University of Redlands

Mojave Desert Ecosystem Program
Solar and Wind Energy Suitability Modeling Tools

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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Abstract

Mojave Desert Ecosystem Program Renewable Energy Suitability Modeling Tools

by
Andrew B. Orr

Interest in renewable energy is growing rapidly and land managers are actively investigating if properties are suitable for development of renewable energy systems in the Mojave Desert region of California. This project focused on photovoltaic solar, concentrating solar, and wind energy as three main renewable energy methods pertaining to the Mojave area. Geographic information systems (GIS) can be used to assess development potential in a specific area. The suitability tools this project produces allow user-defined, feature-importance weighting allocation to data within the model using an ordered weighted average technique. Development of these tools took place in ArcInfo 10 and utilized prebuilt Spatial Analyst tools to process the data. The weighted overlay tool, combined with an exclusion operation, produces a raster file which clearly shows suitable and unsuitable areas using a green, orange, red color scheme, respectively. A comparison of the tool outcome to three, facility locations determined the suitability tools correctly sited potential renewable energy areas of the Mojave Desert.

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List of Acronyms and Definitions

AVSR1	Antelope Valley Solar Ranch One
BLM	Bureau of Land Management
CFCC	Census Feature Class Codes
CSP	Concentrating Solar Power
DEM	Digital Elevation Model
DRECP	Desert Renewable Energy Conservation Plan
FTP	File Transfer Protocol
GIS	Geographic Information System
GW	Gigawatt
MCDA	Multi-Criteria Decision Analysis
MDEP	Mojave Desert Ecosystem Program
MOA	Military Operation Area
MW	Megawatt
PV	Photovoltaic
SEGS	Solar Energy Generating Systems
WLC	Weighted Linear Combination

Chapter 1 – Introduction

Today, interest is rising quickly in the field of alternative energy solutions. Removing dependency on coal and hydrocarbon energy is generally considered a crucial step in maintaining a healthy, clean environment. Scientists, and much of the general public, are showing increasing interest in clean, renewable energy, spurring research into the siting of clean energy and renewable energy locations.

The progression of modern society increases the demand for energy with which humans can power their electrically-dependent lives (Figure 1-1) (United States Department of Energy, Energy Information Administration [US DOE EIA], 2010). This requires innovative new power plants to accommodate changing federal guidelines on emissions. Alternative energy facilities are a solution which satisfies both of these needs. Renewable energy refers to sources of energy which will renew within a useable lifecycle: solar, wind, geothermal, hydroelectric, biomass, and biofuel (Ignizio, 2010). This project pertains to two of these forms of energy; solar: composed of photovoltaic (PV) solar and concentrating solar power (CSP); and wind power.

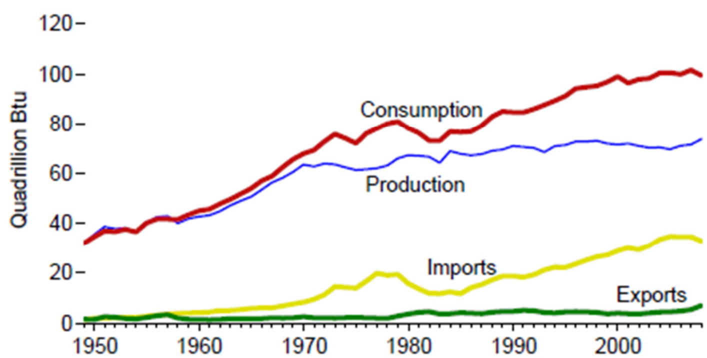

Figure 1-1 U.S. energy consumption: 1950–2009 (from US DOE EIA, 2010).

A dramatic increase in PV solar energy is occurring in the world renewable energy market with high growth forecasted through the future. The 2009 global market share of on-grid PV solar power was 7.3 gigawatts (GW) with a 2014 forecast range of 15.4 - 37GW (Figure 1-2) (Solarbuzz, 2010). This growth is most prevalent in developed countries where government has taken action and offered incentives at regional, commercial, and private levels.

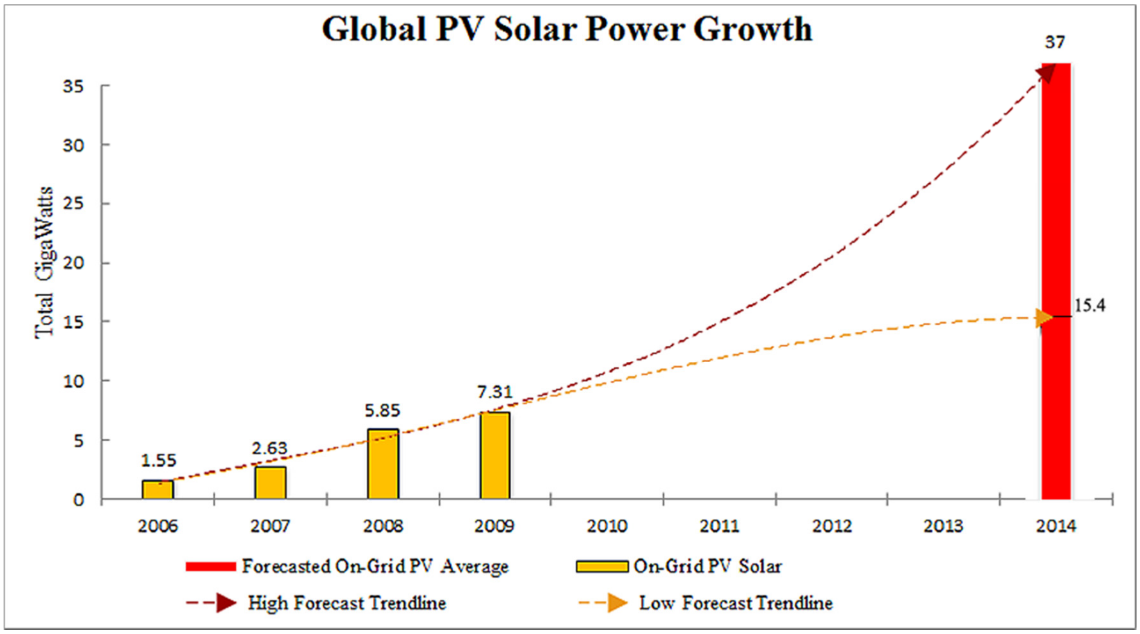

Figure 1-2 Global PV solar power growth (based on Solarbuzz, 2010).

In the last ten years, wind energy installations have multiplied dramatically with 2009 yielding over 158,000 MW of cumulative wind power worldwide. Since 2000, the percent increase of global wind power growth has ranged from 20.8 to 37.4 percent with trends increasing steadily from 2003 onwards (Figure 1-3) (Global Wind Energy Council [GWEC], 2010). Siting new wind farm locations is clearly an important aspect to growth of this magnitude.

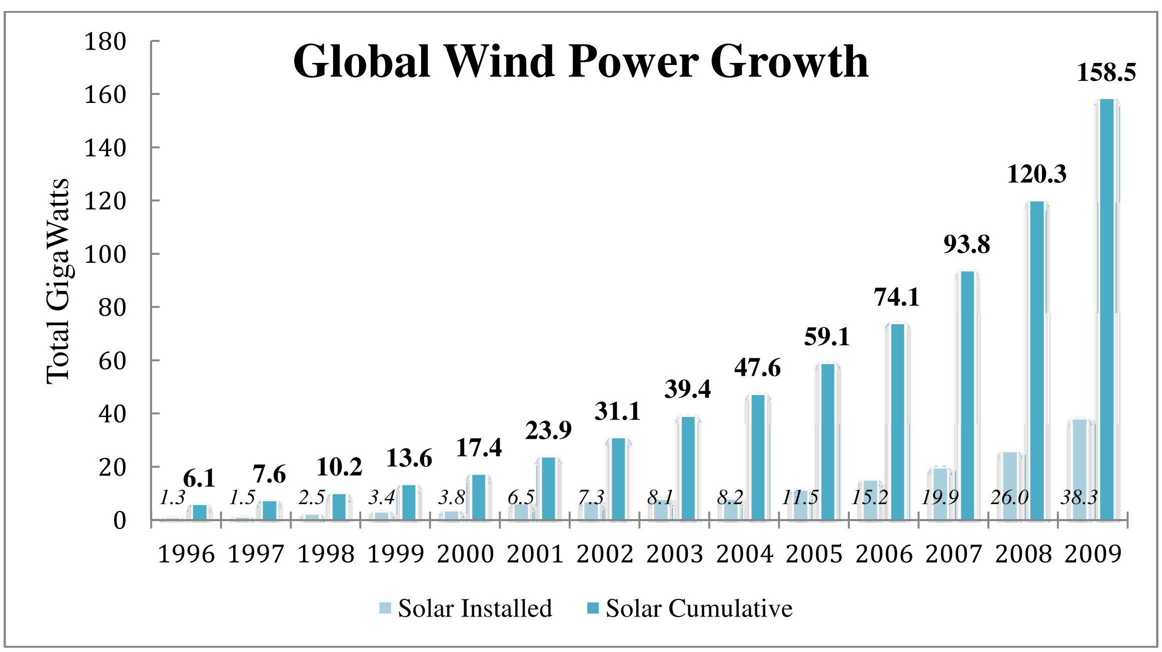

Figure 1-3 Global wind power growth (based on GWEC, 2010).

1.1 Study Area

The Mojave Desert region is a massive expanse of land in southern California that includes 34,700 square miles, with elevations ranging from -273 feet (-83.3 meters) to 14,477 feet (4,412.7 meters) (Figure 1-4). The northern extent of the project area includes the basin and range province of Death Valley, while the southern area has a more scattered array of lower-lying mountainous areas bordering the San Bernardino Mountains. The western boundary of the Mojave Desert project space is a flat plain that makes up much of the military operation areas of Edwards Air Force Base and Naval Air Weapons Station China Lake. The eastern portion of the project expanse is composed of low-lying mountains similar to those of the southern region.

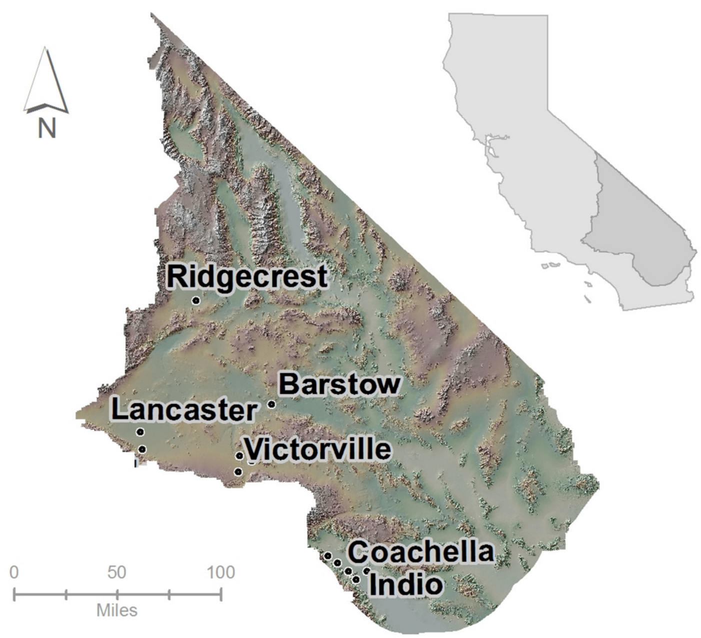

Figure 1-4 Location map of the project area in Southern California.

