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12/07/2017

Analysis of California as an Area for Wind Energy Development

Helper, GIS 327G

Introduction

California is one of the leaders of renewable energy in the United States. In 2015, California passed the Clean Energy and Pollution Reduction Act which calls for California to increase to 50% the electricity obtained from renewable energy sources by 2030. California plans to reduce greenhouse gas emissions 40% below 1990 levels by 2030. This poses the question, where are the best areas to construct areas for the harnessing of renewable resources, more specifically wind energy? There are multiple factors that go into the success of a wind farm, including: wind speed, proximity to transportation networks, proximity to cities and proximity to electrical grids. A suitability analysis can be performed in ArcMap to help narrow down the possibilities of locations through raster analysis. Once the raster analysis is performed, these areas of suitability can be further studied to find the most economical and efficient options for the site placement.

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Factors Determining Suitability of Wind Energy

Wind Speed:

Wind speed is the main factor in the creation of the suitability analysis "heat map". The amount of power generated by a wind turbine is proportional to the cube of the wind speed. This means that increasing the average wind speed from 6 m/s to 7 m/s results in 63% more power from the same turbine. The wind speed will be the main factor in the suitability analysis for this reason. Upon initial assessment, it may seem like the analysis can stop after determination of wind speed, but there are other important factors that play in to the success of harnessing wind resources. The wind dataset used in the analysis is the average wind potential at a height of 50m.

Data from: https://catalog.data.gov/dataset/nrel-gis-data-california-wind-high-resolution

Proximity to Cities:

There are restrictions on how close wind turbines can be to neighborhoods, but the closer the turbines are to neighborhoods, the less energy is lost in transport. Therefore, for this analysis, proximity to cities is considered a good thing, but anything inside of the cities cannot be considered in this analysis.

Data from: http://www.dot.ca.gov/hq/tsip/gis/datalibrary/Metadata/cities.html

Current Wind Resource Areas:

Current wind turbine locations can help validate the results of the final heat map and indicate if any changes need to be made in the weighting or choice of suitability factors. Once the heat map is made, the locations of current wind turbines will be layered on top of the analysis to check the quality of the heat map.

Data from: https://www.sciencebase.gov/catalog/item/57bdf821e4b03fd6b7df5fe1

Commercial Truck Network and Energy Transmission Lines:

In order to construct and maintain Wind Turbines, the areas must be accessible by large trucks which require the use of the Truck Network.

Data from: http://www.dot.ca.gov/hq/tsip/gis/datalibrary/Metadata/Trknet.html

Additionally, to be an economically feasible project, the wind turbines must be located near the energy transmission lines.

Data from: https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines?geometry=-131.006%2C31.764%2C-75.591%2C43.865

Complex Hills/ Valleys:

After the heat map is complete, areas are prospected and DEM are assessed to confirm that prospected areas do not have too complicated of topography. Complex topography may create complex wind patterns which make the area less suitable for wind turbines.

Data from: http://www.brenorbrophy.com/California-DEM.htm

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Data PreProcessing:

Selecting Data Frame/ Projection System

When acquiring data from multiple different sources, it is important to make sure that the projection and coordinate system are the same so that the data aligns correctly. To be able to work in meters, the data is projected to NAD83 / UTM zone 10N, the projection used for California, by using the "Project" tool.

The same process is applied to all of the datasets.

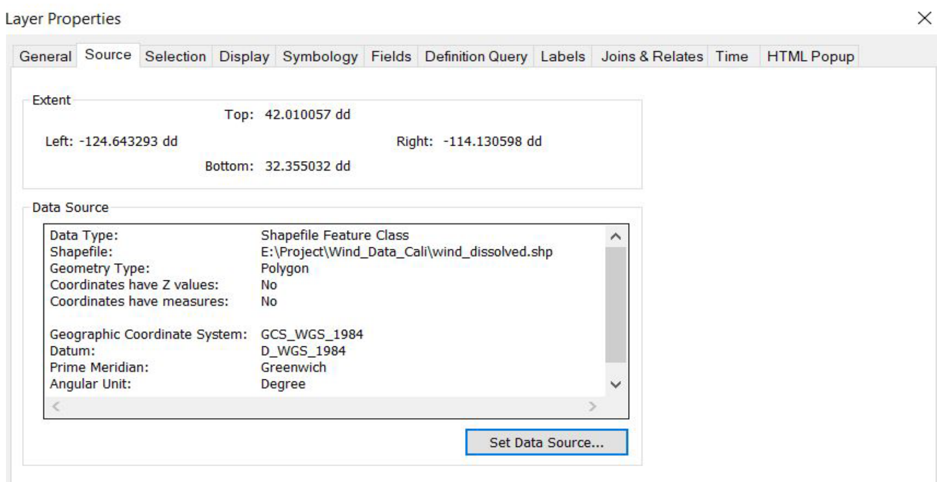

Figure 1. The initial projection and coordinate system for the wind data before processing.

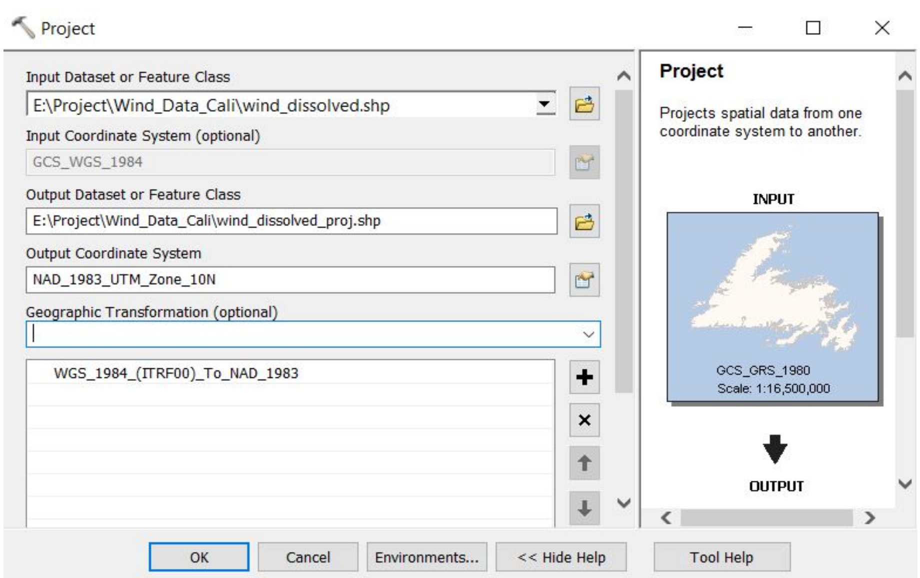

Figure 2. The process of transforming coordinate systems from WGS 1984 to NAD 1983 UTM Zone 10N.

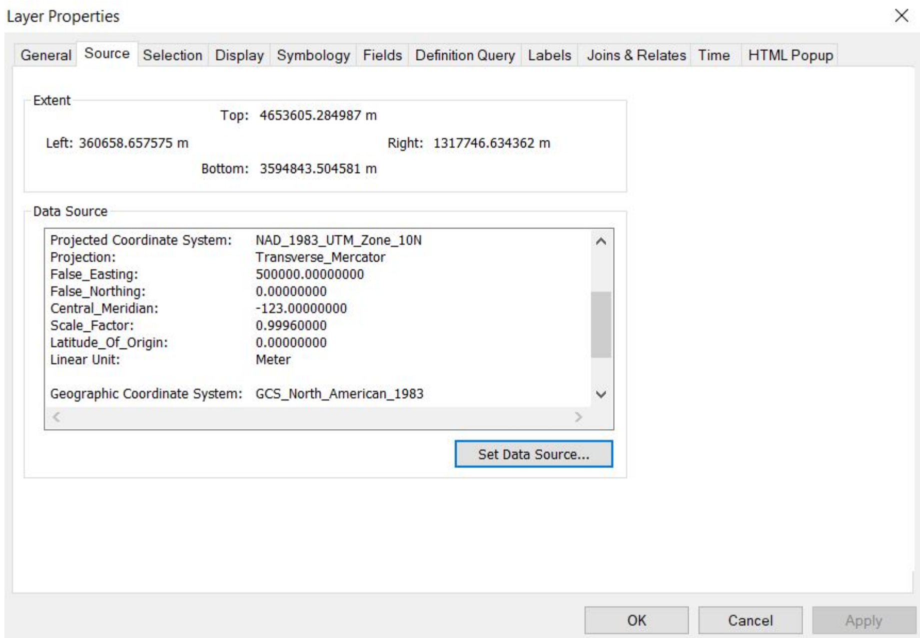

Figure 3. Displays the final result of the coordinate system transformation.

Selecting and Exporting Data to Reduce Size of Datasets

Initially, the Electric Transmission Lines and Truck Network datasets contained many features and ArcMap would crash with each attempt to buffer. Features were selected from each based on line length to reduce the amount of lines ArcMap had to buffer. Statistical analysis for the data on both roads and transmission lines were used to remove all of the lines that were shorter than the mean distance. For the transmission lines, all values less than 26173m, the mean length, were removed. This did not have a large impact on the results obtained from the buffer, it just made the data easier to process.

A similar reduction is made to the Truck Network data.

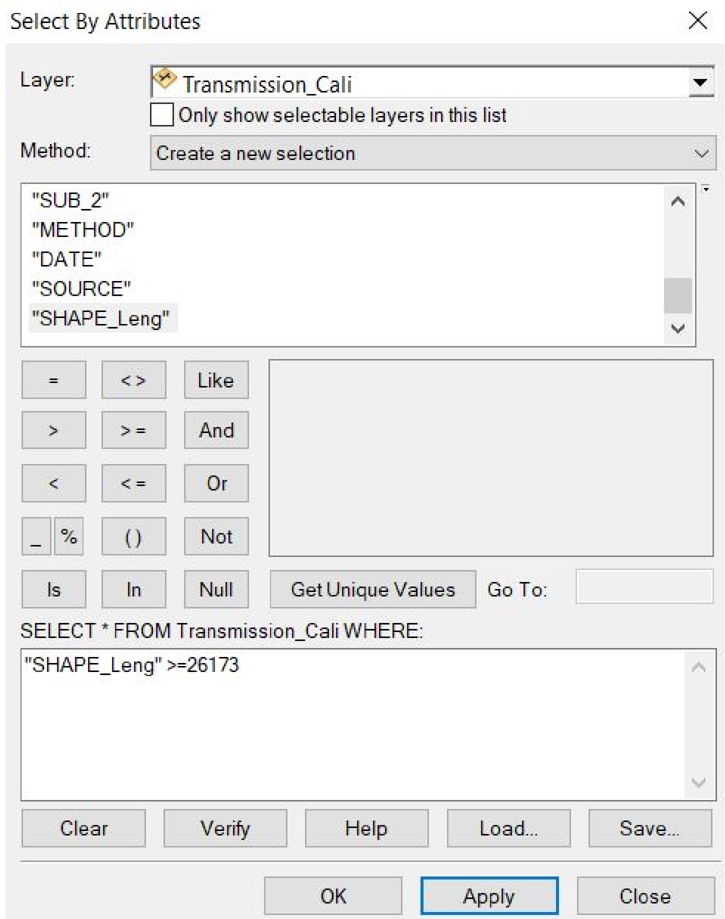

Figure 4. The selection of transmission lines by attribute. All lines with “SHAPE_Leng” (length of the line) greater than 26,173m were selected to create a new shapefile with fewer lines to process.

