Using GIS to Analyze Wind Turbine Sites within the Shakopee Public Utilities Electric Service Territory, Shakopee, MN USA

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Abstract

Shakopee Public Utilities (SPU) has been a publicly owned electric and water utility in Minnesota USA since 1902. Its electric service territory includes most of the City of Shakopee and some surrounding townships and a small portion of the City of Prior Lake. The City of Shakopee contains a main downtown district as well as residential, commercial, industrial, and agricultural zones. SPU is a separate entity from the City of Shakopee with a commission appointed by the Shakopee City Council. As an electric utility, SPU does not generate its own power and purchases all of its electric power demands from outside sources. SPU has been receiving inquiries from developers of power generating wind turbines since energy independence and the worries of global warming have become more prevalent. This study is a macro comprehensive spatial analysis to determine the best placement of wind turbines in SPU's electric territory by analyzing geographic data layers.

Introduction

In the electronic age of computers, MP3s, and plasma TVs, our electric demand has been increasing year after year. A response to the electric demand has been conservation, but new electric resources are still needed to cover the increased electric demand. A technology that has been discussed to the help meet this demand is wind turbines.

There are two reasons to examine wind turbine siting through Geographic Information Systems (GIS). First, according to a subsidiary of the Department of Interior Bureau of Land Management (2008) called Wind Energy Development Programmatic EIS, at the end of 2007, 1% of all global electricity came from wind power or 94 gig watts (GW) of power; economists project that by 2012 wind powered electricity will almost triple to about 2.7% or 290 GW. A Department of Interior Bureau of Land Management (2008) report also indicated that 1 mega watts (MW) of energy can power 240 to 300 households for a year. The global demand of wind power will be increasing from an average of 25,380,000 households to 78,300,000 households in five years. With the typical commercial wind turbine at 1.5MW, this would represent an increase from 62,667 turbines of today to 193,333 turbines or the construction of about 130,000 1.5MW turbines in the next five years globally (Wind of Change, 2008). With today's

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wind turbines extraction at about 50% of its capacity, 59% is about the theoretical limit (Wind of Change) and with transmission needs from rural areas, these elements are a primary element of focus addressed in the U.S. stimulus package (Wikipedia, n.d.). With new capabilities of forecasting wind, wind power is becoming a more viable source of energy with costs of production decreasing from 30 cents per kilowatt hour in the early 1980s to about 10 cents a kilowatt hour in 2007 (Wind of Change).

Second, wind can produce electricity locally. If a region consists of large open areas such as agricultural land, wind projects have the feasibility to be built locally. With local wind generation, a community housing the wind turbine would have a feeling of ownership of the electricity produced and would be more cognitive of its usage. Large power transmission lines engineered and placed through a community could decrease as generated energy is distributed on local distribution power lines. With the increase in the local production of wind power, this could also decrease the cost of wind turbines through increases in production. That could make wind generation as cost effective per energy unit as some of the older electric producers (i.e. coal and natural gas), and increase local jobs through operations (i.e. installation and maintenance jobs).

One limitation of wind generation has been that most wind generation areas have been located in areas that are not heavily populated. Additionally, electric transmission infrastructure must be constructed from the wind turbines and this includes the expansion of roads as well as the transmission infrastructure itself to other wind turbine sites.

Another limitation of wind generation is its generating reliability. The most reliable time for wind generation is at night, which is the time with the lowest electric power demand. Battery technology is being constantly researched for energy storage while turbines generate electricity, and disperses that power when electric demand is high.

With the aforementioned items taken into count, the Shakopee Public Utilities (SPU) service territory, about 33 square miles, is viewed as an ideal area with large areas of agricultural land within its service area. SPU is also a suburb of the Twin Cities Metropolitan area, which has a high electric demand.

The purpose of this project was to develop a process to collect and analyze geographic data related to wind turbine site selection using GIS. In this study, large scale selections of electric wind turbine sites were created within the SPU electric service territory. Four different product summaries were created.

Methods

Software Used

The GIS software used to perform tasks in the wind turbine siting methodology consisted of ESRI ArcGIS 9.3 and Spatial Analyst (ESRI, n.d.).