The federal government, with 18,349 square miles (52%) under their supervision, dominates land ownership of the project region. Private possession is next with 7,116 square miles (20%) and the state of California is responsible for 698 square miles (2%). The expanse of land this project does not consider suitable for siting power facilities – such as wildlife reserves, national parks, and wilderness areas – is 8,538 square miles (26%). The coverage of federal property is mostly Bureau of Land Management (BLM) land with 13,837 square miles (75%) followed by the Department of Defenses with 4,475 square miles (24%). United States Fish and Wildlife, Forest Service, and Native American reservation lands complete the remaining 37 square miles (1%). Desert tortoise habitat extends through much of the project area, covering 7,877 square miles (23%). Figure 1-5 depicts a map of land ownership and the range of desert tortoise habitat.

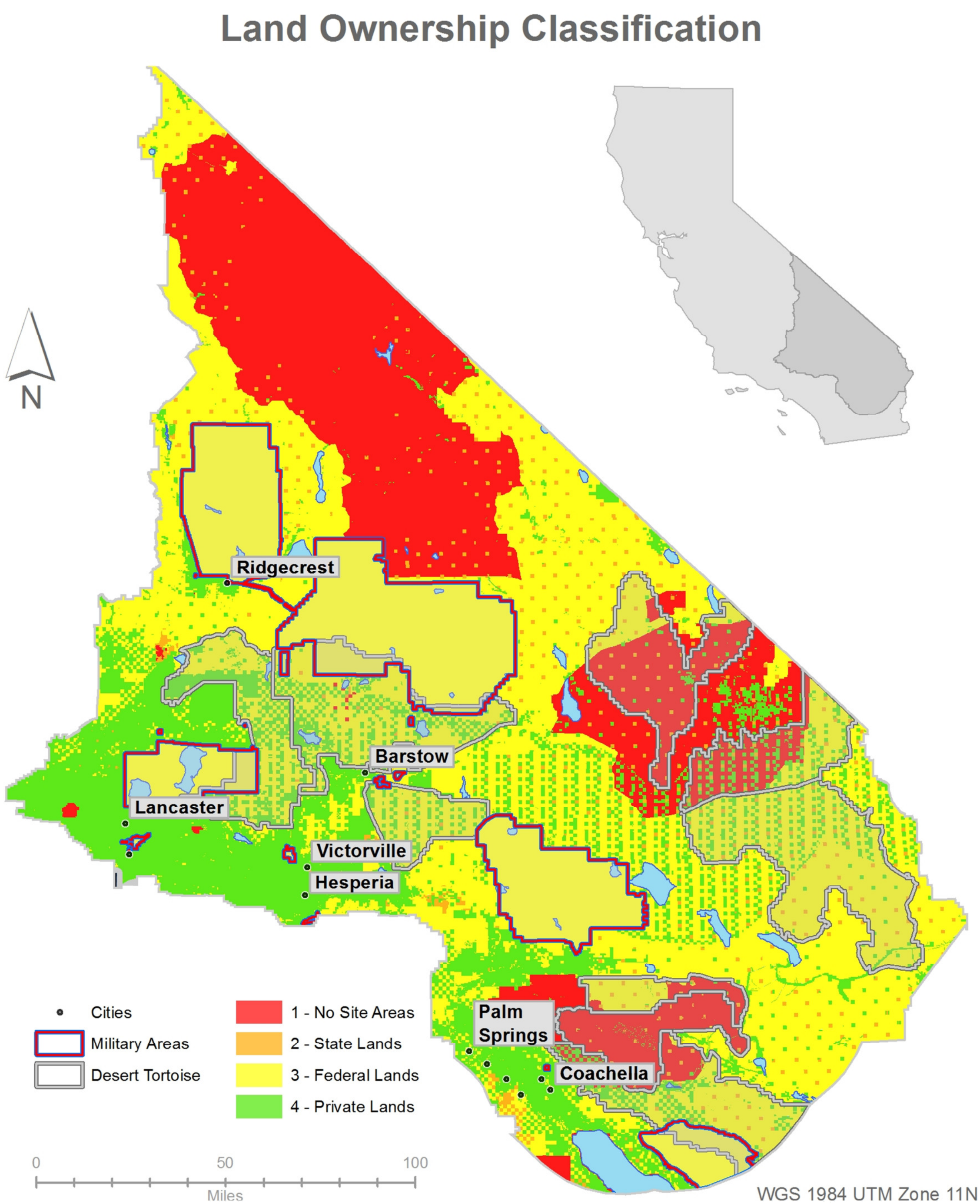

Figure 1-5   Land ownership and desert tortoise habitat.

1.2 Client

The Mojave Desert Ecosystem Program (MDEP), is the geographic information system (GIS) data repository for an 80,000 square mile expanse of land in southeastern California and neighboring states. MDEP is responsible for maintaining the Mojave Desert GIS database for federal, state, and private agencies. Data that MDEP manages include climate, geologic, hydrologic, vegetation, land ownership, road, utility, and various types of aerial imagery (MDEP, n.d.). Ryan Schulz, GIS Analyst of MDEP, is the specific point of contact for this project.

1.3 Problem Statement

With the Mojave Desert being a good location for solar energy collection, land managers are showing accelerating curiosity in developing renewable energy facilities in the region (R. Schulz, personal communication, September 16, 2010). Land managers faced with the challenge of determining if their property is suitable for a renewable energy facility need a tool that will quickly assess their lands for their overall suitability for an alternative energy application.

The MDEP wants to assist land managers in siting development areas for solar and wind facilities in the Mojave Desert region. Because of favorable weather and physical characteristics of the locale, and increased state and federal interest in cleaner energy, finding sites for these energy sources is of interest. This project will provide a tool land managers can use to quickly and easily site a large expanse of land for potential sites of a selected form of renewable energy development.

1.4 Proposed Solution

Determining the best sites for alternative energy facilities can be a very difficult process with many variables. Many of these variables are represented spatially in a GIS geodatabase with vector and raster files. With GIS technology, one can input all of these raster layers into a database and weight each variable independently based on a user's notion of importance. After running a suitability tool, the computer creates a file which shows the most suitable locations. This methodology is an ordered weighted average (OWA) (Mahini et al., 2006).

Using an OWA method allows a maximum amount of flexibility in the tool design without being mathematically complex. A user chooses the data layers they wish to use in the model, chooses weighted values based on feature importance, and then allocates a value of classification for each sub feature. ArcGIS 10 has a tool included with the Spatial Analyst extension which does an analysis as described above. The weighted overlay tool provides a set of mathematical operations which aids in the selection process of a given resource by inputting various raster layers and performing a set of mathematical operations on the individual raster cells (Tomlinson, 2007).

Data collection is the first step for building a renewable energy suitability model. Table 1-1 contains the factors used in each of the three tools. In the case of this project, all data is in vector format, excluding the project area digital elevation model (DEM). In order to do a weighted overlay operation, all vector data had to be converted to raster format.

Table 1-1 Feature layers used in analysis.

Common Variables	Solar Variables
Slope	Insolation
Land ownership	Proximity to rivers (CSP tool only)
Proximity to roads	
Proximity to transmission lines	**Wind Variables**
Desert tortoise habitat	Elevation
Wind speed	Military airspace restrictions
Do not site area	

A significant portion of this project was developing the data conversion tools required for achieving a vector to raster transformation which allows for nearly any shapefile or feature class as user-supplied data to be used in the tools with the assumption it is within the guidelines specified with the tool help for each tool. Raster files require a common cell dimension for weighted overlay operations and this is matched with the original project DEM.

1.4.1 Goals and Objectives

The primary goal of this project is to produce a functional set of renewable energy suitability tools which will allow a weighted set of data sets to be combined together and produce a suitability raster which can be used by land managers' for planning of solar and wind energy facilities. These tools will reside in an ArcGIS toolbox which allows the operator to choose which tool to use for analysis.

The tool has three customization functionalities: choice of feature, feature weighted parameters, and individual feature classification priority levels. Three levels of customization improve the accuracy and complete customization of the tools in a way not possible with a fixed analysis and hard-coded values.

A choice of which features to use in the site selection process was one of the critical tool attributes the client was most interested in. Through personal communication, Schulz emphasized the tool should be able to accept data that an individual wishes to use by their own interest—wind data, for example (R. Schulz, personal communication, January 24, 2011). If a land manager has his own wind dataset and wishes to use the tool with this data, a feature must exist which will allow for this.

Feature weighted parameters is an option given to the land manager which allows a specification of which features are given a more significant priority, as a whole, to the set of considered features. For a wind site-selection process, one may consider land ownership, wind speed, and proximity to existing roads. These three factors are not equally important and a method must be used to reflect the differing importance. Choosing a percent influence is one method of dealing with this issue. Land ownership receives 40 percent priority, wind speed 35 percent priority, and proximity to roads the remaining 25 percent priority.

Various categorization levels exist in each data feature. In a land ownership feature class, these may represent data such as private, state, and federal land. While land ownership, as a whole, is weighted in the model as 40 percent priority, the user does not want state land as heavily considered as private land. One may choose to select a scale which represents these sub-criteria more specifically—perhaps one through nine: nine being the most important value, five a moderate value, and one being the lowest.

The end result of the suitability tools is a raster file which clearly and concisely defines areas that are highly suitable for a solar or wind energy facility. A unique color scheme is the key to producing an easy-to-read results file. The tool results display in a red/green color scheme with green equating suitable and red unsuitable.

Tool performance remained a priority in the development of this tool. While out of the immediate project scope, the ultimate idea of the client was to create an online, website-based map which can access the tool and perform an analysis at home. Speed is clearly a priority for consideration when porting the tool to an online geoprocessing environment. Within the map scale range of 1:100,000 to 1:250,000 (extent view of 24,000 meters to 18,000 meters to 60,000 meters to 45,000 meters respectively) that the tools are optimized for, a goal was set to keep the geoprocessing times under 30 seconds.