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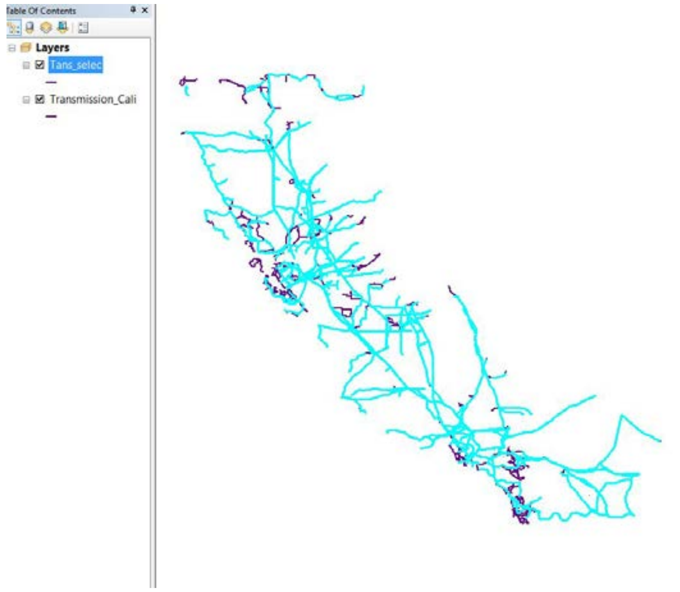


Figure 5. Making this selection reduces the size of the data that ArcMap has to process without sacrificing the end result.

Buffering

To prepare data for analysis, buffers are created around features with the intent of transforming the newly buffered polygons into raster data for the final analysis. For the cities, truck network, and electric transmission lines, the closer the wind farms are to these features, the more suitable the area is.

Distances of 15km, 30km, and 60km are chosen for the buffer distances. The distances of 15km generally contain the wind current wind resource areas, while distances of 60km cover most of the state of California. The 30km buffer is added to improve the final raster analysis so that there are three distance areas to be ranked.

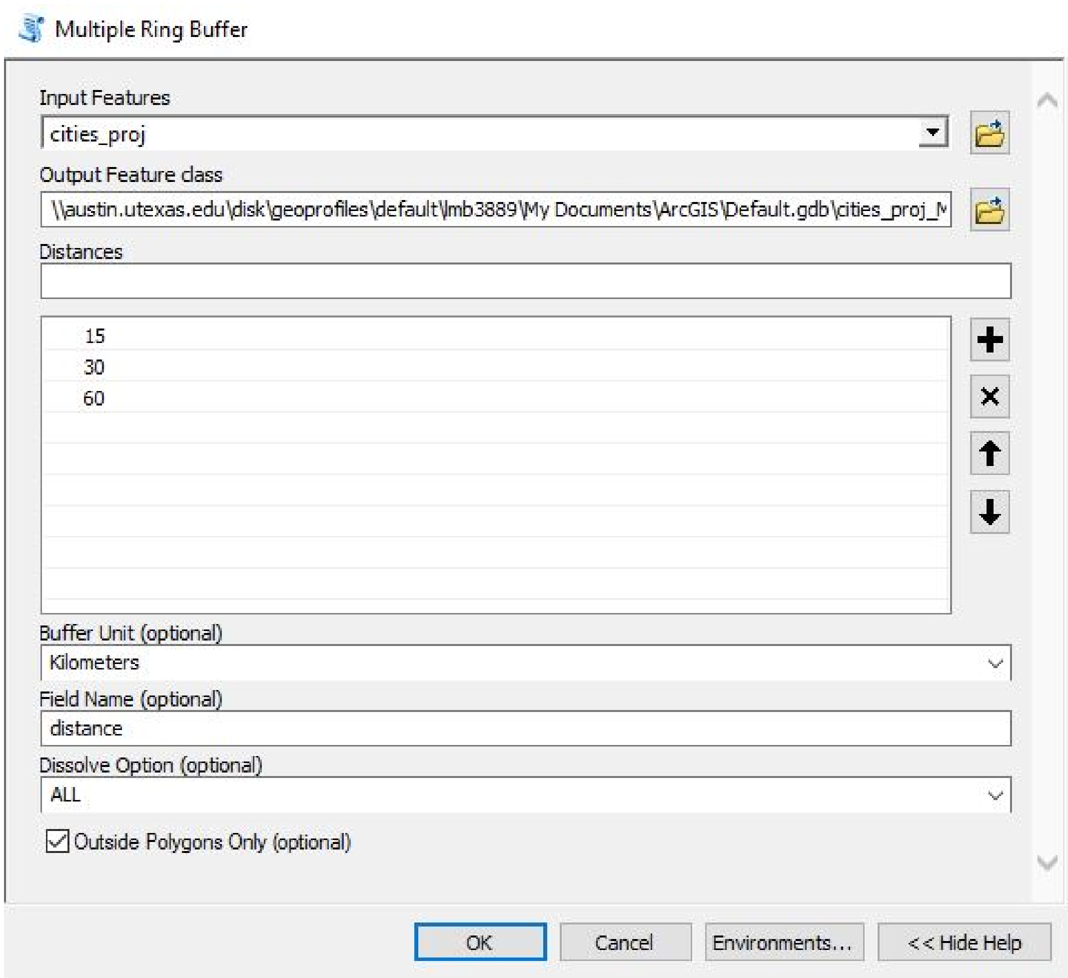


Figure 6. The multiple ring buffer tool creates buffer rings around an input feature. Buffer rings of 15km, 30km, and 60km are created. Dissolve option is checked and allows for polygons to be dissolved together rather than separate for faster data processing for future steps. The buffer polygons are created outside of the cities because the areas where cities are will not be included in potential wind farm areas because cities are already populated.

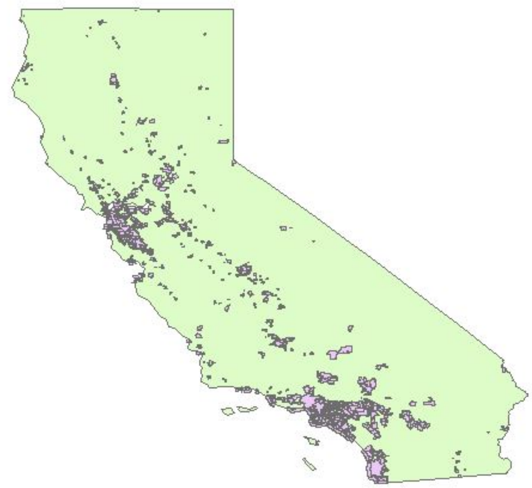


Figure 7. Cities data before the multiple ring buffer tool.

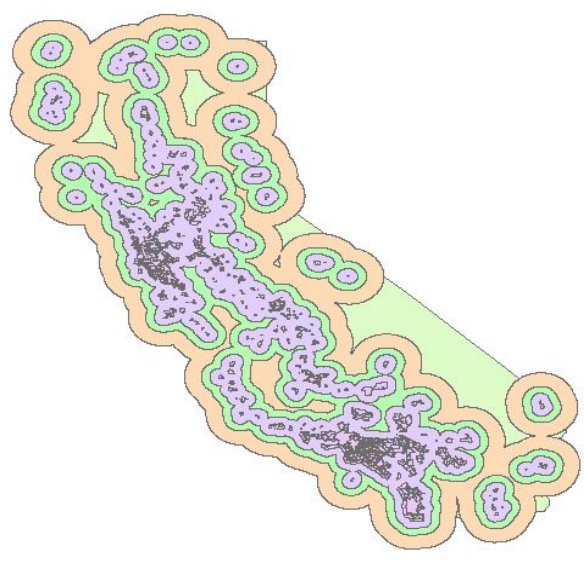


Figure 8. New cities data after the buffer ring tool.

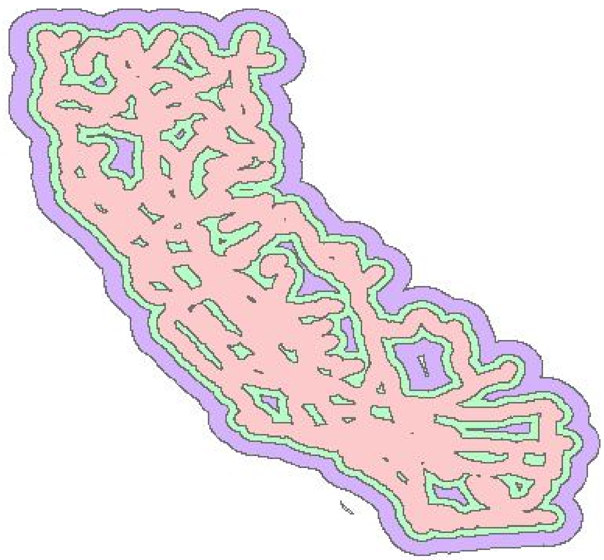


Figure 9. Roads after the multiple buffer ring tool.