Data and Coding the Layers

The geographic layers used in this study were the wind speed resource, Scott County Minnesota land parcels, and two foot land contours, SPU three phase electric lines that consist of three wires with the carrying capacity for the electric power produced, roads, and railways layers. Other layers included in this study were streams, shorelines, wetlands, and wooded areas that were retrieved from Scott County, Minnesota. The final layer collected was the Metropolitan Urban Service Area (MUSA) retrieved from the Metropolitan Council website (2009).

Each layer was converted to a raster. The project was analyzed in raster format because of the ability to add and subtract raster values with subsequent reclassification of each layer's values. The layers were given a (+1) value or a (-1) value if the layer was a valuable asset or hindrance to a wind turbine site location.

The data layers used in this study to assess wind turbine site selection included: wind speed resource, land parcels according to size, land use according to parcel zoning, land elevation contours, roadways, and electric power lines. The wind speed and contours layers were important to insure that wind turbine(s) has the maximum wind capacity to produce electric power. The land parcel size and its zoning were important to determine which parcel and its zone (i.e. residential, commercial, industrial, and agricultural) would best be suited to host a turbine. For example, people would be more resistant to a turbine in a residential area compared to an industrial area. The roadway and electric power lines layers were used to help keep construction costs low.

The data layers that offered information that would be detrimental to wind turbine energy production included: streams, shorelines, wetlands, wooded areas, railways, and MUSA. These were considered to be a hindrance to electric production that that if disturbed, depending on the governing authority, the natural resource might need to be mitigated and this might cost prohibitive to do. The railway layer was of negative impact because of the difficulty in obtaining permits to build in the railway right-of-way (MMPA, 2009). Finally, the MUSA layer was considered detrimental due to the higher value and purchase price of land since water and sewer is available to the parcel (Metropolitan Council, 2006).

Acquiring Data Information

Data layers were obtained from a variety of sources. The Minnesota Department of Commerce provided the wind resource layers for the calculation of wind capacities as a spatial raster grid. This was the best quality resolution data located but is poor in that its cell size is 500 meter cell size or 46 acres.

Scott County provided the parcels, planimetrics, and contour data as well as the datum which all the data was spatial referenced to. The planimetric data included roadways, railways, shorelines, swamp edges, streams, and woods edges. The data was obtained as shapefiles.

Metropolitan (Met) Council provided the Metropolitan Urban Service Area (MUSA) 2010 layer. The data was provided as shapefiles.

Shakopee Public Utilities provided the service territory layer (about 33 square miles) and the electric layers. The electric layer included existing electric overhead and underground three phase power lines needed to insure the capacity of power produced to be distributed was met. The data was obtained as shapefiles.

Calculating Raster Layers

After the data was collected, the first step was to prepare the GIS data. The GIS layers were processed to create seamless layers for the Shakopee Public Utilities (SPU) service territory using the clip tool. Since some of the data's projections had differing coordinate systems (i.e. MUSA and wind resource layers), projections had to be reprocessed to match the other layers projection (i.e. SPU service territory).

The following layers were manipulated by assigning new values to the attributes in preparation for the analysis:

1. Wind resources – the wind speed values, collected at 30 meters in height, were reclassified into four categories (Table 1). The wind raster had a cell size of 500 meters, which represents a cell area of 2,600,000 square feet or 46 acres (Figure 1).

Table 1. Wind Resource values (in meters/ second) with the lowest value set to 1 and the highest value to 4.

Value	Wind Speed (m/s)
1	4.1 - 4.5
2	4.5 - 5.0
3	5.0 - 5.5
4	5.5 - 5.6

2. Parcel land use layer – the following layers were converted to a raster with a cell size of 50 feet, which is 2,500 square feet or 0.06 acres (Figure 2).

   a. Parcel acres which were two acres or greater due to the calculation of 1.1 times the height of the tip of the turbine blade of a 265 foot turbine to its hub with 35 foot blades to the right-of-right line per a draft City of Shakopee ordinance of the wind turbine (City of Shakopee, 2009).
   b. Land use features of residential, commercial, industrial, and agricultural.