1.4.2 Scope

The original project scope required development of a set of renewable energy suitability tools for wind, solar, geothermal, and hydroelectric energy. These tools would be implemented into an online GIS map as a geoprocess which can be accessed from home by land managers in the Mojave Desert region. Upon careful investigation of what this would entail, conversations ensued which restricted the project to two main fields of renewable energy (solar and wind) and the removal of the online map interface. This allowed the majority of time to be spent optimizing the solar and wind energy tools and calibrating them to a state of accuracy needed for site selections.

Within the Spatial Analysis toolbox extension of ArcGIS 10, a tool exists which allows users to complete a weighted overlay operation for site suitability selection. This weighted overlay tool is generic in functionality and not optimized for use in a renewable energy siting assessment. This project took the generic tool and created a set of three tools for optimizations in PV and CSP solar energy, and wind energy. These tools were built within the Model Builder feature of ArcInfo 10. Model Builder was the platform chosen for the client for ease of tool customization as it provides an easy to interpret interface of the tool processes without the knowledge of the Python scripting language.

The nature of weighted overlay tool requests data to be in a specific format. For this, a set of preparation tools were created which take existing vector data and transform it into a set of reclassified raster files.

The project deliverables consisted of a geodatabase with the required data; original vector format, reclassified raster format, and the preparation and suitability tools created in the project. Additionally, a demonstration video that shows how the tool performs was expected. This video consisted of two parts which show the basic quick start guide and a more advanced, how-to guide for a more thorough understanding of working with the data preparation and suitability tools.

1.4.3 Methods

Planning of the development of a suitability assessment tool began with a careful background search of the factors used in a site selection process. Background research on solar and wind energy was critical in determining the site selection criteria. A description of site selection conditions appears in Section 2.2.

Geographic information systems (GIS) display data with spatial attributes which allows for data analyses. Once organized in a GIS, data can be edited, analyzed, and optimized for use in suitability assessments, but not without guidance from a human operator (Vlado, 2002).

The software of choice for this project was ArcInfo 10 with service pack 1.0 installed. Additionally, the Spatial Analysis extension was enabled as the various tools require heavy use of the Spatial Analysis toolbox. ArcInfo 10 was selected as the software for tool development to meet the client requirement the tool perform in ArcInfo 10 with no restrictions on use of extensions. With the client's access to ArcGIS Server, a transition from a toolbox tool to a website-based geoprocess will be straightforward in a future phase of the project.

After a list of feature layers was compiled, a thorough understanding of the data was required. This entailed reading and understanding all available metadata and feature attribute headings. Since the reclassification data process began with the selection of a single attribute to classify data from, it was necessary to pick the attribute field which most closely represented the data to classify. In the case of the land ownership feature class, this was not an existing attribute field and consequentially one was created which housed the weighted overlay reclassification codes (see Appendix A).

Once the data is clearly understood the user could create a set of conversion tools to transform vector into raster data. The basics of this operation were performed using the feature to raster tool in the Spatial Analyst extension. As required, a reclassification operation could then follow which gathers the data into integer format for the weighted overlay tool. Because each source of vector data is diverse, the methods used differed from feature to feature. However, the underlying methodology remained the same.

The suitability tools consisted of two main operations: a weighted overlay and an exclusion operation. When used in conjunction with one another, these operations provide the flexibility and graduation of site selections offered by a weighted overlay, with the true or false site selection options offered by an exclusion operation. This combination, in this application, was perfect for merging continuous data with discrete data. Performing an analysis with continuous data such as slope, or distance to nearest feature, is best used with a weighted overlay operation. Consequently, a location siting contained within a wilderness boundary was not feasible for a building site so a no-siting layer provided the exclusion operation that removes these regions.

Tool testing was chiefly done through comparative analysis of actual solar or wind facilities to the results the tool predicts (Chapter 6). In some cases, the facilities are currently undergoing construction and these are treated the same as facilities in operation since the location and siting criteria are valid and set.

1.5 Audience

The audience for this report has a solid understanding of GIS and the terms utilized by Esri in their software documentation. While not intended to be terminology-intensive, this report does use vocabulary people with little or no background in GIS will have a difficult time understanding. People with a basic understanding of renewable energy systems will be able to grasp the concepts and terminology without difficulty in this paper.

1.6 Overview of the Rest of this Report

The remainder of this report is divided into six chapters. Chapter 2 contains a literature review with two focuses: the various types of suitability modeling and a brief discussion of renewable energy terminology and siting criteria. A systems analysis and design discussion is the focus of Chapter 3, which describes how this project fulfilled the client's project requirements. A descriptive database design section is found in Chapter 4, which discusses the data design models and the methods used to prepare data for analysis. This chapter also gives a thorough description of the required data attributes that the various preparation tools need in order to function properly.

Chapter 5 details implementation, with a comprehensive methodology of what work was performed and in a context in which a GIS operator will be able to replicate the work. Results are discussed in Chapter 6. Finally, future work and project conclusions are discussed in Chapter 7.

Chapter 2 – Background and Literature Review

The methodology of using a computer system to choose the best locations to build a facility is not new. In fact, one report by Malczewski (2006) refers to more than 300 published articles on location siting using computer-based strategies from 1990 through 2004. Suitability modeling approaches fall into three different techniques and methodologies: some are more objective and mathematically advanced; others more subjectively involved.

Siting future renewable energy facilities is a time- and resource-intensive process. Having a preliminary tool which assesses large land expanses is desirable to limit areas which are not favorable to the energy system of interest. This is where creating suitability tools fit in – for land managers who want to look at a large plot of land and assess the desirability of the location for either photovoltaic (PV), concentrating solar power (CSP), or wind energy solutions. A tool that is customizable for these queries is desirable so one can assess the different attributes of an area and determine why the location is favorable for one set of criteria but not another.

This chapter consists of: a review of literature pertaining to Suitability Methods (2.1) and Suitability Criteria (2.2).

2.1 Suitability Methods

Preliminary location planning is aided with a multitude of different data sources in a process known as multi-criteria decision analysis (MCDA). At present, there are several methods for MCDA. One uses Boolean operations to evaluate criteria using union and intersection (Eastman, 2001). Another approach, described by Mahini and Gholamalifard, (2006) is ordered weighted average (OWA) and is a method utilizing tradeoffs and risks involved in the suitability modeling process. This process uses two weights applied to the features: a combination of a feature weight and a feature classification weight. A third procedure for suitability modeling in GIS, weighted linear combination (WLC), uses one weighting class which allows the operator to quickly assign a weighted value of importance, be it negative or positive, to raster data sets, and compute an output raster which displays the best-fit location for the renewable energy source.

There are some variations in the nomenclature for published methodologies of suitability modeling. Malczewski (2006) concluded that weighted summation was the predominant style of site suitability modeling. He summarized the classification of 363 articles and concluded 143 (39.3%) used a combination of WLC and Boolean overlay. This far exceeded the sequentially most common method of using multi-objectives programming algorithms (57 articles, 15.7%).

GIS has proven capable of site suitability modeling numerous times. For example, Al-Shalabi, Mansor, Ahmed, and Shiriff (2006) described a successful attempt to use a computer-based MCDM GIS model and an established, pre-computer method for the selection of a housing project. Al-Shalabi et al. described two steps involved in the initial project evaluation:

> "(1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives" (2006, pg. 4-5).

Al-Shalabi et al. discussed the issue of determining the weighted values associated with the spatial datasets used in a MCDA model. He used an approach first mentioned by Saaty (1980) which uses analytic hierarchy process (AHP) to compare the spatial variables with one another and establish the trade-offs associated with each.

Ignizio (2010) compares GIS-cited locations using a WLC model to real-world solar energy plants. He analyzed two types of solar power: photovoltaic and concentrating solar. Ignizio's findings indicated that using GIS to discern locations for solar energy is possible for photovoltaic siting with his model. Concentrating solar locations did not compare as closely and he believed defining two separate suitability models will help increase the accuracy of GIS to real-world location mapping. This multi-tool solar energy suitability approach conclusion is considered and developed in this project by developing separate suitability tools for both solar facility styles.

It is also interesting to note the form of data types used in historical examples of GIS suitability modeling. Malczewski (2006) summarized the predominant format of data for 319 papers and determined 152 (47.6%) used raster data, 150 (47.0%) used vector data, and 17 (5.4%) did not publish the data model. While some of the articles used multiple data types, it is important to note that the methods of suitability modeling may help to determine the base format for data.

2.2 Suitability Criteria

All considerations in the suitability modeling criteria of this project are reflections of others' work. The goal of this project was to create the GIS tools to aide in criteria specified by the user. The default values of the tools are a reflection of the criteria identified by the literature review.

2.2.1 Solar Energy

Solar energy can be divided into two main methods of energy collection: photovoltaic (PV) and concentrating solar power (CSP). While similar in that they both use sunlight as an energy form to generate power, the methodology between the two systems differs.

PV solar electricity conversion takes place by a process of solar radiation, in the form of photons, running through a semiconductor which in turn generates a direct current of electricity (Soga, 2006). Figure 2-1 is a photograph of the photovoltaic solar array at Nellis Air Force Base in Nevada. While clean in the sense of a lack of pollutants formed with the generation of electricity from solar energy, photovoltaic panels do have a useful life of approximately 30 years at which time recycling must take place (Fthenakis, 2000).

Figure 2-1 Nellis AFB photovoltaic solar facility (from Brighthub, 2011).

Alternatively, CSP systems generate electricity by means of two systems: a transfer of heat to steam and a conversion of steam into electrical power. The first part of a CSP system utilizes a solar concentrating array in the form of heliostats, parabolic dishes, or a line of mirrored troughs. Each of these systems collects the concentrated solar energy into a heated medium which then goes through a conversion of heat into electricity through means of a mechanical process. Heliostats aim the concentrated solar energy into a main tower which converts a liquid heat medium into a gas and then turns a turbine (Figure 2-2).

Figure 2-2 Ivanpah CSP facility (from BrightSource Energy, 2010).

Parabolic mirrors use a closed system Stirling engine with a heat medium of helium or hydrogen, typically. The trough method utilizes a channel line of mirrors which direct sunlight onto a central pipe that contains water. This forms steam which runs an electrical turbine (Masters, 2004). Among the CSP technologies, the dish-Stirling system is the most efficient, with a record set in New Mexico of 31.25% net efficiency in 2008 (United States Department of Energy Sandia National Laboratories, 2008).

The criteria used as a basis for feature layers in the solar suitability tools is from reports by various sources: the Bureau of Land Management (United States Department of Interior, Bureau of Land Management [US DOI BLM], 2003), Drew Ignizio (2010), and Black and Veatch Corporation (2005). Table 2-1 summarizes the criteria with preferred value ranges for PV systems:

Table 2-1 Preferred range of siting criteria for PV solar power.