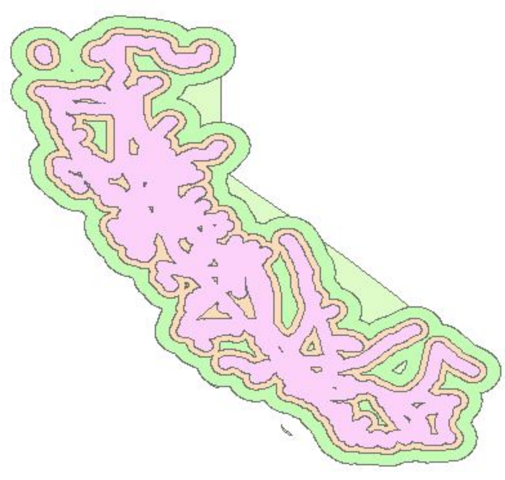
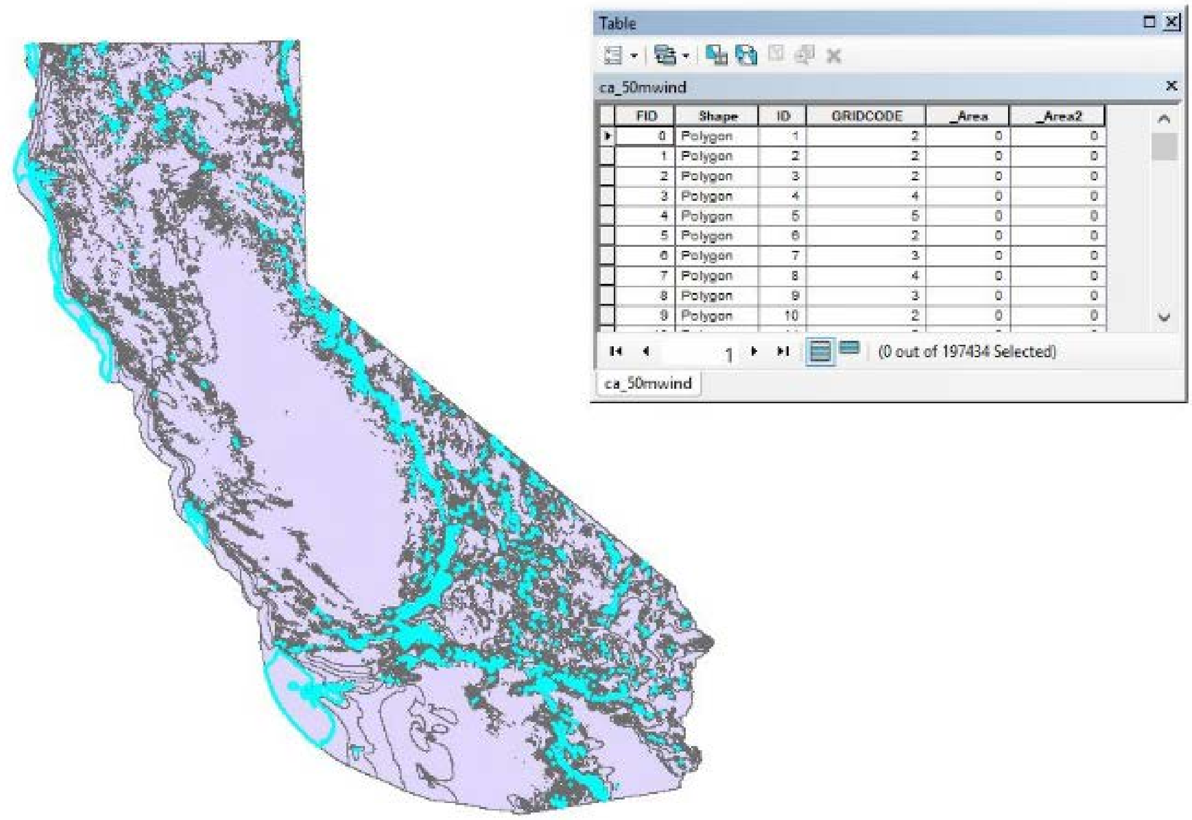


Figure 10. Transmission lines after multiple ring buffer tool.

Dissolving Wind Data Polygons

The downloaded wind data was composed of 197,434 polygons. This made any analysis very slow and cumbersome. Using the Dissolve Tool, the polygons are combined based on the attribute “GRIDCODE”. The grid code corresponds to 7 categories of wind speed, which are used to assign value to the polygons and are used for raster weighting.



FID	Shape	ID	GRIDCODE	_Area	_Area2
0	Polygon	1	2	0	0
1	Polygon	2	2	0	0
2	Polygon	3	2	0	0
3	Polygon	4	4	0	0
4	Polygon	5	5	0	0
5	Polygon	6	2	0	0
6	Polygon	7	3	0	0
7	Polygon	8	4	0	0
8	Polygon	9	3	0	0
9	Polygon	10	2	0	0

Figure 11. The attribute table for the average California wind Data. There are 197,434 polygons that contain data on a “GRIDCODE” that corresponds to wind speed.

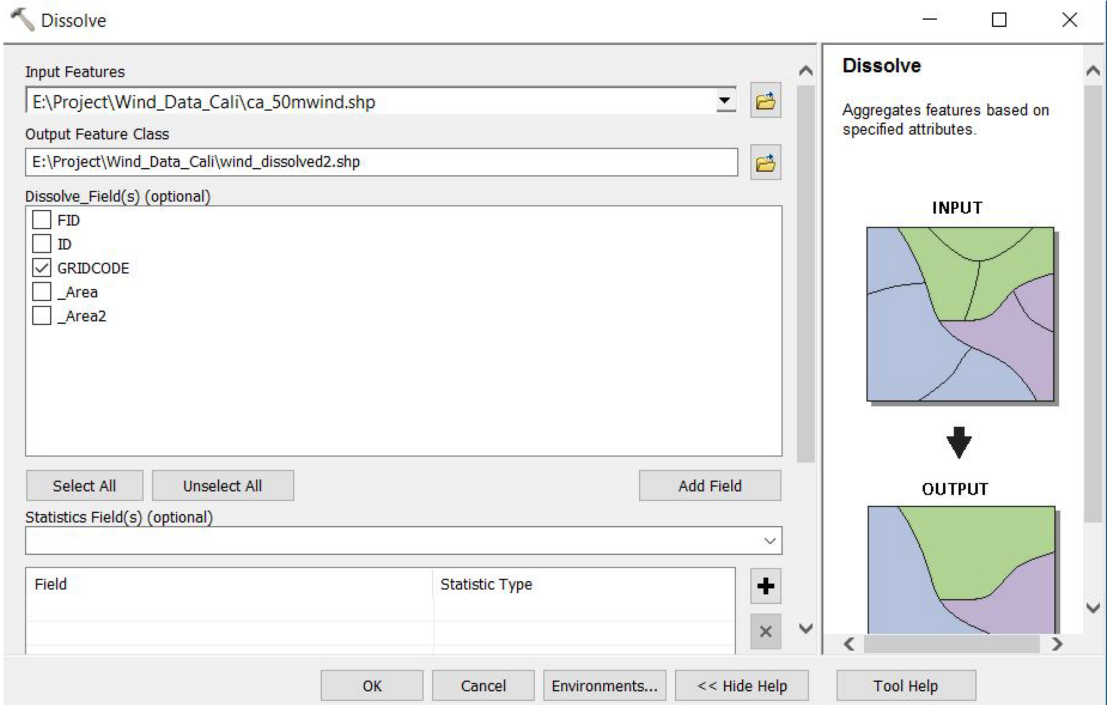
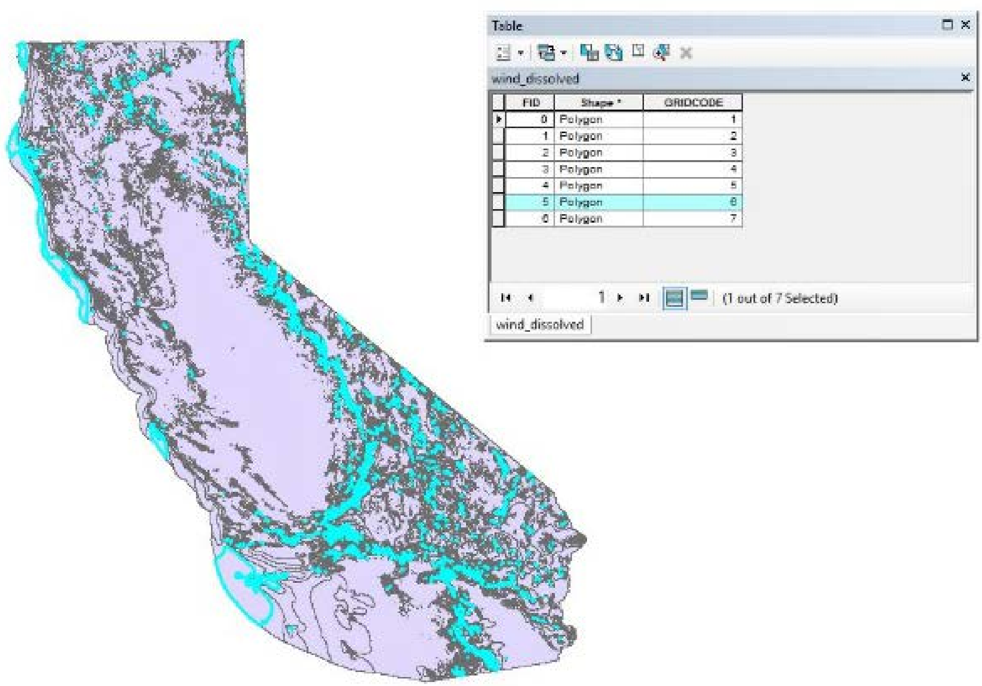


Figure 12. Dissolve tool. The polygons are dissolved based on grid code to make data analysis possible.



FID	Shape *	GRIDCODE
0	Polygon	1
1	Polygon	2
2	Polygon	3
3	Polygon	4
4	Polygon	5
5	Polygon	6
6	Polygon	7

Figure 13. The end result of the dissolve tool applied to the California Wind Data polygons. The end result is 7 polygons, each containing all of the area for each wind speed category.

