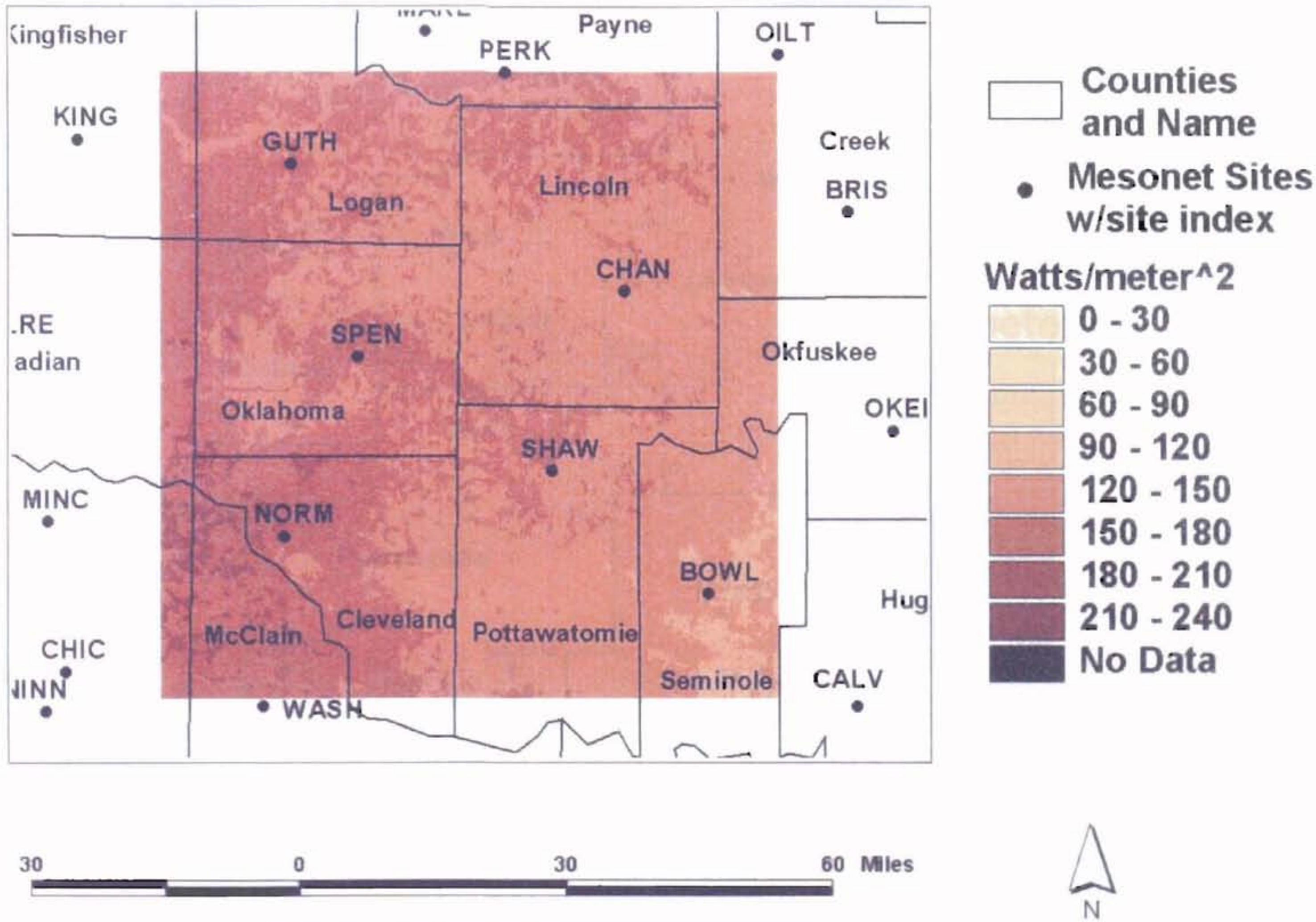

Figure 9. Center area wind power density at 50m

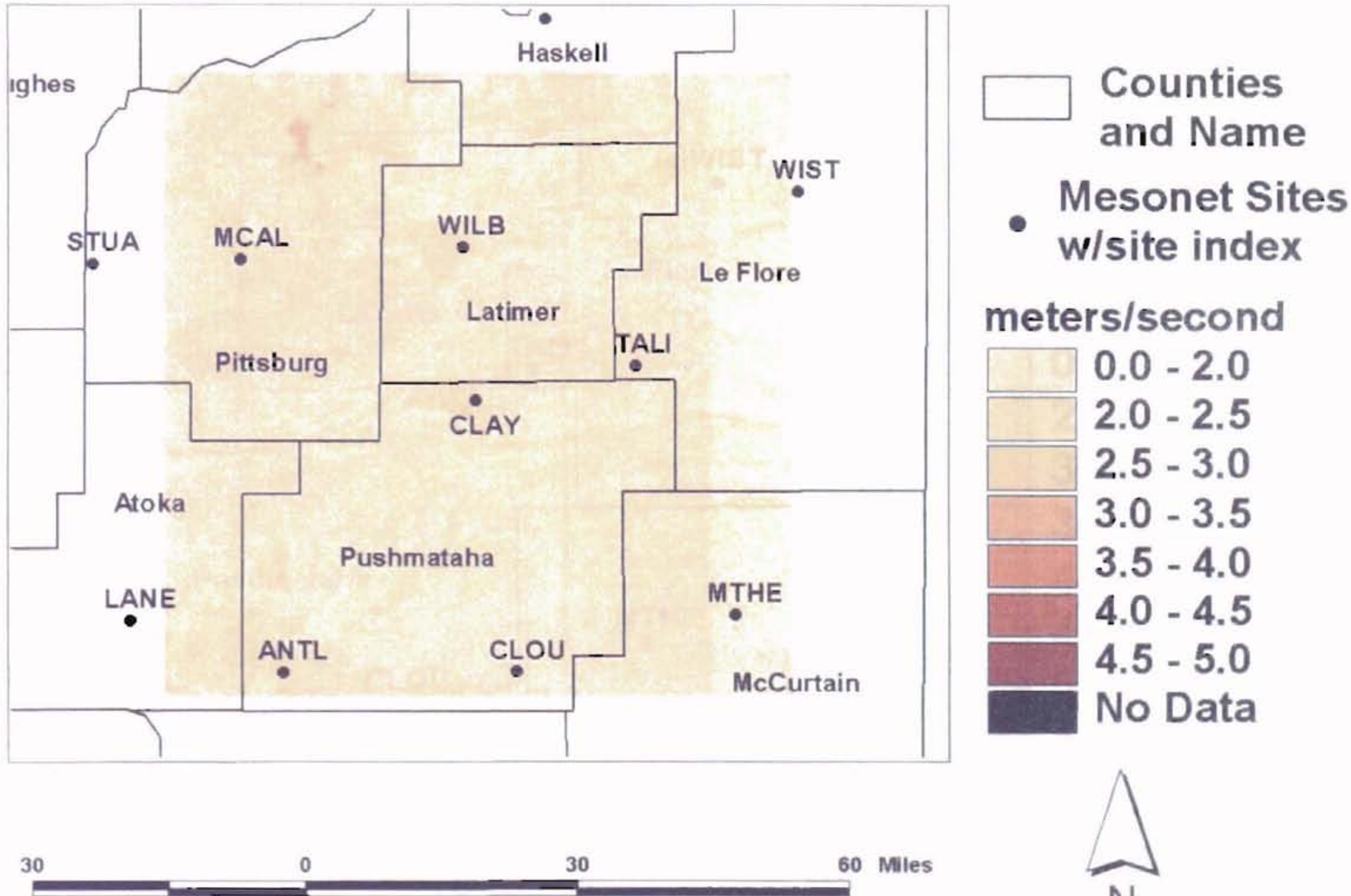

Figure 10. SE area wind speed at 10m

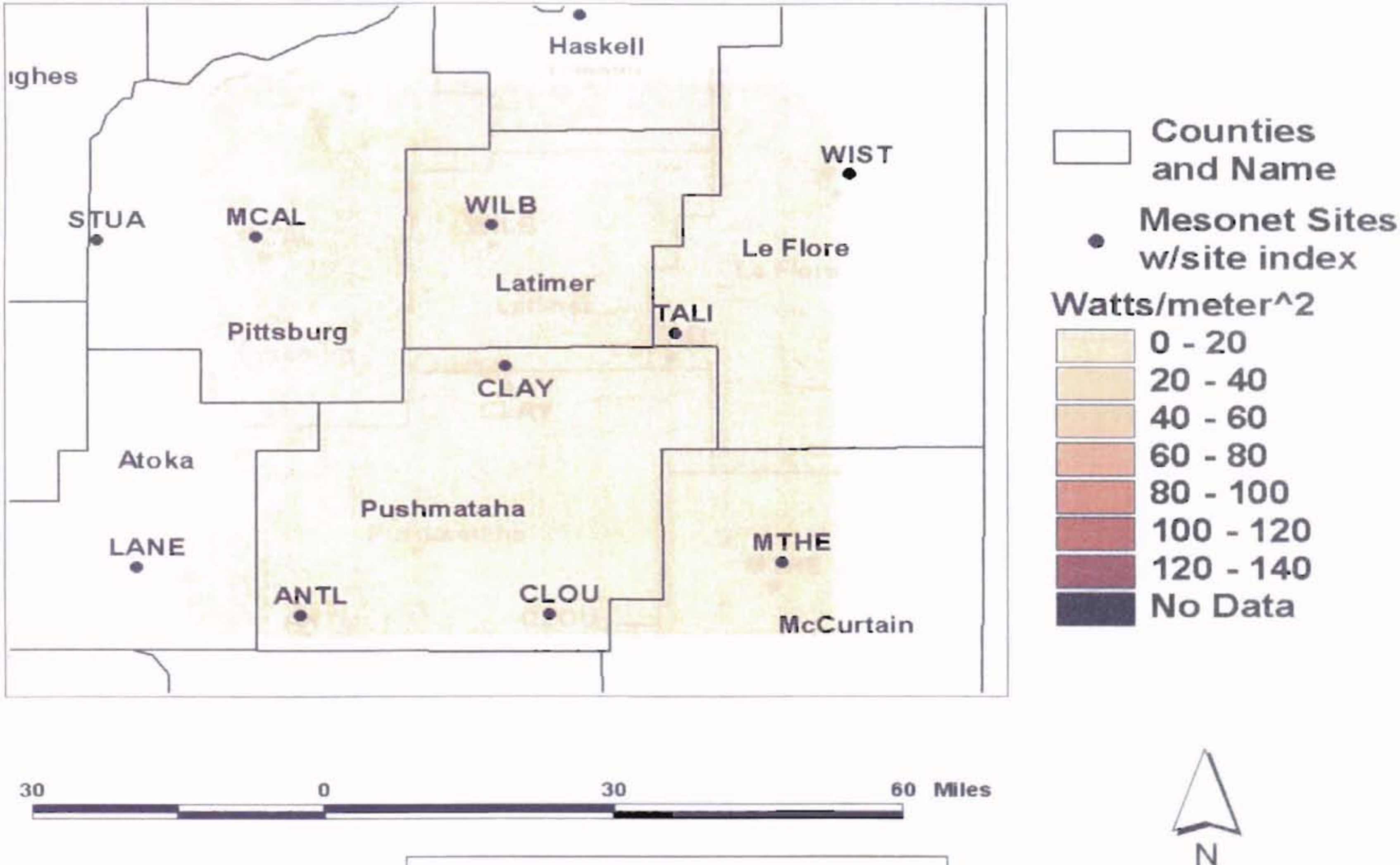

Figure 12. SE area wind power density at 10m

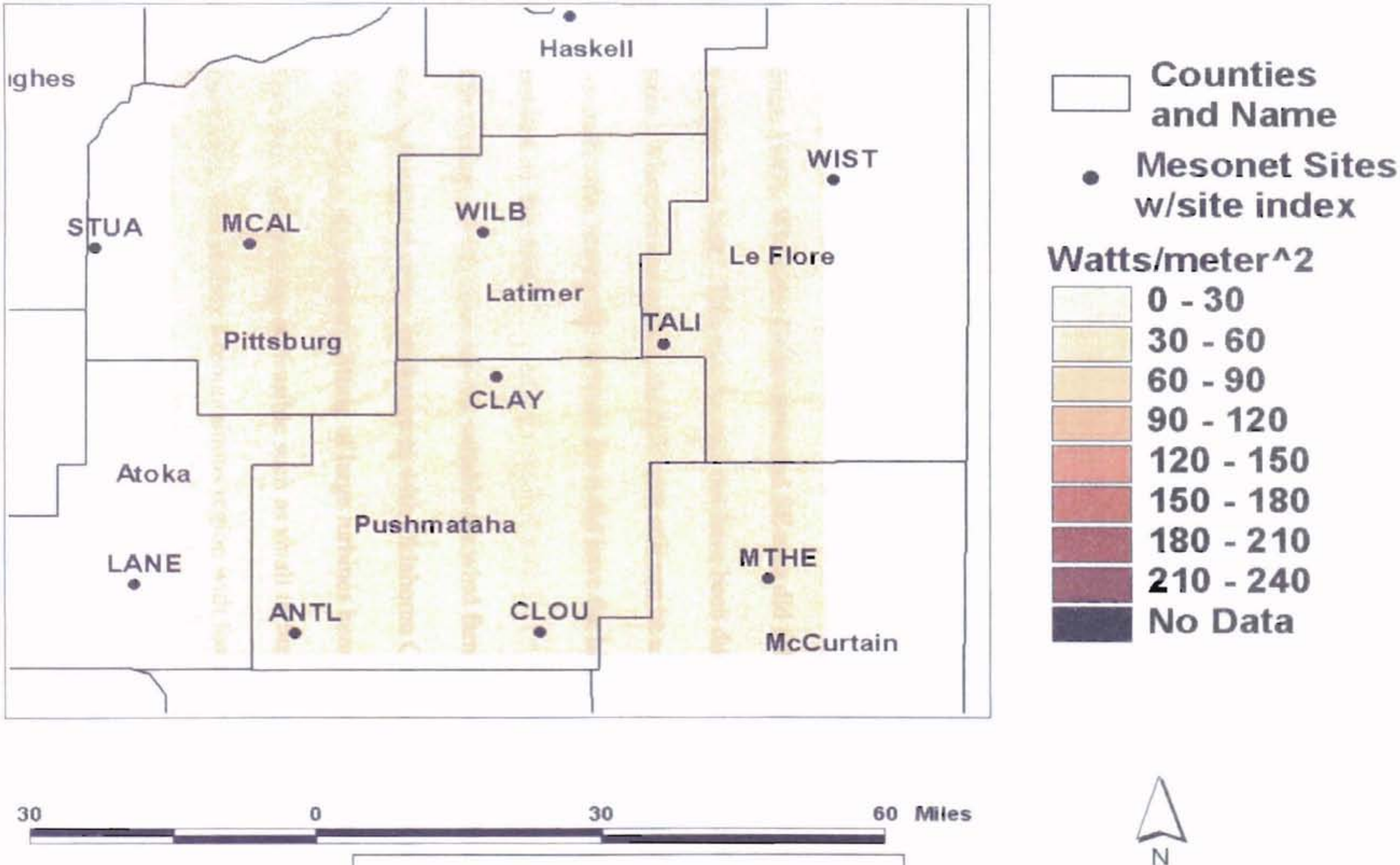

Figure 13. SE area wind power density at 50m

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In the process of this research, it was thought that the results from the model would be more positive in the way of showing that the NW area is a good site for wind farms and the SE site a bad area since that was the trend shown in the National Wind Atlas (Elliot, 1987). While the Center