Feature Layer	Preferred Range
Solar insolation	> 6750 $Wh/m^2/day$ (Ignizio, 2010).
Land ownership	Depends on application.
Slope	< 3% optimal (Carrion et al., 2007).
Proximity to electrical lines	Within 50 miles (DOI BLM, 2003).
Proximity to existing roads	Within 50 miles (DOI BLM, 2003).
Wind	Preferred low-wind areas.

Concentrating solar power adapts a similar guideline as photovoltaic solar conditions with the addition of a proximity to rivers feature layer (Table 2-2).

Table 2-2 Preferred range of siting criteria for CSP solar power.

Feature Layer	Preferred Range
Solar insolation	> 6750 Wh/m^2/day (Ignizio2010).
Land ownership	Depends on application.
Slope	< 2% optimal (Carrion et al., 2007).
Proximity to electrical lines	Within 50 miles (DOI BLM, 2003).
Proximity to existing roads	Within 50 miles (DOI BLM, 2003).
Proximity to rivers	"Water resources must be available" (DOI BLM, 2003).
Wind	Preferred low-wind areas, average wind speed < 10 miles per hour (DOI BLM, 2003).

Given the project location in the Mojave Desert, a factor that may be of concern to some readers is the proximity of solar facilities to military operation areas (MOA) with the risk of sonic booms breaking or disrupting solar panel arrays. Siegel (2008) discussed that this is not true and mentioned a conversation with officials from Solar Energy Generating Systems (SEGS) determined the facility was not affected by the close proximity to Edwards Air Force Base and the frequent sonic booms that are heard there.

2.2.2 Wind Energy

Harvesting the power of wind to do work for humans has been around for thousands of years with the earliest example being sailboats. Progressing through water pumping and grinding grain (Dodge, 2006), modern day applications utilize wind turbines to transform wind, as a fluid medium, into electricity. By the rotating blades of a propeller-shaped airfoil, wind is converted to electrical energy through an onboard generator. Historically, windmills were placed in areas where the work was needed. Modern day location siting is more advanced in order to optimize efficiency and cost, and the energy generated by the windmills is transmittable.

The conditions used for siting locations of wind energy in this project come predominantly from a report by the BLM (US DOI BLM, 2003) and work by Tabor (2006). Together, these reports give the suitability criteria outlined in Table 2-3.

Table 2-3 Preferred range of siting criteria for wind power.

Feature Layer	Preferred Range
Mean Wind Speed	Power class 4 and greater – short term facilities. Power class 3 and greater – long term facilities. (US DOI BLM, 2003).
Land ownership	Depends on application.
Slope	< 14% grade for ease of site access and limiting building costs. (US DOI BLM, 2003).
Elevation range	3,000 – 4,500 feet optimal. Suggested to be below 7,000 feet. (US DOI BLM, 2003).
Proximity to electrical lines	25 miles (US DOI BLM, 2003).
Proximity to existing roads	50 miles (US DOI BLM, 2003).
Military airways	Restricted to areas with a minimum altitude of 600' (adapted from Tabor, 2006).

2.3 Summary

Multi-criteria decision analysis (MCDA) requires a methodology which aids in accomplishing the goals of a suitability model. With a choice of three options, this project utilized a common ordered weighted average (OWA) method because of its flexibility in specifying the importance of varying criteria as the main operation. Mentioned in section 1.4.1, the goal of this project was to develop a tool which allows users to specify the levels of importance in criteria used for the suitability analyses. One of the other methods, the Boolean approach, was not a wholly suitable method for this project, as it works best with discrete data. The siting tools in this project use this methodology as a secondary operation when utilizing a "no siting" layer which includes areas that are not suitable for renewable energy development. The third method, ordered weighted average (OWA), requires a more subjective analysis utilizing personal research, or knowledge, in order to gain accuracy in results. Because this project's intent was to provide a tool which land managers, with limited understanding of renewable energy, could use to quickly create and compare varying results of the tools together, OWA was not used.

Solar and wind energy have differing suitability criteria; however, both can use a similar methodology for site selection. As illustrated in Table 2-1, Table 2-2, and Table 2-3, many of the feature layers are the same with only the preferred ranges changing between the different renewable energy types. As this report progresses, further details are discussed about the criteria and preferred range of each feature layer.

Chapter 3 – Systems Analysis and Design

Planning, initiation, and design are crucial phases to any large-scale project. This chapter describes the mechanics of how the set of suitability tools was conceived in order to satisfy the goals that were set forth in section 1.4.1. The chapter begins with a description of the problem addressed in this paper (3.1) and is followed by a discussion and tables outlining the requirements of project analysis (3.2). The major components of this project are brought together and discussed in detail in section 3.3. Finally, the original project plan, along with an examination of the changes that came about, is the focus of section 3.4.

3.1 Problem Statement

The focus of this project was to create a set of suitability modeling tools with which land managers may evaluate their property for the likelihood of developing a renewable energy facility there. Photovoltaic (PV), concentrating solar power (CSP), and wind power were the renewable energy types of interest. The tools had to provide an easy-to-customize, small to moderate scale, overall assessment of a user-specified area within the Mojave Desert region. Using a base set of data, the user needed to have the option of selecting and modifying various criteria of feature importance quickly and effectively. The user also needed to have the option of being able to incorporate other data into the model as either a replacement for existing data or as additional data sets for the suitability model.

3.2 Requirements Analysis

A requirements analysis is a crucial part of any planning phase of a software product. This section outlines the considerations deliberated for development of the suitability tools. The section is broken into the functional (3.2.1) and non-functional (3.2.2) requirements.

3.2.1 Functional Requirements

A general, all-purpose suitability tool to site locations of all renewable energy types is not feasible. It would have to contain far too much unique data to handle multiple renewable energy systems. To accurately evaluate these systems, separate tools are required for each. In this project, this was accomplished through differing data sets and adapted default values for each tool. However, the underlying structure of the suitability tools was the same.

In the case of solar and wind farm suitability modeling, a similar tool methodology was adapted. For siting solar facilities, two separate tools were developed to correctly site photovoltaic and concentrating solar power uniquely, as Ignizio (2010) suggested in his conclusions. Namely, the difference between the tools was in the base level data each uses for calculation. For example, a solar insolation data set is important to PV and CSP requirements, but is not needed for wind farm siting.

Tool customization was a strict requirement set forth by the client. The idea behind this was that anyone can utilize the tool and adjust the level of importance for each modeling feature layer. The functionality of this also allows comparisons between differently weighted runs of the tool. One can run an analysis with a conservative set of siting criteria, and then compare it to one with moderate or liberal conditions.

Tool customization was strongly facilitated by having a base set of values from which to derive a new feature-weighting scheme. The base values, or tool defaults, are a combination of using the tool multiple times in the project area and a result of reading the literature discussed in sections 2.2.1 and 2.2.2.

Along the same lines as weighted customization, allowing the operator to use unique data was important to this project. Take, for example, solar insolation data. The insolation file this project uses comes from the National Renewable Energy Laboratory (NREL) and is a fishnet data representation structure of approximately ten kilometer squares with solar insolation values represented by an averaged direct normal solar value in $Wh/m^2/day$ from 1998 to 2002. If the user wishes to use a solar insolation file – perhaps one computed with the Spatial Analyst solar tool – he or she may do so by running it through a data preparation tool. The preparation tools are included with this project which satisfies the user-provided data functional requirement.

The functional requirements this project utilized are summarized in Table 3-1.

Table 3-1 Functional requirements of the suitability tools.

Functional Requirements	Description
Photovoltaic tool	Suitability tool for photovoltaic (PV) solar energy.
Concentrating solar tool	Suitability tool for concentrating solar power (CSP).
Wind tool	Suitability tool for wind energy.
Customizable	User-derived weighting criteria of feature importance without hard-coded values.
Default values	Default values which provide a useful, general, basis in which user-specified customizations will be adapted.
User-provided data	Utilize user's data when provided – in the form of replacement data – or as an embellishing data set for the model.

3.2.2 Non-Functional Requirements

Non-functional requirements are just as crucial as functional requirements in the project planning stage. These set forth the important criteria which outline how the tools will work. The non-functional requirements are summarized in Table 3-2.

Table 3-2 Non-functional requirements of the suitability tools.

Non-Functional Requirements	Description
ArcInfo 10	ArcInfo 10 is the software used for the project.
Ease of operation	Useable for non-GIS and renewable energy specialists: land managers.
Rapid in processing time	Fast processing time needed for the future website-based interface.
Results are easy to interpret	An easy and concise results display which clearly shows which areas are suitable.
MXD	An .mxd file is provided for ease of use operating the tools and interpreting the results.

The software package this project employed was Esri's ArcGIS 10; specifically, ArcInfo with the Spatial Analyst extension. While it is possible that the tools will run with lower levels of ArcGIS, testing was not performed at those licensing levels.

Ease of use and operation ensure that these tools will be useable by land managers who have no prior GIS or renewable energy background. With an easy-to-grasp interface, a user can quickly get results to start refining their modeling choices. The tools are composed of three main components which have thorough documentation walking the user through the process of selecting the weights they wish to use. A training video was also provided which gives the user background on how the tools operate.

Tool processing speed was an important consideration in the design of the siting tools. A future phase of this project will be a website-based geoprocessing tool which will run on ArcGIS Server. For online geoprocessing, the amount of time a user is willing to wait for a process to run is limited. Keeping the processing time to a minimum, a threshold was set at less than 30 seconds for which the intended scale range the tool was optimized.

A pleasant user experience is not complete without an easy-to-read display of the tool output. The choice of a red-to-green color scheme accomplished this, as many English-speaking people are already accustomed to green and red representing "good" and "bad," respectively. Within those extremes, yellow and orange hues identify the areas that are marginally suitable. This ease of results interpretation was key to satisfying one of the non-functional requirements.

A map document, known as an .mxd file, brings all of the components of the project together in a format which allows the user to search for an area of land, decide the extent at which they want to display results, execute the tool, and interpret the results. The .mxd in this project houses layers of original vector data, coupled with the derived raster layers. This is all on top of a basemap digital elevation model (DEM) shaded with an elevation color scheme.

3.3 System Design

There are three main components of the project: the data within the geodatabase, the suitability tools, and the map document (.mxd file).

3.3.1 Geodatabase

Project data were stored in an Esri geodatabase. Geodatabases are the present form of a data storage and organization structure Esri has utilized since 1999 (C. Childs, personal communication, May 11, 2011). The suitability tools in this project can use one or two geodatabases, depending on the client's preference. The first geodatabase houses the base level data – data that the tools default to when not utilizing user-supplied data. The second, optional, geodatabase houses the tool results after a suitability modeling session. An advantage of having model results stored in a second geodatabase is that they can be transported easily to another folder or computer for later use and analysis. More detail on the primary geodatabase is discussed in Chapter 4.