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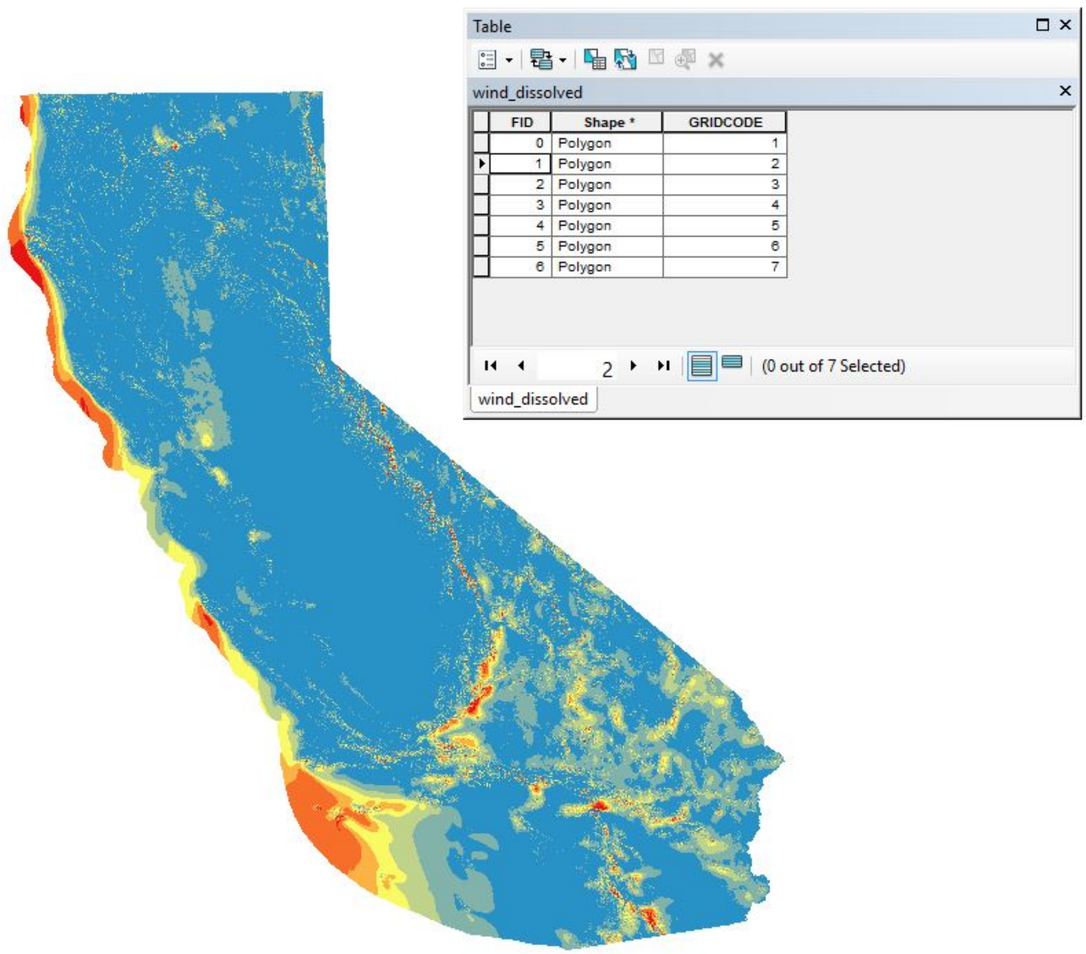
Converting from Vector Data to Raster Data

Initially, all of the data was in vector format. To perform the desired suitability analysis, all data is converted to raster data so that it is able to be used in raster calculations to get the suitability ranking. The higher the number in the final calculation, the more suitable.



FID	Shape *	GRIDCODE
0	Polygon	1
1	Polygon	2
2	Polygon	3
3	Polygon	4
4	Polygon	5
5	Polygon	6
6	Polygon	7

Figure 14. Vector data before conversion into raster data.

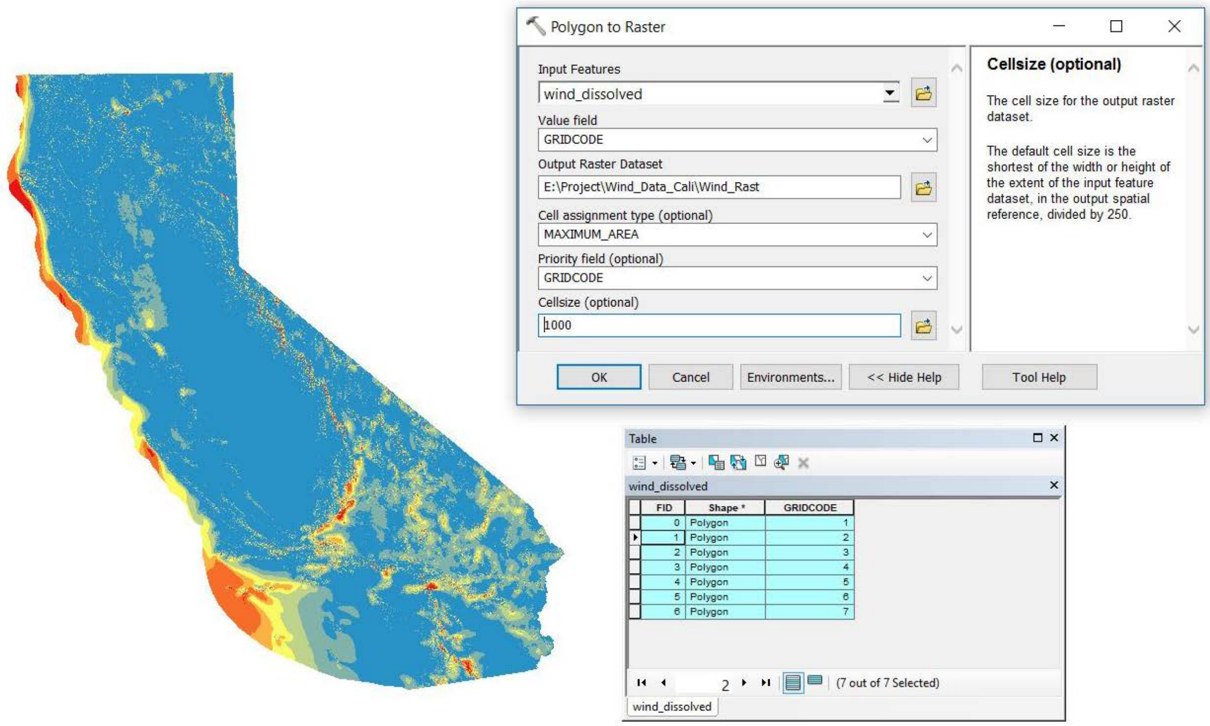


Figure 15. Polygon to raster tool. First, all of the polygons were selected in the original attribute table, and then the value field to convert to raster was set to "GRIDCODE" the raster data corresponds to wind speed in this analysis. The cell size is set to 1000 so that the output raster has a resolution of 1km x 1km (Units for UTM Zone 10N are meters).

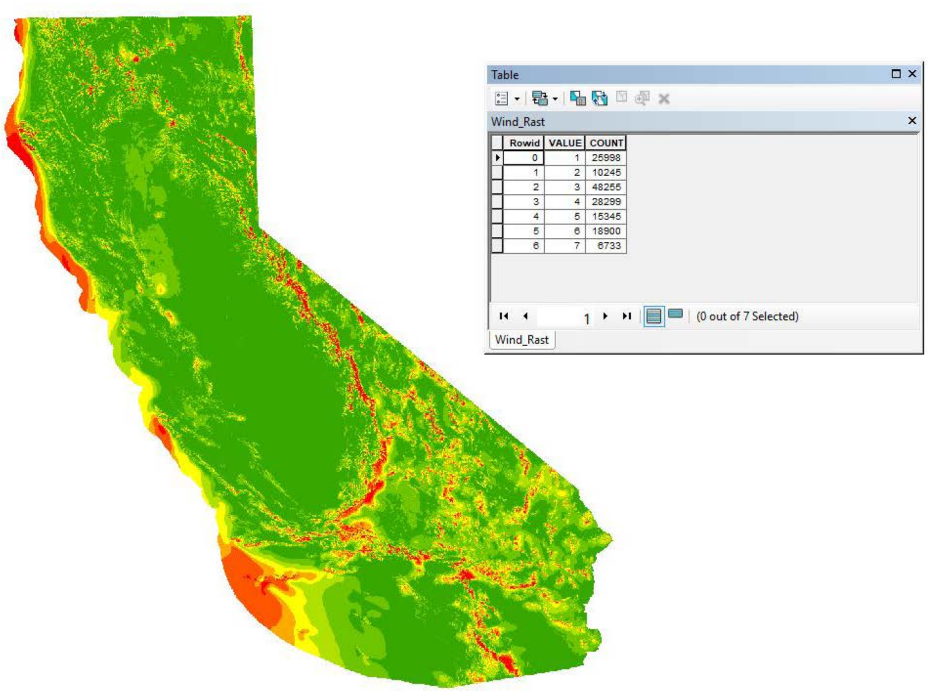


Figure 16. New raster of wind data.

For the buffered datasets, the polygon to raster tool is used to convert data from vector data to raster data.

The same process below is used for the truck network, cities, and electric transmission lines data.

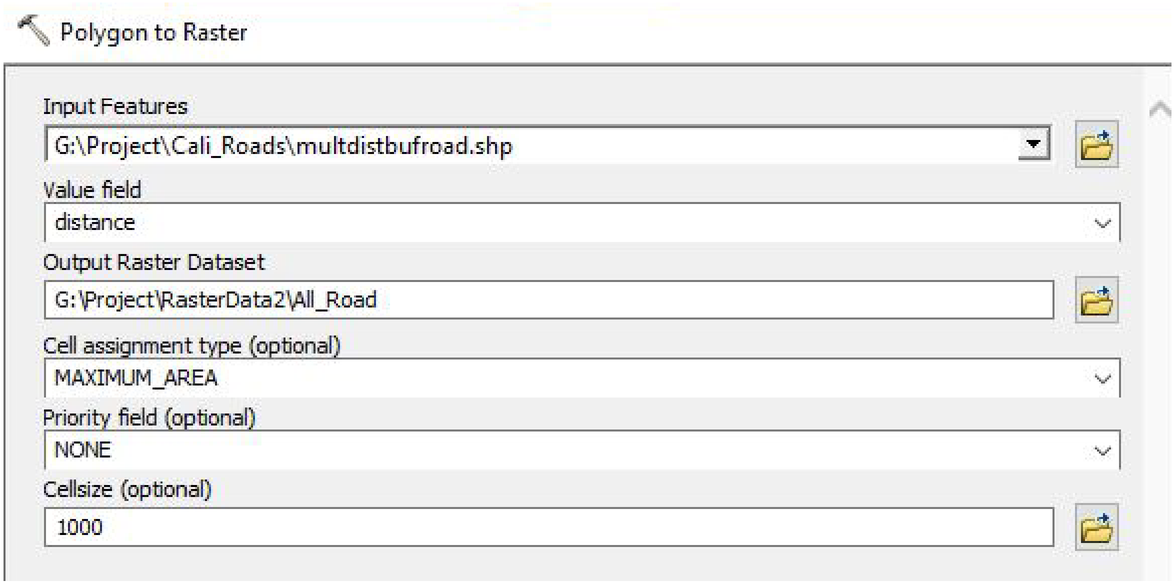


Figure 17. The buffered truck network polygons are converted to raster data. The distance from the original truck network shapefile is saved in the table column "distance".