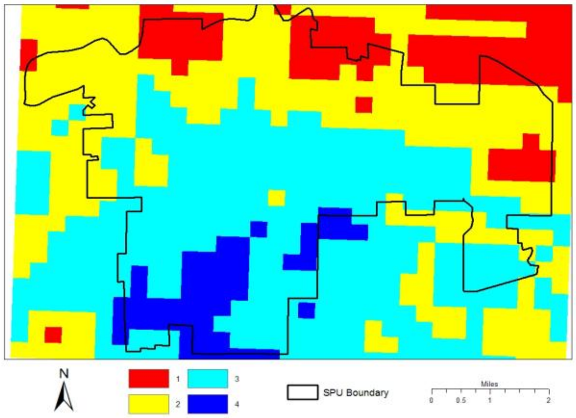

Figure 1. Wind Resource reclassified raster illustrating values of wind speeds. The least desirable areas (red) are classified as 1, while the best areas (blue) are classified as 4.

Table 2. Reclassified land parcel use values.

Value	Land Use
0	Residential
1	Commercial
2	Industrial
3	Agricultural

The parcel values were divided into four categories (Table 2). Residential parcels would be hardest to develop a turbine and as such were assigned a value of zero, with zero being the least desirable. Agricultural parcels would be easiest to develop a turbine on and were assigned a value of three, with three being the most desirable.

3. Contour layer – this layer was converted from two foot

elevation contour lines into an aspect raster. Northwest-facing areas were extracted for optimum wind exposure (Figure 3).
4. Electric power lines – this layer was selected for three phase subtype for overhead and underground electric lines.
5. Roads – this layer consisted of main highways and county roads.

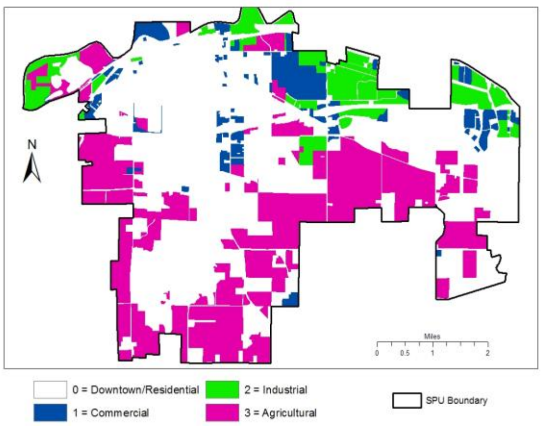

Figure 2. Land parcels consisting of two acres or greater. Areas in white color (residential values of 0) are least desirable. Areas with magenta color (agricultural values of 3) are most desirable for turbine development.

Buffers were applied to the following natural resource, railway, MUSA, power lines, and road layers. The natural resource buffers were created based on the recommendations of the Scott County Advisory Commission (2006). The power lines and roads buffer were based on the MMPA (2009). The railways buffer used exceeded the buffer recommended by the Scott County Advisory Commission based on information from the Union Pacific Railroad website (2009). This was done to minimize conflicts with railroad infrastructure. The following buffer zones were converted to a raster with an output cell size of 50 feet:

1. Streams - 150 foot buffer
2. Woods - 150 foot buffer
3. Wetlands - 70 foot buffer
4. Shorelines - 150 foot buffer
5. Railways - 150 foot buffer which exceeded the Union Pacific Railroad restrictions of 50 feet center of right-of-way (2009)
6. MUSA – no buffer and value of one was used when reclassified
7. Electric power lines - 1320 foot buffer (MMPA, 2009)
8. Major roads - 1320 foot buffer (MMPA, 2009)

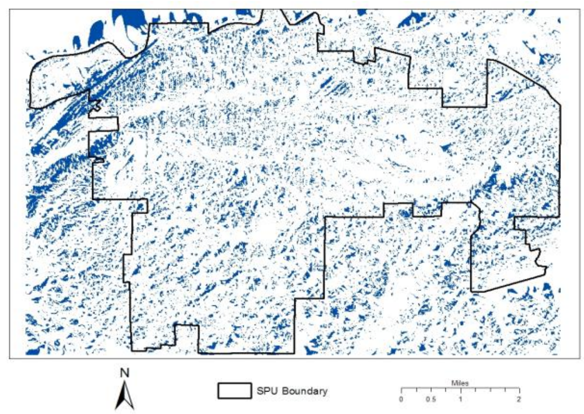

Figure 3. Northwest-facing land areas presented in blue with a 50 foot cell size.

Table 3. Reclassified values for layers except Wind Resource and Parcel Land Use.