The base level project data within the geodatabase are found in two formats: vector and raster. Some analyses are aided by viewing the raw data in vector format, and some in raster format. Depending on which layers the user is trying to interpret, having the multiple attribute fields of the original vector data may be helpful. Land ownership, for example, requires many useful attributes in consideration of using a given plot of land for an energy facility. If private, the owner must be contacted and purchasing agreements arranged. This is possible through ownership attributes remaining in the vector file. Alternately, finding the distance to the nearest river may be easier to interpret with the Euclidian distance raster rather than the original, vector file.

3.3.2 Tools

The set of tools this project created is comprised of 13 data preparation tools and three suitability modeling tools. The tools a user operates to prepare data for use in the suitability tools are contained in an ArcGIS toolbox entitled Prepping Data within the main Toolbox folder in the geodatabase. The tools are named Desert Tortoise, Electric Line Data, Land Ownership Data, Military Airspace, PV CSP Slope Data, Rivers Data, Roads Data, Solar Data, Solar Do Not Site Areas, Wind Data, Wind Do Not Site Areas, Wind Elevation Range, and Wind Slope Data. These tools convert vector format files to raster format for use in the suitability tools. Operations are unique to each tool and are discussed in further detail in Section 5.1.1.

The suitability tools are contained at the initial tier of the toolbox and are named CSP Solar Tool, PV Solar Tool, and Wind Power Tool. The three solar and wind suitability tools are based on two operations: weighted overlay analysis using an ordered weighted average method, and exclusion operation analysis. The weighted overlay operation derives a raster of suitable locations using continuous data. Following this, the exclusion operation uses a discrete “no siting” layer to block out areas deemed unsuitable. Further details on the creation and specifications of these tools are explained in Section 5.1.2.

3.3.3 Map Document

The third component of the system design is a map document, or .mxd. This file opens in ArcMap to provide a working environment for analysis with the suitability tools. Among the reasons for having a prepared map document is for ease of navigation within the project area. Of specific interest to land managers, the land ownership layer is included as a base layer to aide in finding the property of interest. Along with land ownership, a hillshade map is included for terrain awareness and topographical feature identification.

The feature class hierarchy is outlined in Table 3-3. The section on the project geodatabase (3.3.1) discusses the need for both vector and raster layers in analysis of the tool result. This is why the map document provides this form of redundancy of original and derived data layers.

Table 3-3 Map document feature class hierarchy.

Main Folder Level	Feature Class	Main Folder Level	Feature Class
	Data Boundary		
Reference	MDEP Boundary		Electric Lines
	Large Scale Cities		Solar Insolation
	Small Scale Cities		Military Airspace
		Original Data	Roads
	Military Areas (DOD*)		Average Wind
Do Not Site	Wilderness Areas		Rivers
	Desert Tortoise		Lakes
	Lakes		Land Ownership
	Desert Tortoise Areas		
	Military Airspace		
	Wind Elevation		
	Electric		
	Roads		Imagery
Complete Rasters	Rivers	Base Map Layers	DEM
	Solar Insolation		Hillshade
	Land Ownership		
	Solar Slope		
	Wind Slope		
	Average Wind		

* = United States Department of Defense

3.4 Project Plan

Over all, the tool design methodology progressed similarly to the plan proposed at the beginning of the project, with a few major changes. Originally, the project scope defined the project as creating a set of four renewable energy tools: solar, wind, geothermal, and hydroelectric energy, with the final implementation of the tools being a website map and tool geoprocessing integration. Through a process of assessing the time involved in a project of this magnitude, the deliverables were reduced to an ArcInfo 10 geoprocesssing operation for three tools: photovoltaic solar, concentrating solar, and wind power. At the beginning it was thought that all four tools would utilize very similar design mechanics. After a close examination of the literature and the factors required for geothermal and hydroelectric siting, developing these tools with the solar and wind tools, was not a realistic option with the time constraints of the University of Redlands MS GIS program.

The initial proposal called for the tools to be programmed in the Java programming language on top of the existing weighted overlay tool in the Spatial Analyst extension. This method, while possible, evolved to a simpler development approach which did not include learning Java. The new methodology utilized the built-in Model Builder feature of the ArcGIS software package. During the planning stages, Model Builder was deemed a useable platform for tool modifications since the weighted overlay calculations were the same as the author wished to utilize in a Java-modified tool.

Another element of the original plan that required modification was the methodology used for tool instruction. The client did not require a specific tutorial document in writing. Instead, an instructional video was provided which demonstrates the tools with a quick example analysis procedure for discovering why the results look as they do.

3.5 Summary

Understanding the importance of a project planning stage is necessary. Through careful steps of realizing and understanding the functional and non-functional requirements of the project, a more precise methodology to solving a problem can be conceived. As with many project plans, this one changed a fair degree from the original proposal and plan. This, in itself, gave a more thorough understanding to the author of the importance of looking at each variable carefully before undertaking a project.

Chapter 4 – Database Design

An integral part of this project was the database, which exists in the form of an Esri geodatabase. The geodatabase contains the components that make the suitability modeling tools function properly. The project geodatabase, titled "RenewableEnergy," contains three categories of information: the original, vector-formatted feature classes; the rasters derived from the vector feature classes; and the toolbox which houses the renewable energy tools.

In the rest of this chapter the conceptual model (4.1) is first addressed giving an account of the project entities and how they relate to each other. A unified modeling language (UML) diagram is presented for the conceptual ideology of the project (Figure 4-1).

4.1 Conceptual Data Model

A suitability modeling tool was straight forward to describe in a conceptual model as illustrated by Figure 4-1. The general orientation of the diagram is such that a section of land is described by the center Land class. This class has attributes which consist of both human-influenced qualities and physical qualities. Land ownership and land bounds make up the human-influenced qualities while the slope attributes the physical nature of the land, as does the elevation attribute.

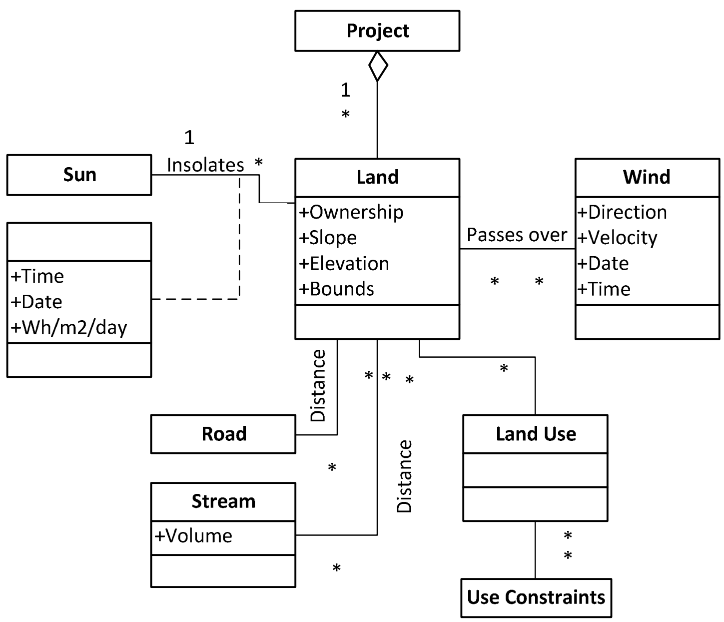

Figure 4-1 UML diagram of the conceptual model.

On the left side of the diagram a subclass exists for the sun; connected to the land class. The sun provides a source for insolation values which is an influencing component of a solar suitability analysis. The data that represents the sun insolation has attributes reflecting the time, date and the insolation, as expressed in Wh/m^2/day. One sun exists so the relationship is that of a one to many for the sun-to-land relationship.

Below this, roads and streams are represented by distance from the project area. The relationships are that of many to many signifying that multiple instances can happen for each case.

Land use is a subclass that represents what exactly is being used on the land. This could be in the form of desert tortoise habitats, military airways, or other land use types. Regardless of the land use type, use constraints can be placed on these subclasses limiting the suitability of each. As a whole, the land use is a many to many relationship with land.

The Wind subclass has attributes accounting for the direction, velocity, date, and time. These relate to the Land as a many to many relationship meaning that there can, and could be, many instances of wind for an area of land.

4.2 Logical Data Model

Choosing the software package is one of the first considerations in taking the conceptual model idea into the design and implementation stages. This project used the ArcGIS database management system in the form of a geodatabase. This allows for a close integration and transition from ArcInfo to ArcGIS Server when the web feature of the project is implemented. ArcGIS uses an extended relational database management system which provides continuous, large dataset support. Since many of the raster files used in this project exceed 300 megabytes, with some as large as 1.5 gigabytes, support for these large raster arrays was crucial.

The ArcGIS geodatabase allows an organizational function for vector data which was used to organize the data provided by the Mojave Desert Ecosystem Program (MDEP). This folder structure is called a feature dataset and contains the vector data as individual feature classes. The MDEP data arrived in the form of shapefiles which were projected into feature classes using the WGS 1984 UTM Zone 11N projection. With few exceptions, the nomenclature of each feature class is that of the files presented at the start of this project. The exceptions are cases where the names were shortened to aid in quick identification of the files and to allow for shorter file pathways.

The geodatabase also contains the derived rasters that the tools utilized for the suitability analyses. These data were stored in continuous, integer file geodatabase raster formats with the exception of the digital elevation model (DEM), which is a continuous floating point format. Each raster was given a nomenclature based on the tools that utilize the files. Otherwise, names indicated the data they represent. Section 5.1 details the conversion of vector data into feature classes. Table 4-1 provides an overview of the geodatabase design.

Table 4-1 Organization of the Geodatabase

Geodatabase: RenewableEnergy

Feature Dataset	Feature Class
Boundaries	Bnd_CDCA_Project DataBoundary MDEPBoundary
Land_Use	Cities DesertTortoise_CHU Hydrology_Rivers_2006 Lakes MilitaryAreasDoD Mojave_Land_Ownership Wilderness_Areas
Solar	Solar_Potential
Transportation	CA_RYG_NOV07_CDCA CA_RYG_NOV07_Modified Roads
Utilities	ElectricLines
Wind	ca_50mwind CANVwind Nevada_50mwind

Rasters
CSPtoolRivers
DEM
DesertTortoiseAreas
Electric
Hillshade
LandOwnership
MilitaryAirspace
PVtoolSlope
SolarInsolation
SolarNoSiteAreas
toolRoads
Wind
WindElevation
WindNoSiteAreas
WindtoolSlope

= denotes geodatabase (grey)
= denotes vector-based data (blue)
= denotes raster-based data (orange)

Since the siting tools rely on data within the geodatabase, they were stored inside the geodatabase. This allows all aspects of the tool to be concentrated together and provides ease of transition between computer installations.