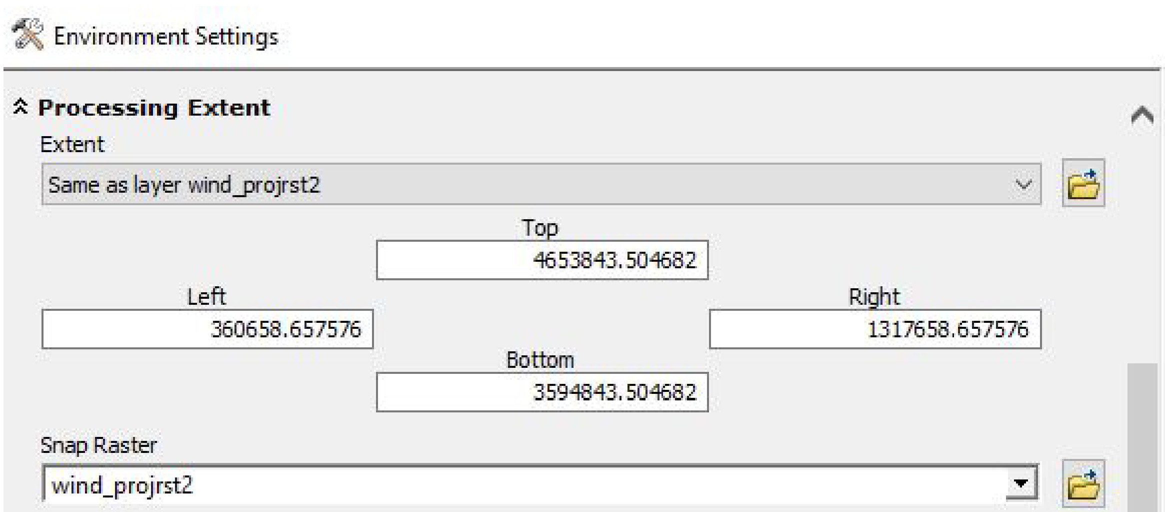


Figure 18. The area extent is set to the wind data coordinates. This ensures that all of the raster data occupies the same extent and can be added together.

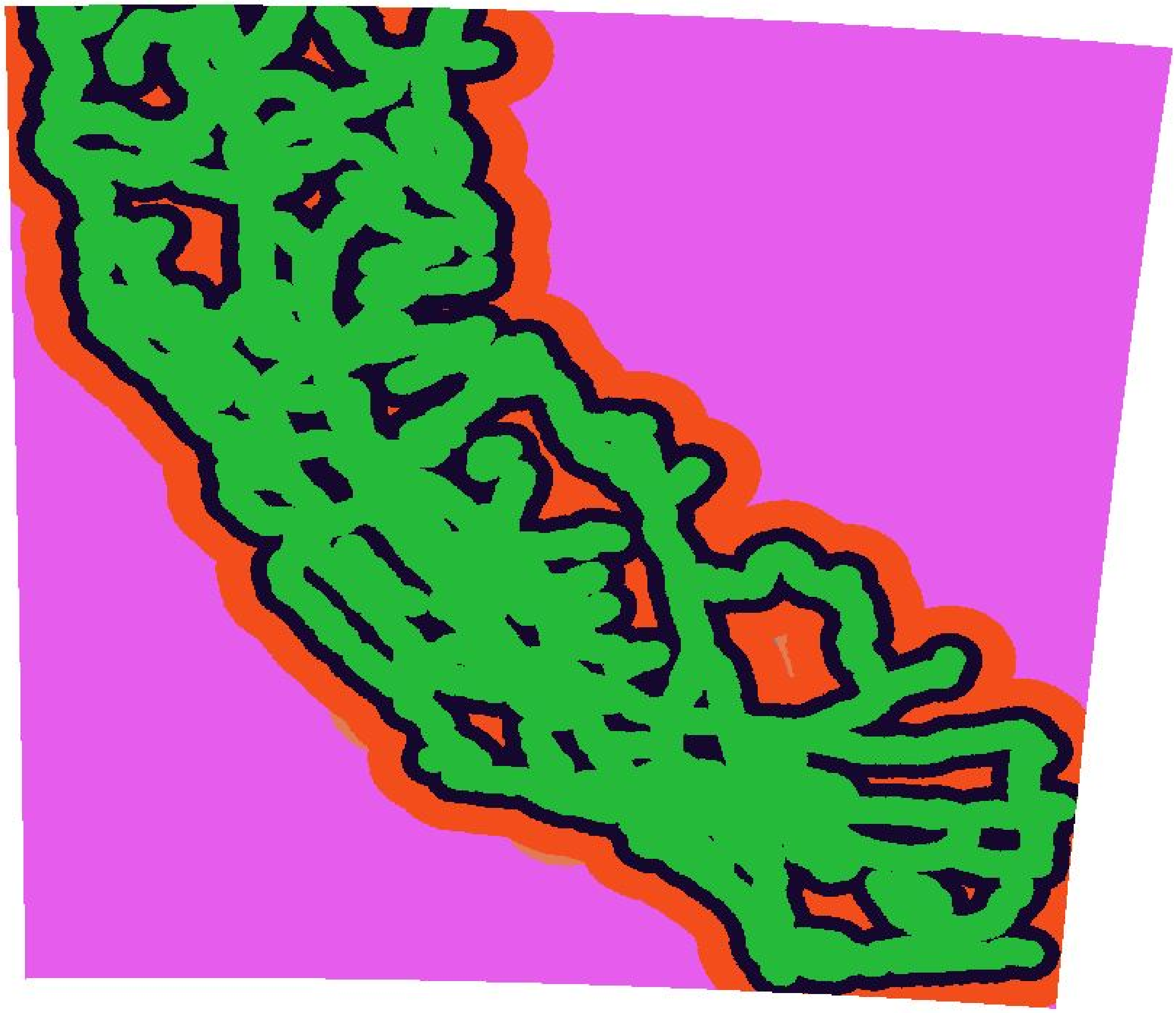


Figure 19. Output of raster Data for the Truck Network. Pink corresponds to “NoData”, orange to 60km distance, black to 30km distance, green to 15km distance.

Data Reclassification

Now that all of the data is in raster format, it needs to be reclassified so that when it is added together, the final results output the most accurate analysis for wind resource potential in California.

The same process was used for electric transmission lines, city, and truck network data.

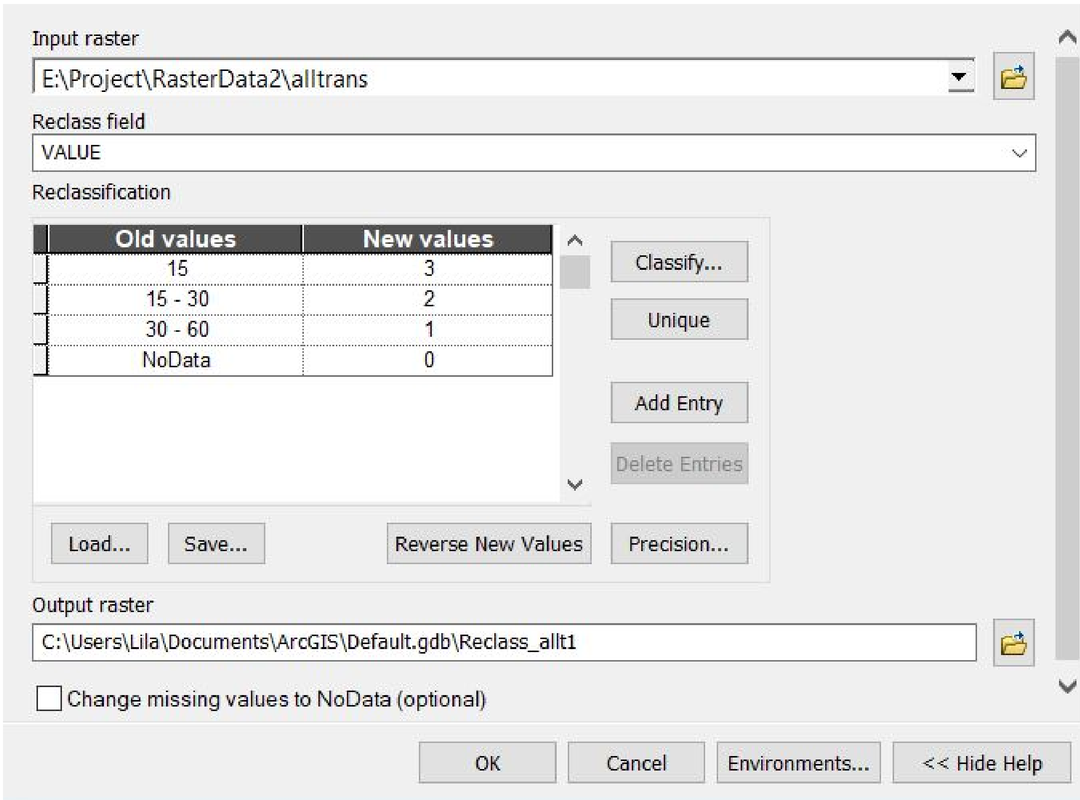


Figure 20. Reclassify tool used to assign new values to distances. The 15km value is ranked the highest, with a weight of 3 because it is the closest distance class from the electric transmission lines. The NoData value must be reclassified to 0 so that the raster layers can be added together. The raster calculator will not include areas of "NoData" in raster calculations so the data must be assigned a value.

Analysis

Raster Calculator

Four factors are included in the raster calculation: wind speed, buffered truck network, buffered electric transmission lines, and buffered cities.

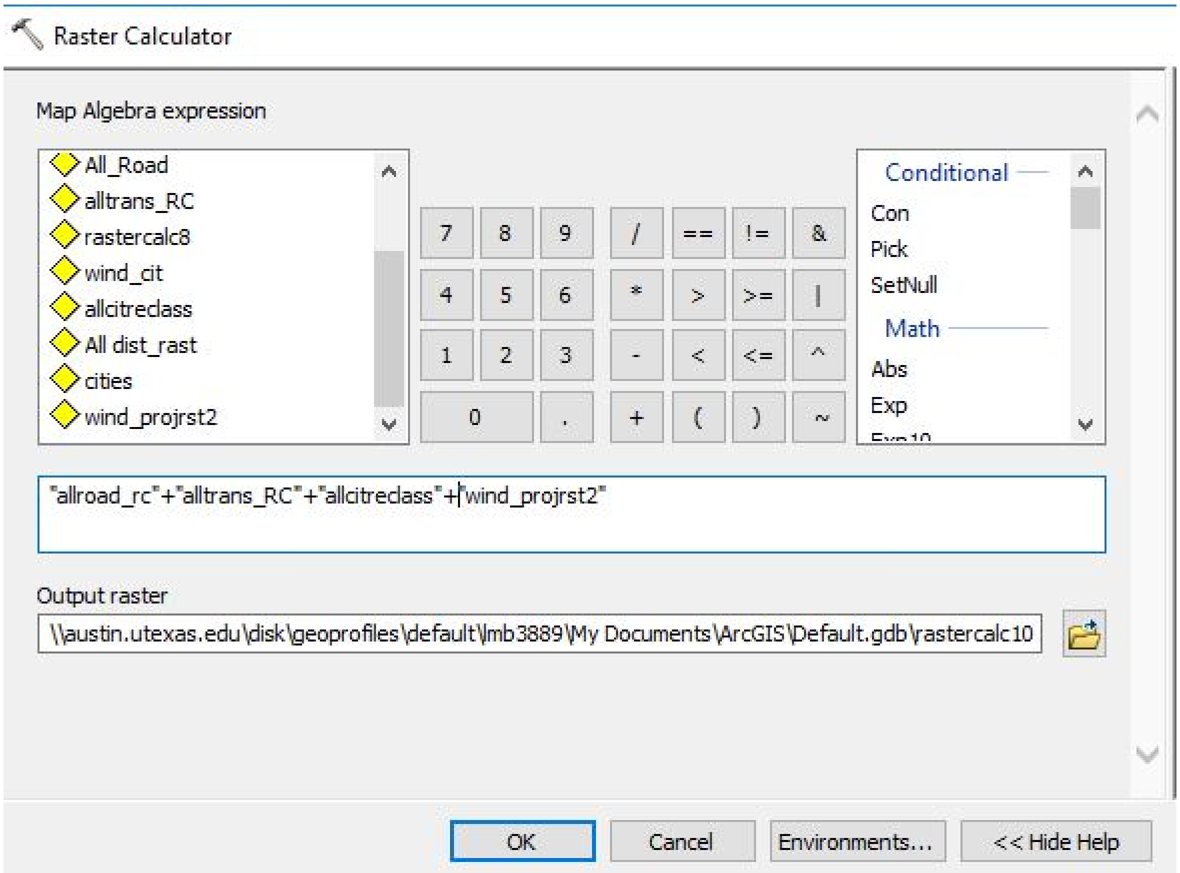


Figure 21. The raster calculation including the four factors contributing to the wind turbine potential heat map.