area and SE area did follow this trend, the NW area was only a class 2 at best. This may or may not have been due to the model itself or human error. Whatever the reason, the NW area still can be a viable area for small turbines or individual residential turbines for it did have the highest wind speeds. All hope is not lost on this area.

The Center and SE areas are not suitable for wind farms of large turbines. The Center area is mainly an urban environment with Oklahoma City and it surrounding suburbs as it largest area feature. Siting of large turbines here would not be practical. Some individual turbines may be feasible such as small turbines for home use. The SE area is unsuitable. It is mainly a mountainous region with forest cover and the lowest wind speeds. Individual turbines may not be feasible here.

Recommendations

Future use of this model could extend to mapping the entire state. In doing so the use of all the stations may be used to increase model potential by creating a statewide initial wind field from which the final simulated field more closely matches. The frequencies could be averaged to get a better statewide weighting instead of a weighting for each piece that is run in the model. This might help to model the terrain better. For generating wind map statewide, it should be noted that the resolution on this study was 372m. It may be beneficial to use a smaller resolution even though the state wind assessments done by Brower used a resolution of 1 km. A smaller resolution may enable the user to see areas suitable for small wind farms and individual turbines. Testing techniques used in this research are adequate for testing on a larger scale such as for the state as a whole. The future of this wind power project lies with the creation of a statewide wind power map. This study shows that with this model makes a good regional assessment. The next step is to determine where specific site assessments should be made in order to create a more detailed statewide map.

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