Layers	Value
Land Contours	1
Roads	1
Electric Power Lines	1
MUSA	-1
Railways	-1
Streams	-1
Shorelines	-1
Swamps/Wetland	-1
Woods	-1

The reclassify tool was used to give a (+1) or (-1) value to each layer (Table 3). No Data values were reclassified to a value of zero to insure all of SPU electric service territory was given a value to be analyzed.

Analysis

Constructing the Final Layer Values and Analyses

Each step in the analysis used all of the layers listed in the following paragraph to complete the analysis. Each layer in each analysis step (described below) was given a different value according to a survey that had ranked each layer for each analysis, except for the Equal Value Layer Analysis which used its original negative or positive value layer.

Environmental and Political Analysis

The environmental and political weighted analysis emphasized issues that impacted the sites environmentally and politically. The natural resource layers were used to indicate areas where high bird and bat migration and sensitive environmental areas might be impacted. The layers that were weighted for government/political analysis were land use and/or zoning and used to indicate agricultural, industrial, commercial, and residential areas. The political analysis identified the more regulated sections of the territory by the City. Where there are larger population densities, the more likely one will find expressions of NIMBY (not in my back yard) for a wind turbine structure.

Geographical Analysis

The geographically weighted analysis emphasized layers that took into consideration the physical land properties of the sites. The primary use of the geography analysis was to explore and evaluate orientation for optimum wind generation such as land facing to the northwest. The geographical analysis included the physical land site and how it would meet the wind turbines physical infrastructure requirements such as having sufficient land area to structurally construct a turbine. Another physical site requirement was being in close proximity to roadways that support larger capacities of traffic and larger vehicles (i.e. county roads, major city collector streets, and highways). Finally, the geography analysis examined the restrictive areas that railroads require as buffers from its facilities.

Cost Effective Analysis

The cost effectiveness analysis identified the optimum site with the greatest return on the investment of the wind turbine. An example of being cost effective was evaluating the wind resource layer for the greatest wind speed and direction. This analysis evaluated data layers that helped indicate land cost value such as the Metropolitan Urban Service Area, or MUSA, 2010 layer from the Twin Cities Metropolitan Area of Minnesota. The MUSA layer indicated if city water and sewer hookup would be available. City water and sewer hookup information helped with the assessment of the value of a parcel and its surrounding parcels. If the parcel has MUSA, the parcel would be more costly to buy or lease. A secondary use of the cost effectiveness analysis was to minimize the cost of construction and maintenance of the site (i.e. vicinity of the three phase power lines and roadways). Finally, close vicinity to main roadways helps decrease costs for road improvements and the driveway construction needed for transportation in and out of a site.

Equal Value Layer Analysis

The final analysis produced was the Equal Value Layer Analysis. The Equal Value Analysis used the original values to generate its map (Tables 1, 2, and 3). The analysis gave insight to all layers with no emphasis on any.

Analysis Construct

A survey was given to thirteen employees at SPU consisting of engineers, electric linemen, and office workers. Each respondent was given a description of each layer for each of the three analyses (i.e. environmental and political analysis, geographical analysis, and cost effective analysis) and was asked to rank the importance of each layer on a scale of one to three with three being the most important value. All responses ranked values for each of the layers in each of the four analyses (Environmental and Political analysis, Geographical analysis, Cost Effective analysis, and Equal Value Layer analysis) were summed to give a total measure of importance for each layer for each analyses. The value with the highest score from the surveys was then designated the "value" for each layer. With this designated value, each layer was then added to the original value from Table 2 and 3. The new value for each layer was created by using the reclassify command (Table 4). Parcels that had multiple zoning classifications were managed as a separate table and appended to the different sets of parcel zones (Tables 2 and 5). The wind resource, also with multiple wind values was left to its original values so as to not allow the study to set excessive importance to the wind resource over the other layers being summed (Table 1).

Table 5. Parcel land use with summed values of original value and survey.

Value	Land Use
1	Residential
2	Commercial
3	Industrial
4	Agricultural

As each layer was reclassified to reflect its new value, the raster calculator was used to analyze each layer. The raster calculator displayed an accrual of each cell's value in each raster layer. As value in the output raster increased, it signified areas that were more suitable for locating a wind turbine site (Figures 4, 5, 6, and 7). To simplify the number

Table 4. Summed values for reclassification in final analysis except wind resource and parcel land use which are in separate tables.