Clip to State of California

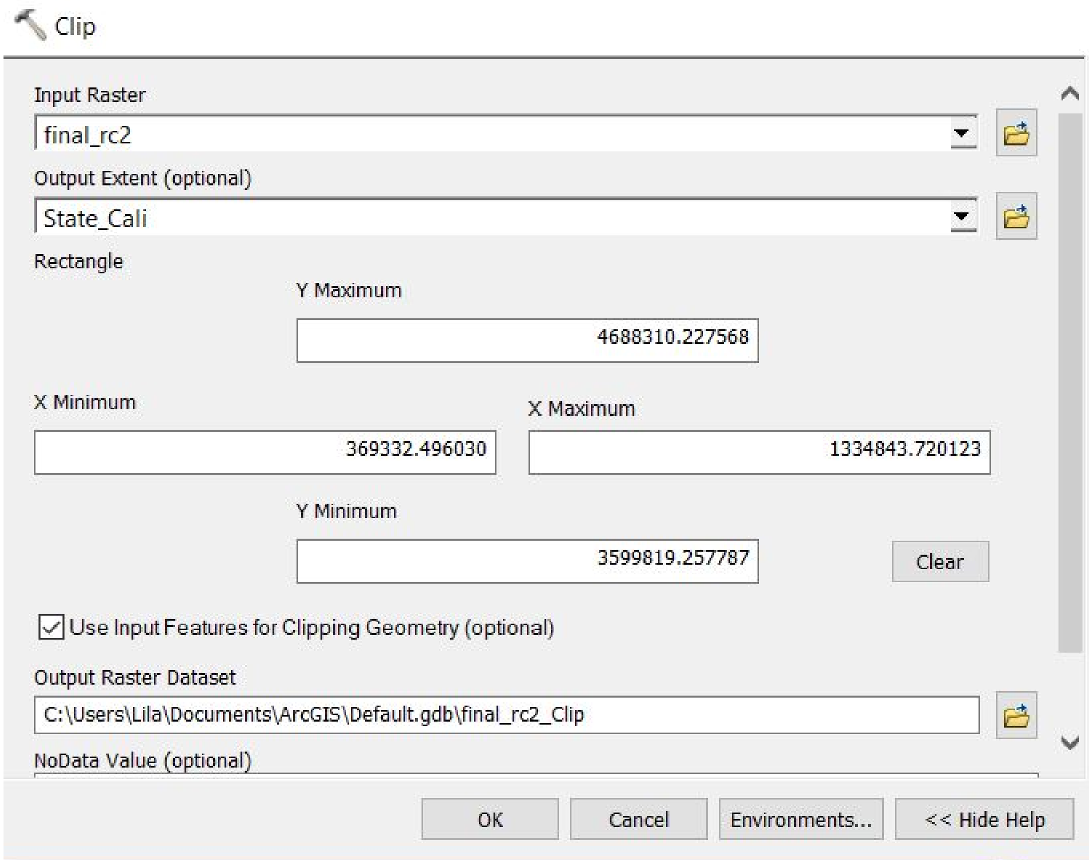


Figure 22. The clip tool is used to make the shape of the raster data the shape of the state of California for display of the final product.

The output is a heat map for potential wind turbine locations for the state of California. To check for accuracy of the locations, the current wind data on wind turbine locations is overlain onto the final raster to check for correlation within the map and the turbine locations.

Correlation of Current Wind Turbine Data with Calculated Heat Map

The wind turbine data correlates well with the heat map produced. Add the cities data on top to know what locations are out of the analysis.

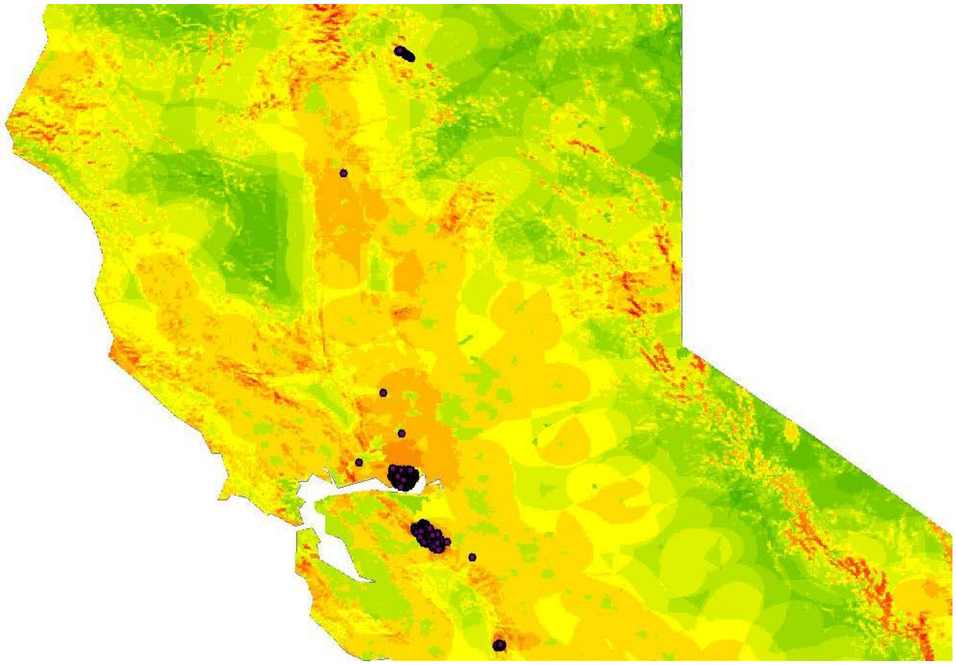


Figure 23. Correlation between wind turbine location and generated heat map of northern portion of California. Orange-red areas contain current

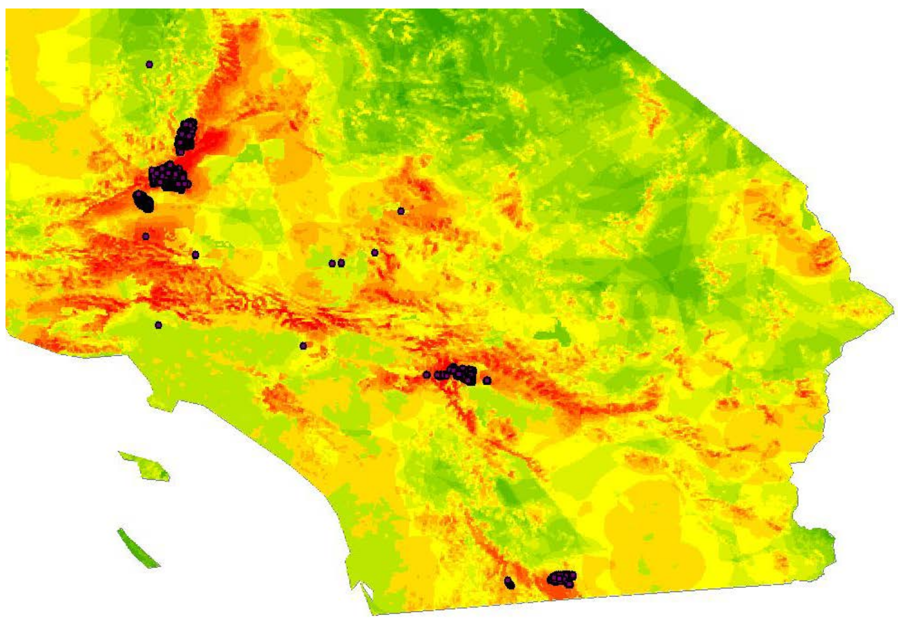


Figure 24. Correlation between wind turbine location and generated heat map of southern portion of California.

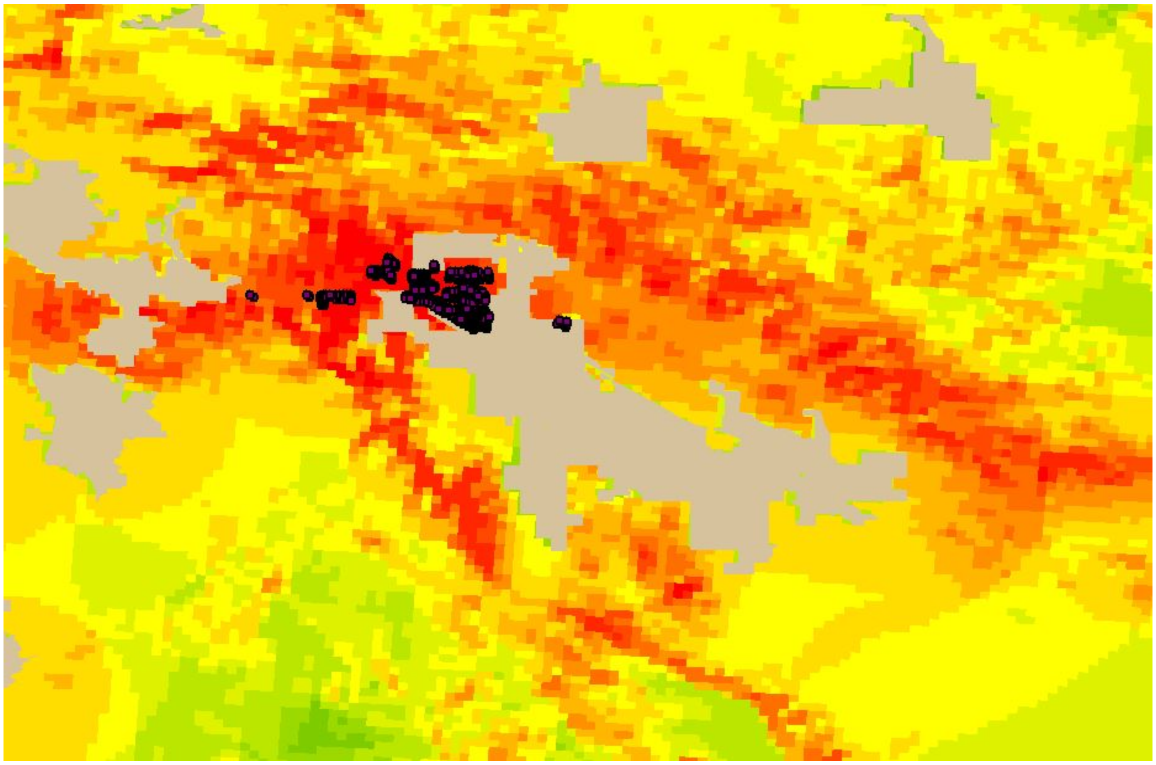


Figure 25. Current wind turbine data illustrates the ideal situation. New wind turbine installments should be in areas where the heat map has the highest value in the area closest to cities.