The individual tools provided the getValue and sendValue operations (shown in the UML diagrams in the previous section) behind the scenes. All transactions were invisible and mostly private with the exception of the weighting table. This table is accessible to the user in order to update the weighting values and alter the tool calculation variables. The tools were placed in the main toolbox, which has a sub-toolbox that houses the data preparation tools for creating the vector-to-raster formats discussed in further detail in Chapter 5.

4.3 Data Sources

The Mojave Desert Ecosystem Program (MDEP) provided data for this project in December of 2010 and January of 2011. Information on the original source of the data layers was limited. Table 4-2 summarizes the data sources and completeness of metadata.

Table 4-2 Original source and metadata completeness table of project data.

Data Name	Original Source (from Metadata)	Completeness of Metadata
Hydrology_Rivers_2006	U.S. National Atlas	Complete
MoJave_Hydrology_2002	U.S. National Atlas	Complete
CA_RYG_NOV07_CDCA	Does not include.	Missing
DEM	Does not include.	Missing
Mojave_LandOwnership	BLM	Complete
Roads_Detail	U.S. Census TIGER	Partial
Ca_50mwind	NREL*	Partial
Nevada_50mwind	NREL*	Partial
DesertTortoise_CHU	Multiple**	Partial
ElectricLines	Does not include.	Missing
Solar_Potential	NREL*	Partial
Wilderness_Areas	BLM	Partial

* National Renewable Energy Laboratory
** US Fish and Wildlife, MDEP, TopoWorks, and the University of Nevada, Reno.

Maps depicting each feature class provided by MDEP are shown in Figure 4-2 on the following page.

4.4 Summary

The process of moving from a conceptual model to a logical model involved making several choices at the proper project planning stages. In this project, the software, which solved the conceptual model's needs, is also the software that was requested by the client: ArcGIS 10. The database structure of ArcGIS 10 provided the necessary framework for organizing the data and processes found in the conceptual model.

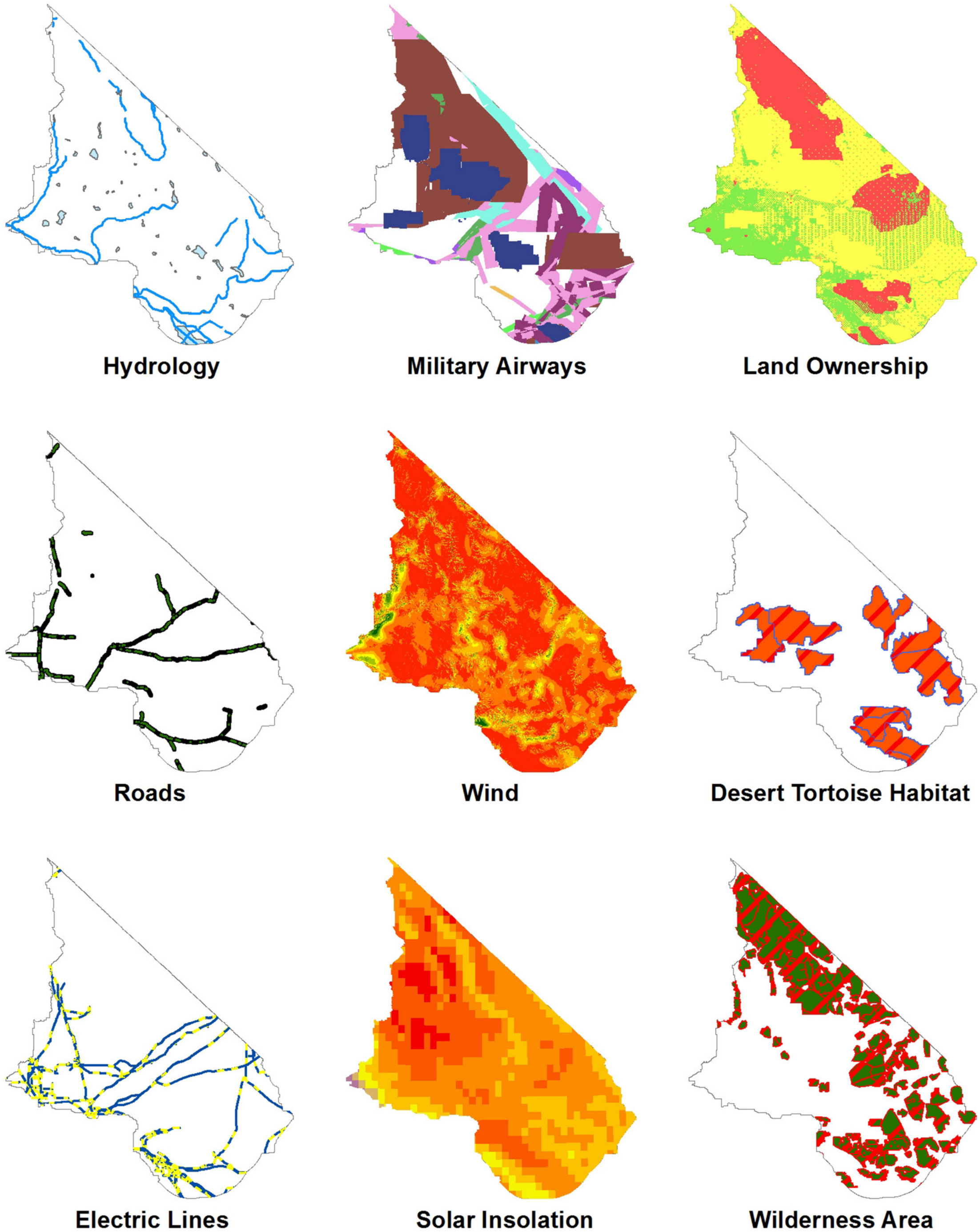

Figure 4-2 Thumbnails of MDEP data.

Chapter 5 – Implementation

Project implementation is the stage at which the conceptual and logical models become reality. This chapter explains the procedures used to create the three suitability tools that constitute this project. After the planning phases, the first step was preparing data for use in a weighted overlay operation.

5.1 Data Scrubbing and Loading

The data provided by the client were in shapefile format. While still a valid data format, it is not as contemporary as a feature class. In order to contain multiple files in a feature dataset of a geodatabase, a common spatial reference was selected. As the sole original raster of the project – and later determined to be a critical element in the data scrubbing procedures – the spatial reference used for the DEM was the natural choice. This is the WGS 1984 UTM Zone 11N with units of meters. To transfer shapefiles into a geodatabase, a reproject tool was used to convert the data to UTM Zone 11N. Once the organizational hierarchy described in section 4.2 was populated with feature classes, the necessary steps for vector to raster conversion were created.

Creating the tools that convert vector to raster files consumed a significant portion of project time. This was due mostly to the various types of vector data used and discerning which attributes of the data were critical to preserve in raster format. Raster cells can only contain one numerical value, so this needed to be a representative attribute. This section describes the procedures of the data conversions in a per-feature-class description.

The first step in preparing data for a suitability tool was to pick a raster file that had a cell structure which could be the key for defining other rasters' cell sizes and locations. The project area DEM was the raster template used for this step.

5.1.1 Creating the Preparation Tools

Preparing the terrain slope raster for the suitability tools was a straightforward procedure. In order to prepare a raster that represents terrain slope, a project DEM was used that covers the extent of the project area. The slope tool, of the Spatial Analyst extension, calculates a percent slope using the DEM raster as a source. This tool does so by a set of trigonometric operations using the DEM elevation values of nearby cells. When understanding site selection of renewable energy, slope is a critical value to consider. Due to some banding imperfections that are clearly visible on the slope raster created from the DEM, a low pass filter was applied to the slope file. While not removing all the banding, the filter helped to blend the bands with the surrounding pixels. Because the weighted overlay tool needs integer values for its algebra, quarter percent slope values needed to somehow remain preserved as integer values. Multiplying the value of cells by 100 preserved the digits to the hundredths place, allowing for these numbers to be preserved as integer values. The values of each cell were then displayed as hundreds of percent slope; for example, a slope value of 1.25 percent was stored as 125. Reclassification of the cells created a stepped set of values that the suitability tool uses to represent the slope file in the suitability tools. The methods for creating the slope rasters were the same for the solar and wind tools, but the interval classifications of the files were different because of the varying degrees of allotted slope range for the respective tools. The solar siting criterion has a threshold of up to four percent slope while the wind tool utilizes a slope approaching 14 percent. Figure 5-1 summarizes the process. The reclassification tables are presented in Appendix A for both solar and wind slope rasters. Figure 5-2 and Figure 5-3 show the resulting rasters for solar and wind tools.

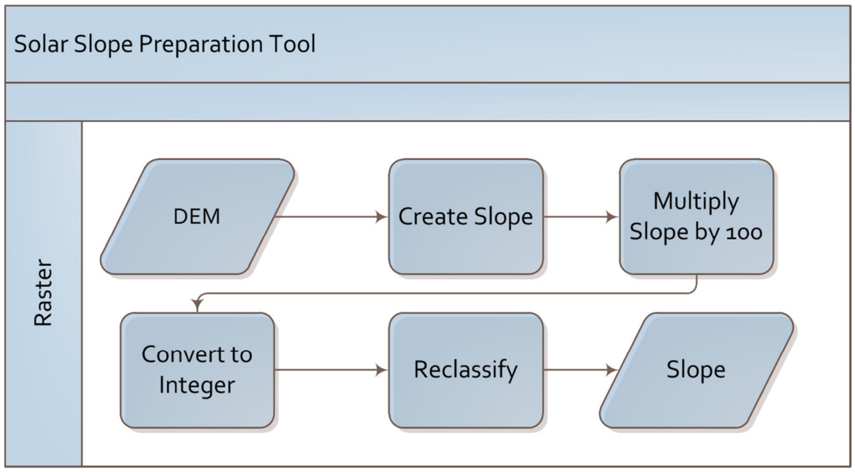

Figure 5-1   Model of the slope raster creation process.