Layers	Geography Analysis Value	Cost Effective Analysis Value	Environmental & Political Analysis Value
Wind Resource	Table 1	Table 1	Table 1
Land Parcel Use	Table 2	Table 5	Table 5
Land Contours	4	4	2
Roads	2	2	2
Electric Power Lines	3	4	2
MUSA	-2	-2	-2
Railways	-2	-2	-2
Streams	-3	-2	-4
Shorelines	-2	-2	-4
Wetlands	-3	-3	-4
Woods	-3	-2	-3

of different values, analysis layers were reclassified for a final analysis (Table 6) (Figures 8, 9, 10, and 11).

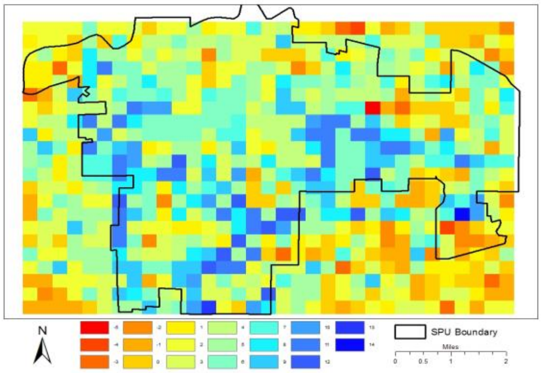

Figure 4. Final calculation of geography analysis where red is the least suitable and blue is most suitable for turbine site(s).

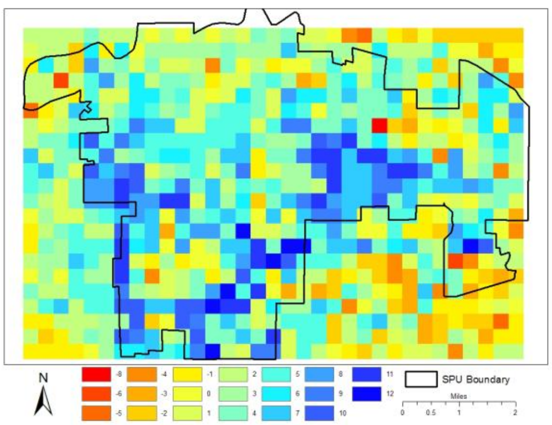

Figure 5. Final calculation of environmental and political analysis where red is the least suitable and blue is most suitable for turbine site(s).

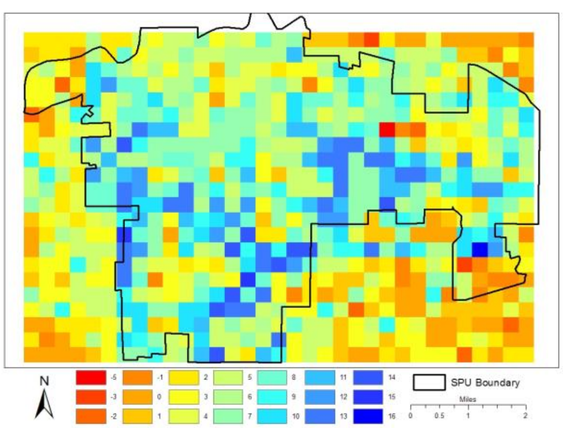

Figure 6. Final calculation of cost effective analysis where red is the least suitable and blue is most suitable for turbine site(s).

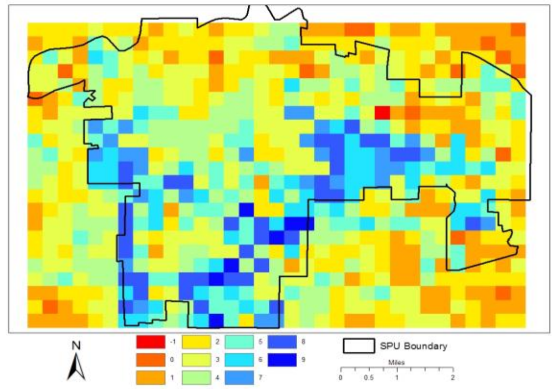

Figure 7. Final calculation of equal value layer analysis where red is the least suitable and blue is most suitable for turbine site(s).

Table 6. Final reclassified calculated values for each analysis from group to single value.