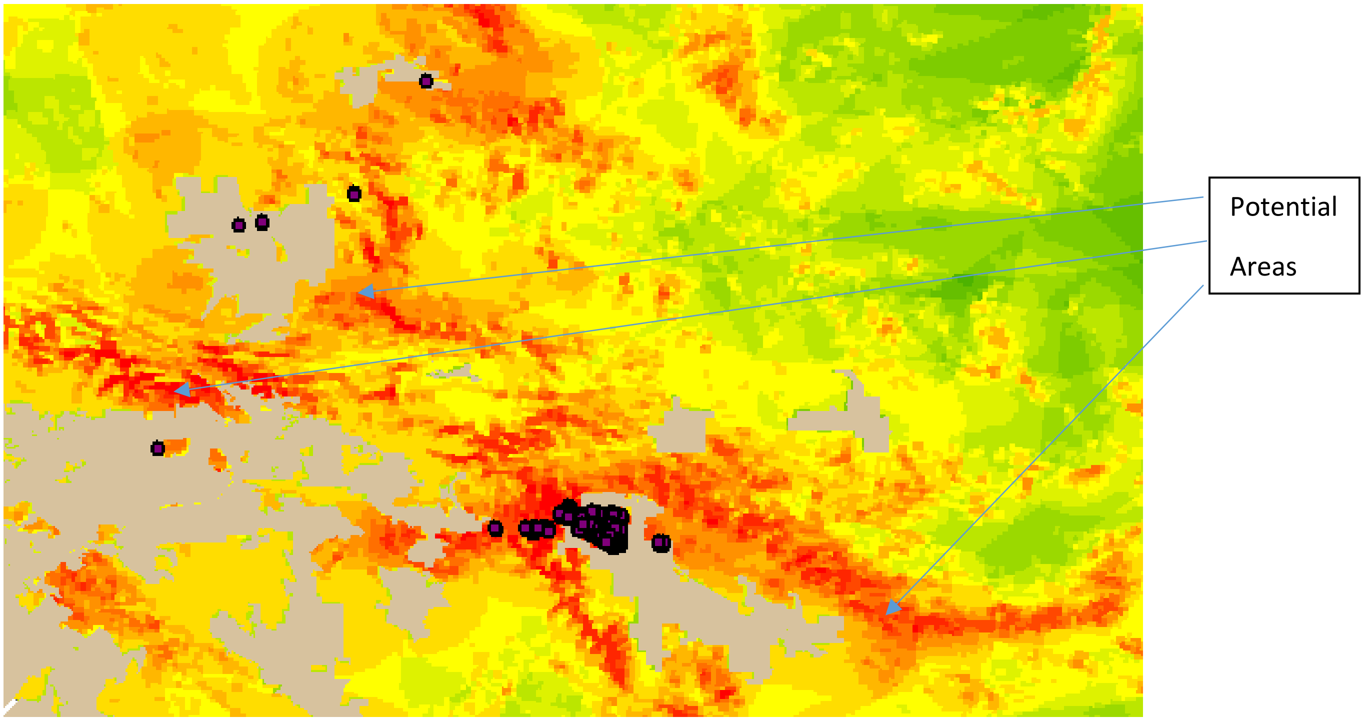


Figure 26. Proposed potential areas for development based off of heat map and characteristics of existing wind turbine locations.

After all rasters are added together, there is potential for values 2-16, 16 being the most suitable and 2 being the least suitable. This data is then categorized with the Reclassify tool into five values: (1) not suitable, (2), poorly suitable, (3) fairly suitable, (4) very suitable, and (5) extremely suitable.

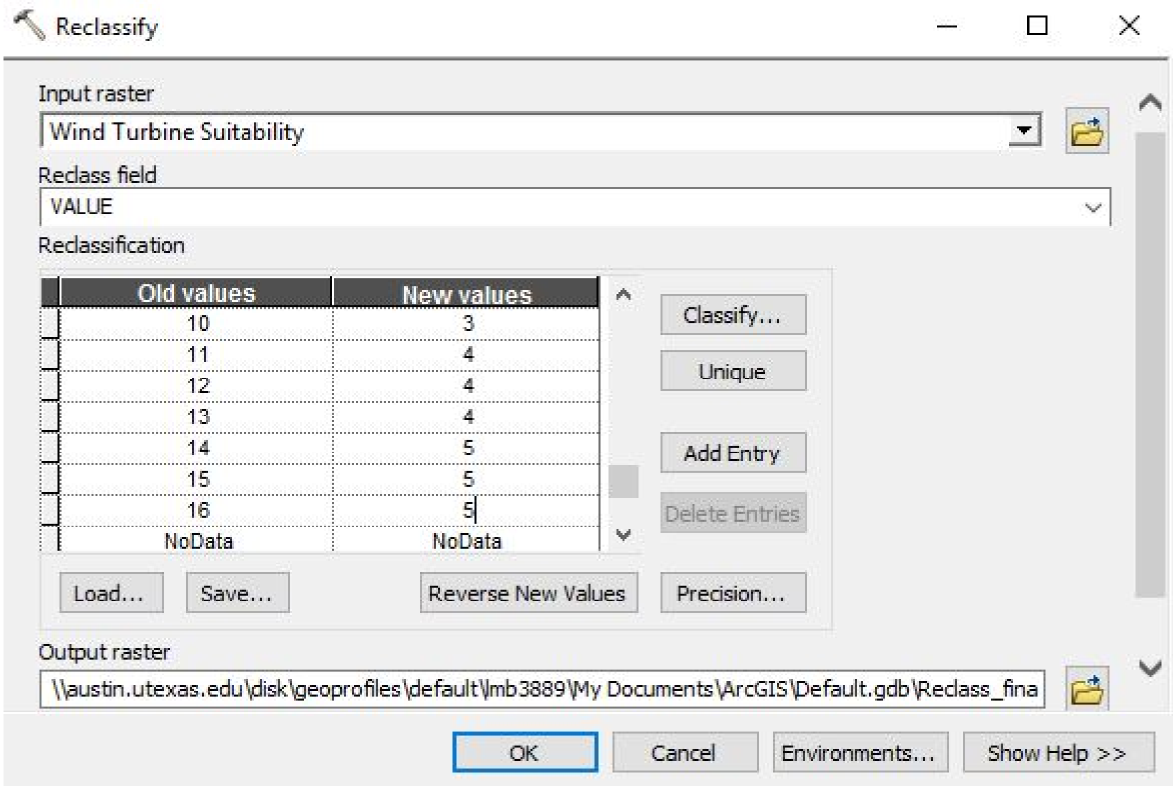


Figure 27. Final raster classification for suitability analysis into five ranks.

Potential areas are chosen based in areas with Very Suitable to Extremely Suitable ranks. The locations are then placed closest to cities as possible to minimize energy lost. In ArcCatalog, a new shapefile is created to hold points for proposed wind turbine localities. One wind farm may contain hundreds of turbines, so these points do not just represent a single turbine but a proposed location for tens- hundreds of turbines. Data is then checked with DEM and hydrogeological data to find the most flatling area near the areas of greatest suitability. The proposed areas are compared to hydrogeological data so that wind turbine propositions are not made in the middle of a river.

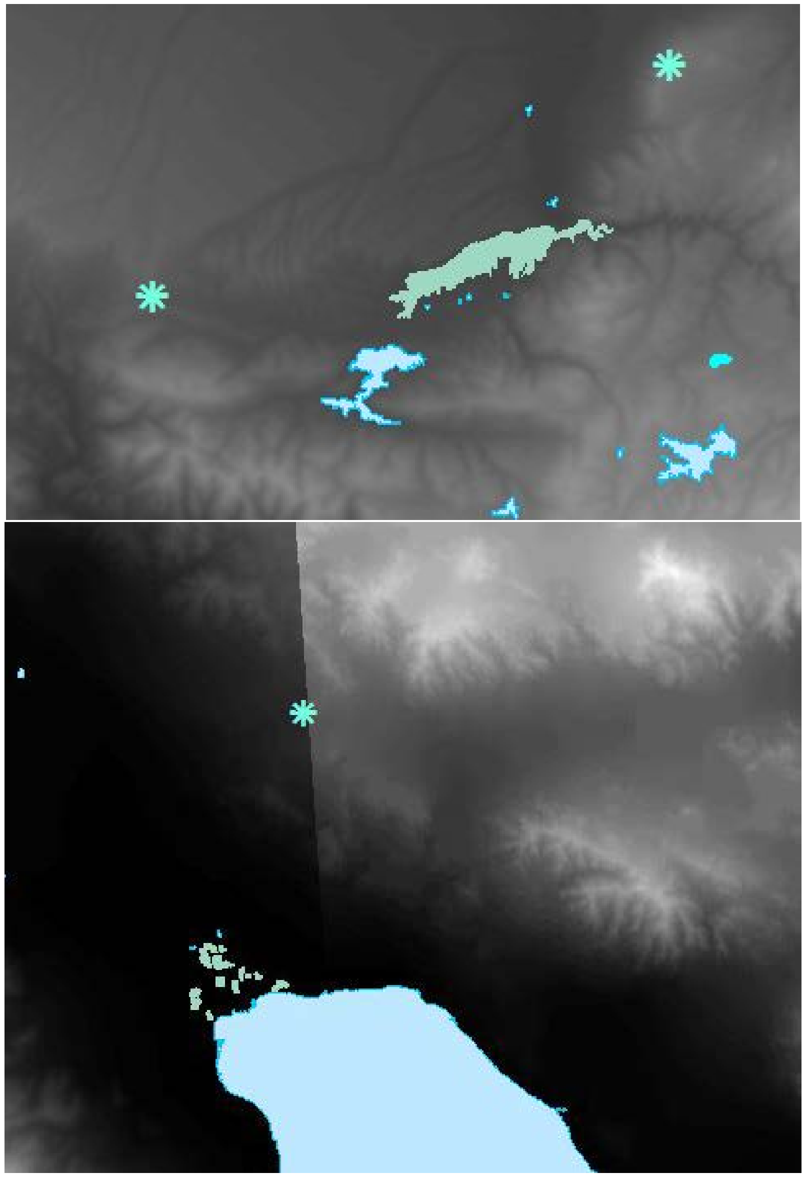


Figure 28. Assessment of wind turbine locations with DEM and hydrologic data.