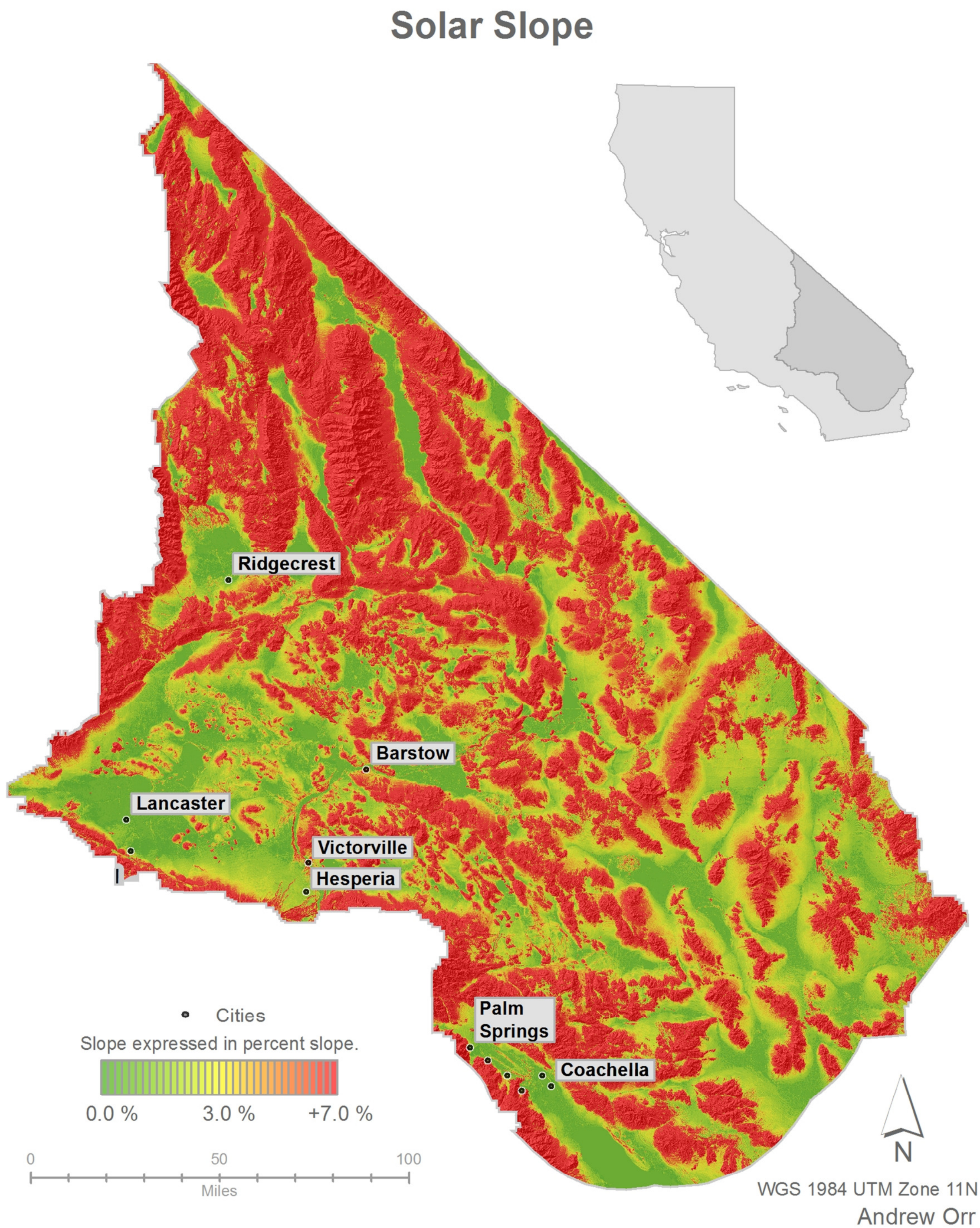

Figure 5-2 Map of the solar slope raster.

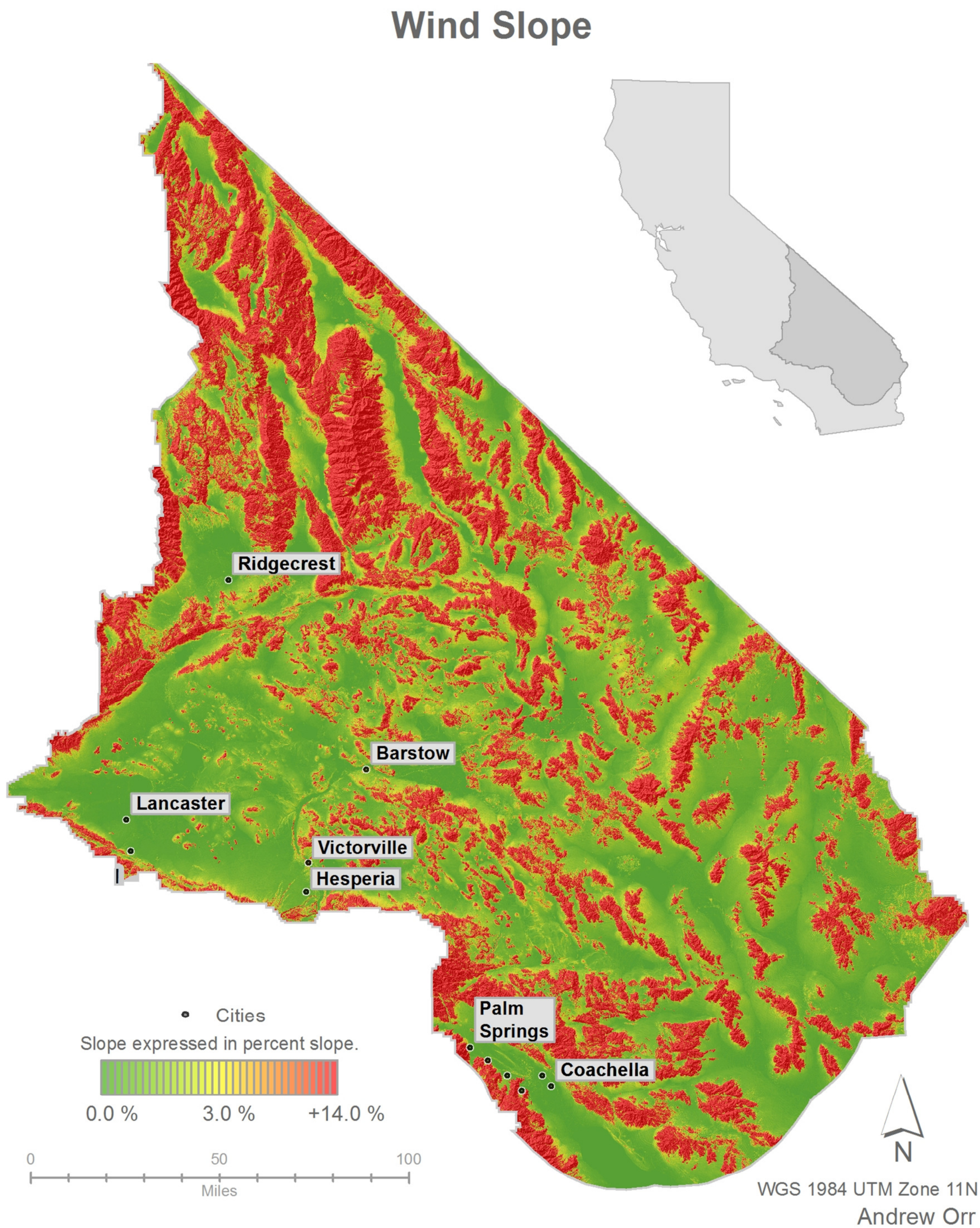

Figure 5-3 Map of the wind slope raster.

The density of air can be correlated to altitude. As elevation increases, the density of air drops in a near-linear fashion. Given temperature and dew point as constants, air is more dense at sea level (approximately 0.075 pounds per cubic foot) and decreases with higher elevation (approximately 0.06 pounds per cubic foot at 6,000 feet) (The Engineering Toolbox, n.d.). This information was incorporated into the wind suitability tool through an elevation raster classified from a DEM (Figure 5-4). The DEM cells represent elevation values in meters so the conversion constant, 3.2808399, was multiplied to each cell to arrive at feet. The raster was then reclassified to elevation intervals of 500 feet. Because the project area contains land that falls below sea level, the first elevation classification contains all negative elevation values. The increments of the raster classification extend to an elevation of 14,500 feet. Appendix A includes the classification table. Figure 5-5 is a map depicting the wind elevation raster.

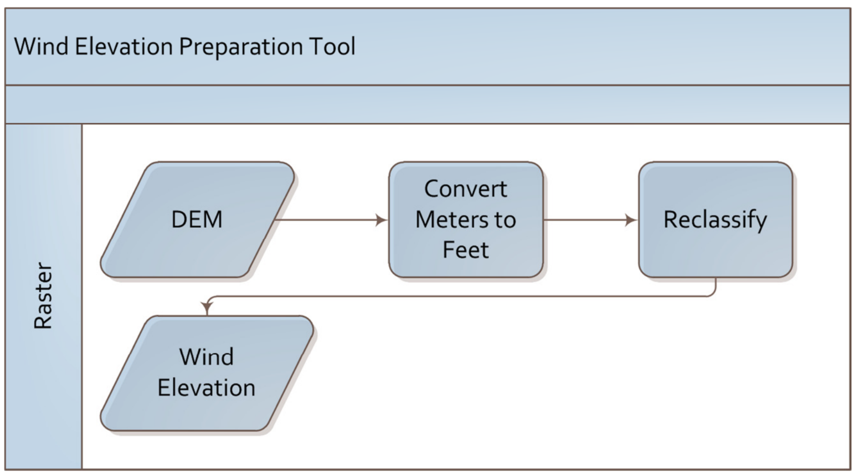

Figure 5-4 Model of the wind elevation raster creation process.