Geography Analysis		**Cost Effective Analysis**	
Old Values	New Values	Old Values	New Values
(-5 - 0)	1	(-5 - 0)	1
(0 to 4)	2	(0 to 4)	2
(4 to 8)	3	(4 to 8)	3
(8 to 12)	4	(8 to 12)	4
(12 to 14)	5	(12 to 16)	5
Environment & Political Analysis		**Equal Value Layer Analysis**	
Old Values	New Values	Old Values	New Values
(-8 to 0)	1	(-1 to 0)	1
(0 to 3)	2	(0 to 3)	2
(3 to 6)	3	(3 to 6)	3
(6 to 9)	4	(6 to 9)	4
(9 to 12)	5	[redacted]	[redacted]

Results

The results of this study identified the following:

1. A profile of the SPU service territory
2. Areas where the wind resources were strong, but other resources (i.e. electric lines, roads, and natural resources) were weak
3. Areas showing different potentials for wind turbine placement according to analyses with different layer values

4. Unexpected areas of potential wind turbine sites

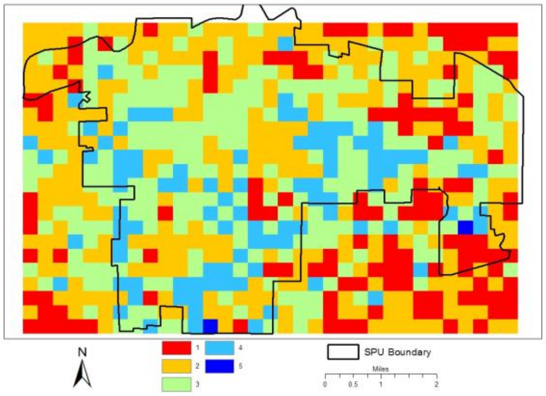

Figure 8. Final reclassified calculation of geography analysis where red is the least suitable and blue is most suitable for turbine site(s).

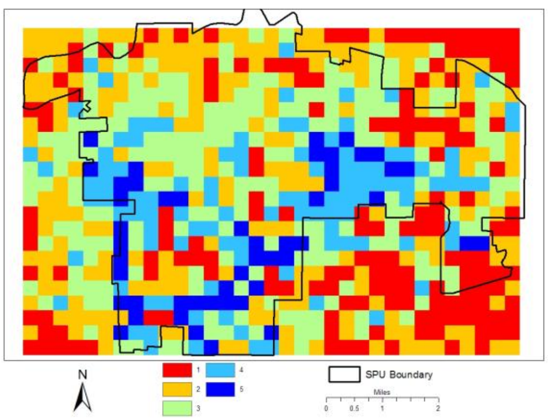

Figure 9. Final reclassified calculation of environmental and political analysis where red is the least suitable and blue is most suitable for turbine site(s).

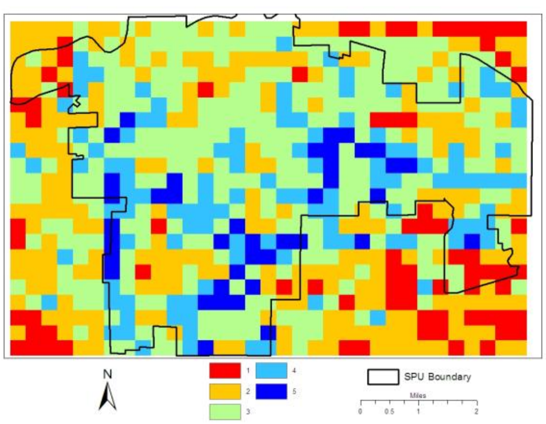

Figure 10. Final reclassified calculation of cost effective analysis where red is the least suitable and blue is most suitable for turbine site(s).

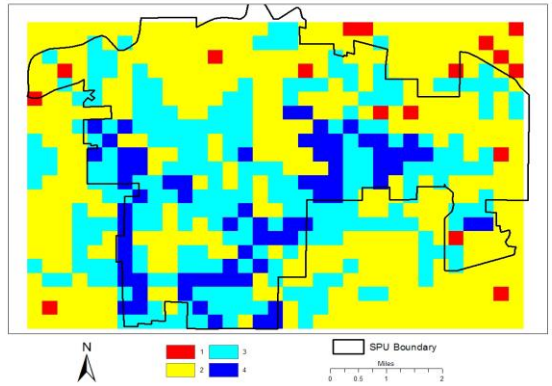

Figure 11. Final reclassified calculation of equal value layer analysis where red is the least suitable and blue is most suitable for turbine site(s).