Conclusion

By superimposing Wind, Transmission Line, Truck Network, and City raster data, a map of suitability analysis for wind resource in California is created. From there, specific sites can be analyzed. Two maps are created for these purposes. The first map gives a large-scale view of wind resource potential for all of California. The second map gives a smaller-scale example of an area that has been compared to hydrological and DEM data to propose specific areas for wind turbine development.

The addition of the transmission, truck, and city data allows to separate the high wind speed areas that are good for development from the areas that would not be as economically feasible. When energy loss in electric transmission is reduced, many other areas in California can be developed, but as of right now not all areas with extremely high wind speed should be developed because of distance from cities and the other infrastructure related factors.

Assessment of Wind Turbine Potential, California, USA

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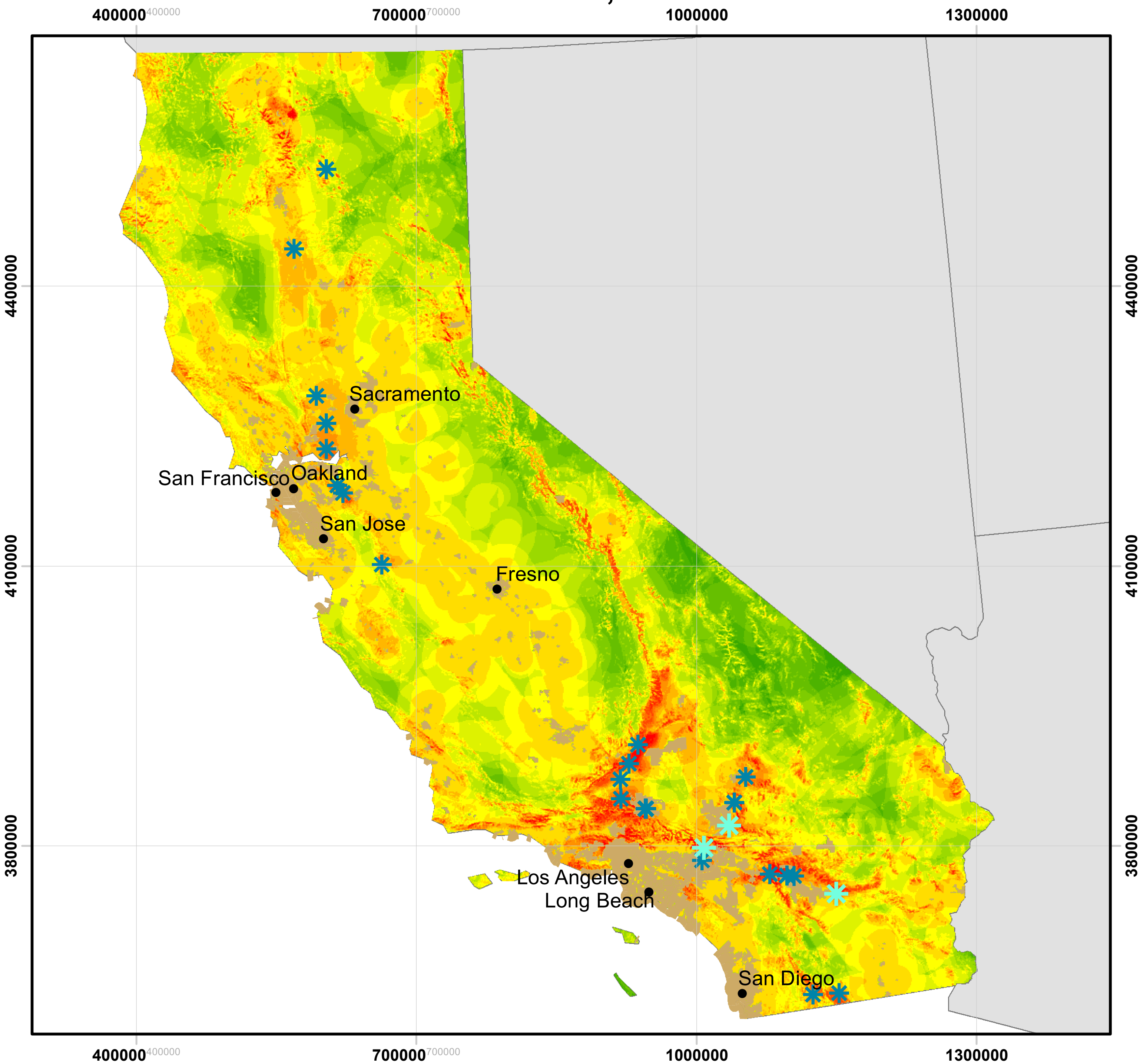
12/7/2017



Explanation

Wind Turbine Suitability

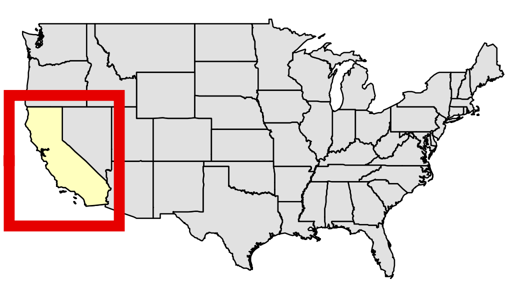
Value

- Not Suitable
- Poorly Suitable
- Fairly Suitable
- Very Suitable
- Extremely Suitable

- Major Cities
- Existing Wind Turbine
- Proposed Wind Turbine
- Urban Areas

1:6,000,000

0 75 150 300
Kilometers



Coordinate System: NAD 1983 UTM Zone 10N

Assessment of Wind Turbine Potential and Proposed Developments, Southern California, USA

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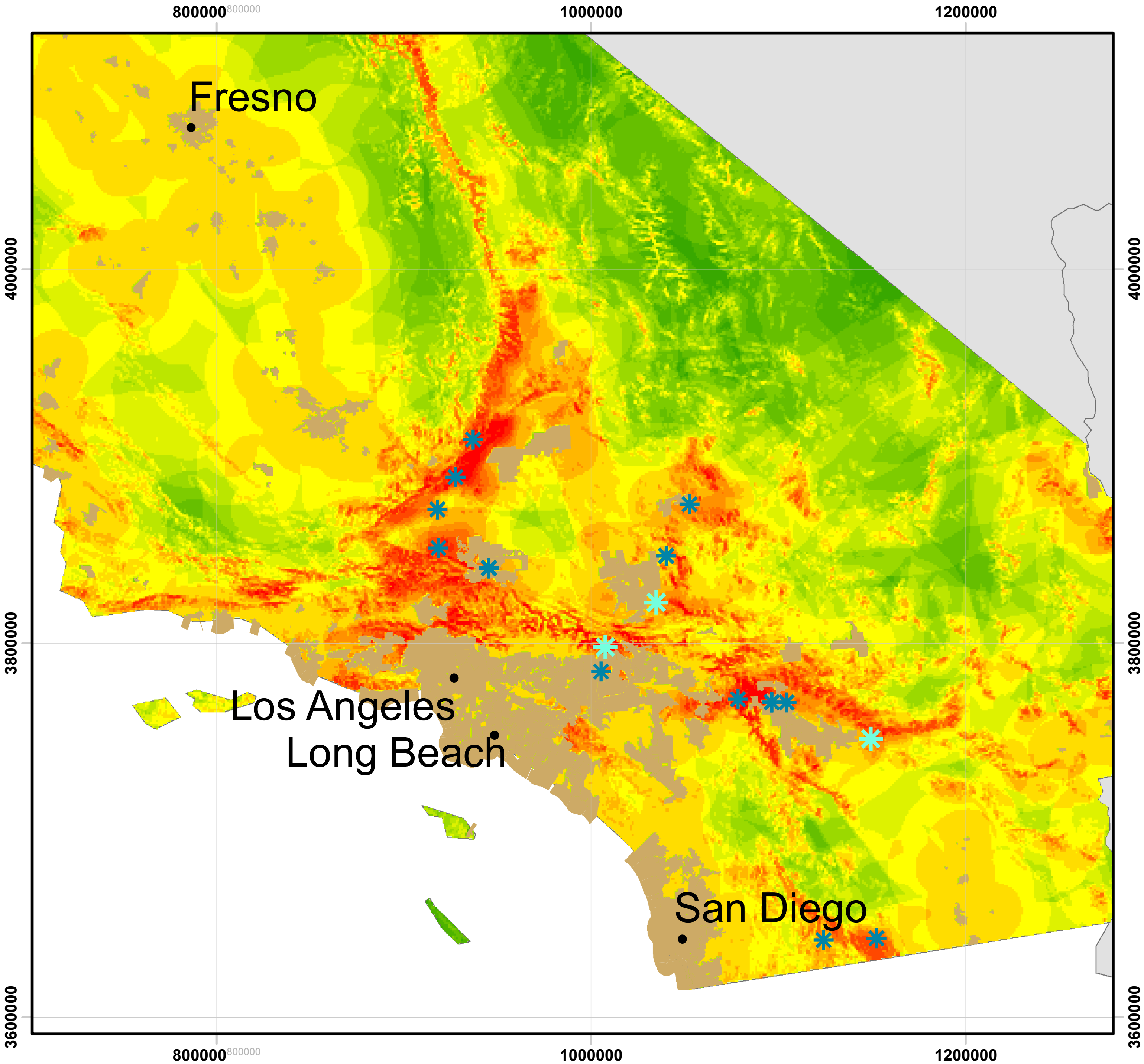
12/7/2017



Explanation

Wind Turbine Suitability

Value

- Not Suitable
- Poorly Suitable
- Fairly Suitable
- Very Suitable
- Extremely Suitable

- Major Cities
- Existing Wind Turbine
- Proposed Wind Turbine
- Urban Areas

1:3,000,000

0 37.5 75 150
Kilometers

Coordinate System: NAD 1983 UTM Zone 10N