There were challenges to take into consideration with the results of these four analyses. The first two considerations were due to the wind resource layer. The first consideration was the spatial reference of the datum. All the vector layers were projected into the Scott County's User Defined Lambert Conformal Conic Coordinate System. However the wind resource layer was projected as a North American Datum (NAD) 1983 Lambert Conformal Conic Coordinate System. Although both projections were projected on the fly, the data was skewed to the west of the SPU electric service border creating a small area of no data (Figure 12).

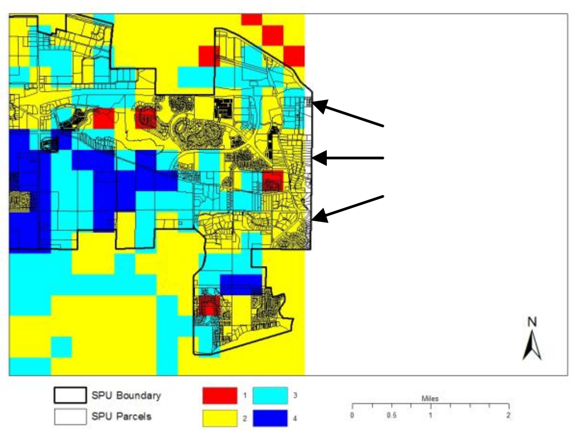

Figure 12. Lack of analysis on eastern border of SPU territory due to projection on the fly.

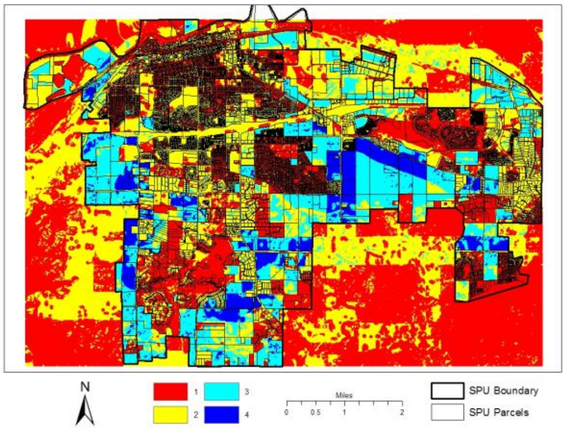

Figure 13. Final reclassified calculation of equal value layer analysis, with a cell size of 50 feet, without wind resource layer where red is the least suitable and blue is most suitable for turbine site.

A second concern was the final cell size. The acquired wind resource data from the Minnesota Department of Commerce was the least accurate data. The wind resource layer, with a cell size of 500 meters was 99.9% larger than the other layers which had a cell size of 50 feet. Due to the large cell size of the wind layer, the overall project analysis was only able to be evaluated using the larger cell size of 500 meter or 46 acre cells. Excluding the wind resource layer with a larger cell size left no evidence of significant change when viewed with side-by-side comparisons to the final results with the cell size of 50 feet, except if one is trying to study a specific land parcel (Figure 13). This indicates the integrity of the data was not compromised since this study was at a macro level. Further onsite field data could be collected when designated sites are studied for potential turbines to improve specific placement. If one was studying a larger area such as the Twin Cities metropolitan area, this large cell size would be more acceptable.

A final concern was that each of the layer buffers (i.e. wetlands buffer of 70 feet) was interpreted to specific bylaws and ordinances of SPU's territory. These buffers could have further interpretations within the border of SPU at a later date as well as different buffer in other electric service territories.

Conclusions

Wind turbine site selection is almost as much of an art as it is a science. Many facts have to be interpreted in the eye of the beholder when placing wind turbines. Each layer can be manipulated in its value, buffer distance, and its original data acquisition. In addition to interpreting the acquired information for the buffering of the layer data, new regulations are often imposed by various government bodies as time proceeds. One example is the Minnesota Public Utilities Commission (2008) requesting a 1,000 foot offset from all wetlands, streams, rivers and lakes listed in the state Public Waters Inventory and listed on the National Wetlands Inventory. This study, from the start, was interpreted as a guide to finding the best wind turbine sites in a given service territory at a macro level. Without a follow-up micro study with onsite data collection of a suitable site, a project's goal of electric production and payback could be wildly off the mark.

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