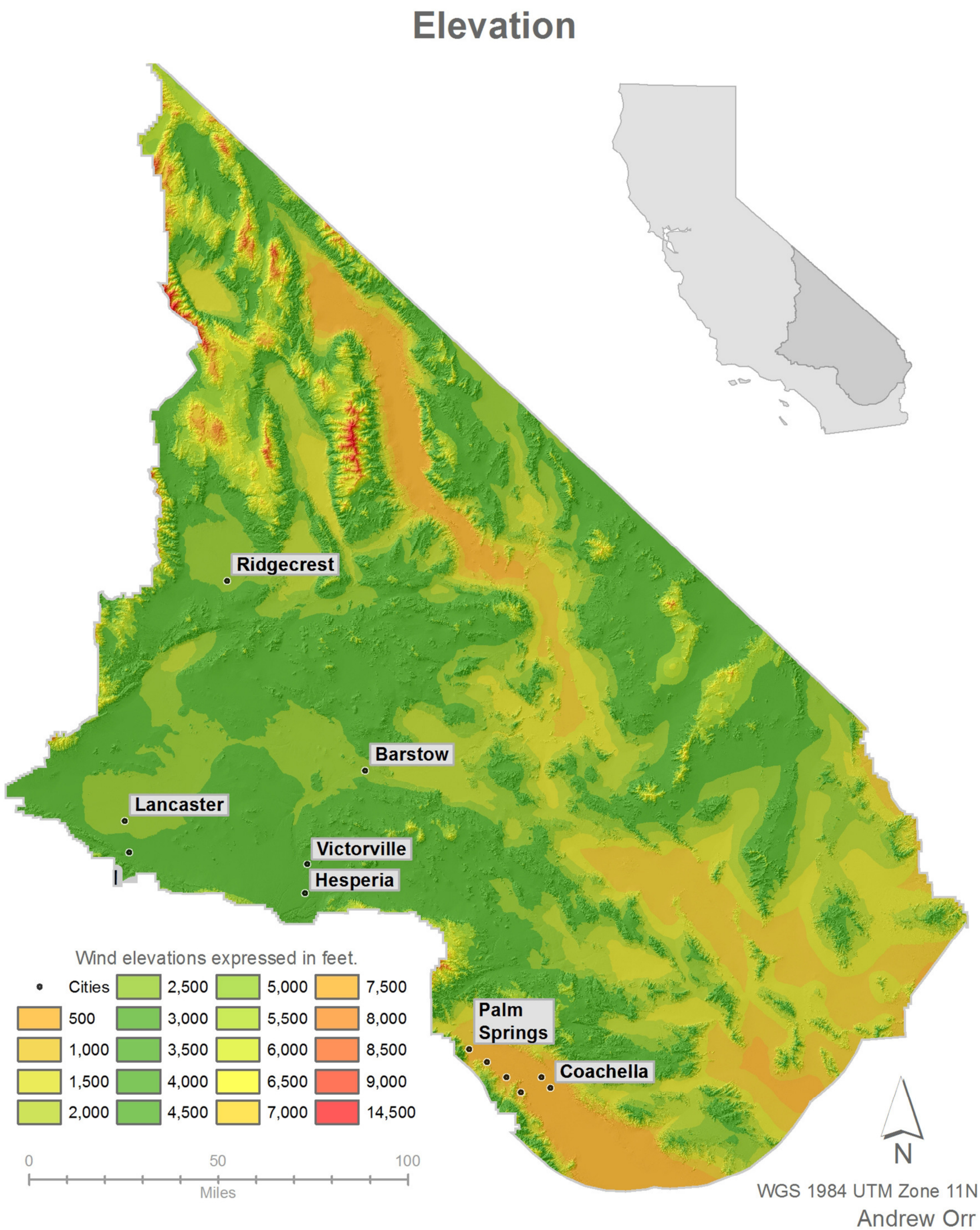

Figure 5-5 Map of the wind elevation raster.

A key component of the suitability model is land ownership. This project's suitability tools employ land ownership in a categorized raster representing four land classifications: no siting areas (1), state lands (2), federal lands (3), and private lands (4). An attribute field was added to the land ownership attribute table which designated each land ownership polygon to a classification. Table 5-1 summarizes how each land ownership polygon was classified.

Table 5-1 Land ownership classification.

Land Ownership	Owner	Classification Code
Private	Private	4
U.S. Fish and Wildlife Service	Federal	3
Native American Reservation	Federal	3
Forest Service	Federal	3
DOD	Federal	3
BLM	Federal	3
State	State	2
Water	NoSite	1
State Wildlife Reserve	NoSite	1
State Park	NoSite	1
National Preserve	NoSite	1
National Park	NoSite	1

With this attribute now in the feature class table, the conversion from vector to raster took place (Figure 5-6). This created the classified land ownership raster that the three suitability models use in calculations, with the cell values being the classified attribute field codes created previously. Figure 5-7 shows the land ownership raster.

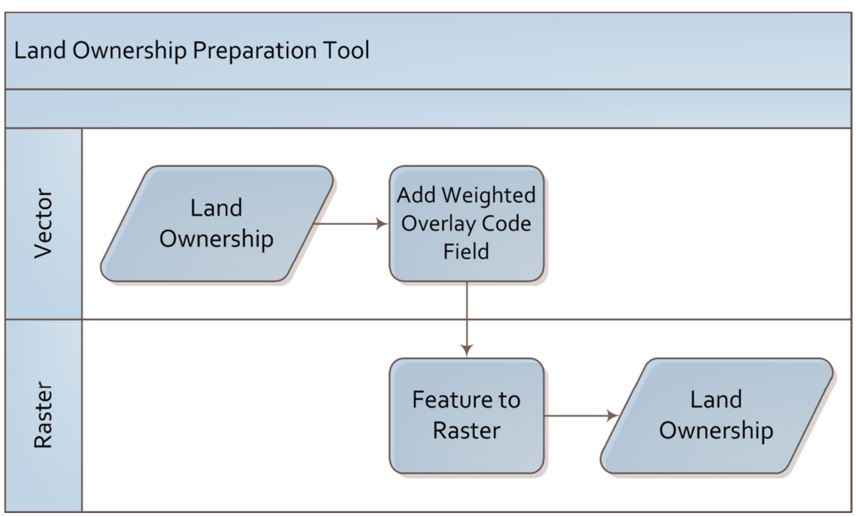

Figure 5-6 Model of the land ownership raster creation process.

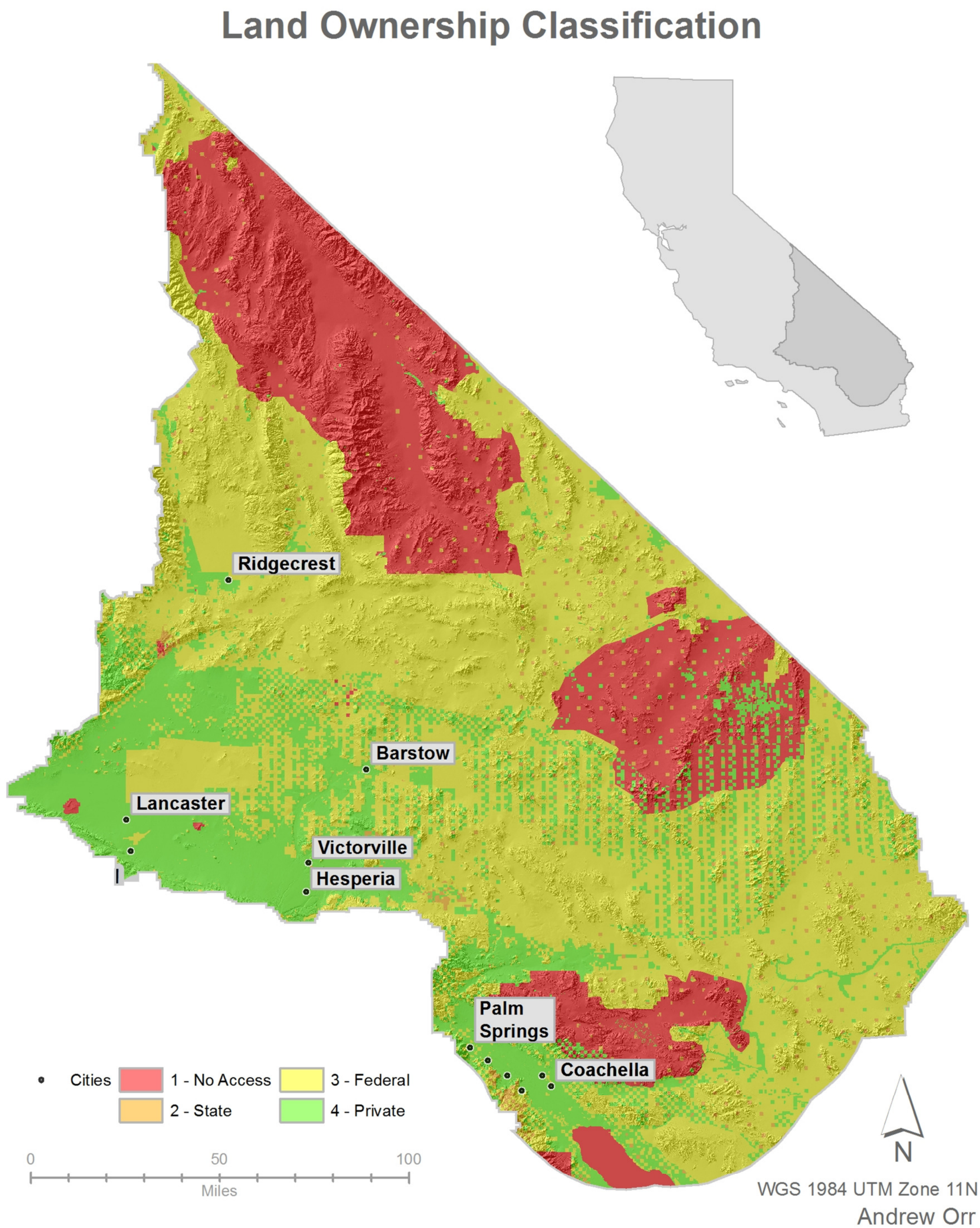

Figure 5-7 Map of the land ownership raster.

For the two solar renewable energy tools, the solar insolation raster is a key component. The data preparation of this raster was a straightforward vector feature to raster conversion (Figure 5-8). The raster cell values came from the insolation value expressed in Wh/m^2/day (watt-hour per square meter per day). Once in raster form, the cells are reclassified to 250 Wh/m^2/day intervals. The first class was defined to be values from 5228 to 6250 Wh/m^2/day because these are out of range for utility-scale facilities. Breaking this interval into smaller divisions would be irrelevant and needlessly clutter the suitability tool interface. Ignizio (2010) indicated that 6750 Wh/m^2/day is a reasonable cutoff threshold for utility-scale power facilities. The solar insolation reclassification had a maximum value of 8250 Wh/m^2/day. A map illustrating the solar insolation value is displayed in Figure 5-9.

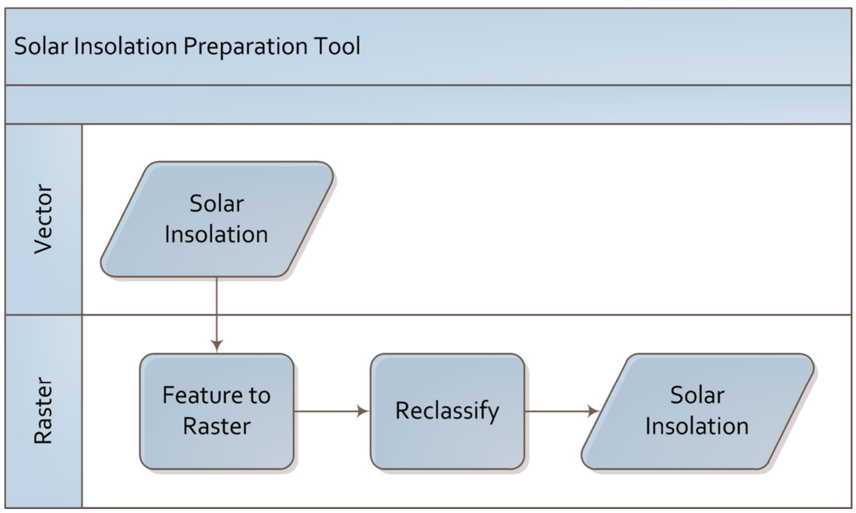

Figure 5-8 Model of the solar insolation raster creation process.

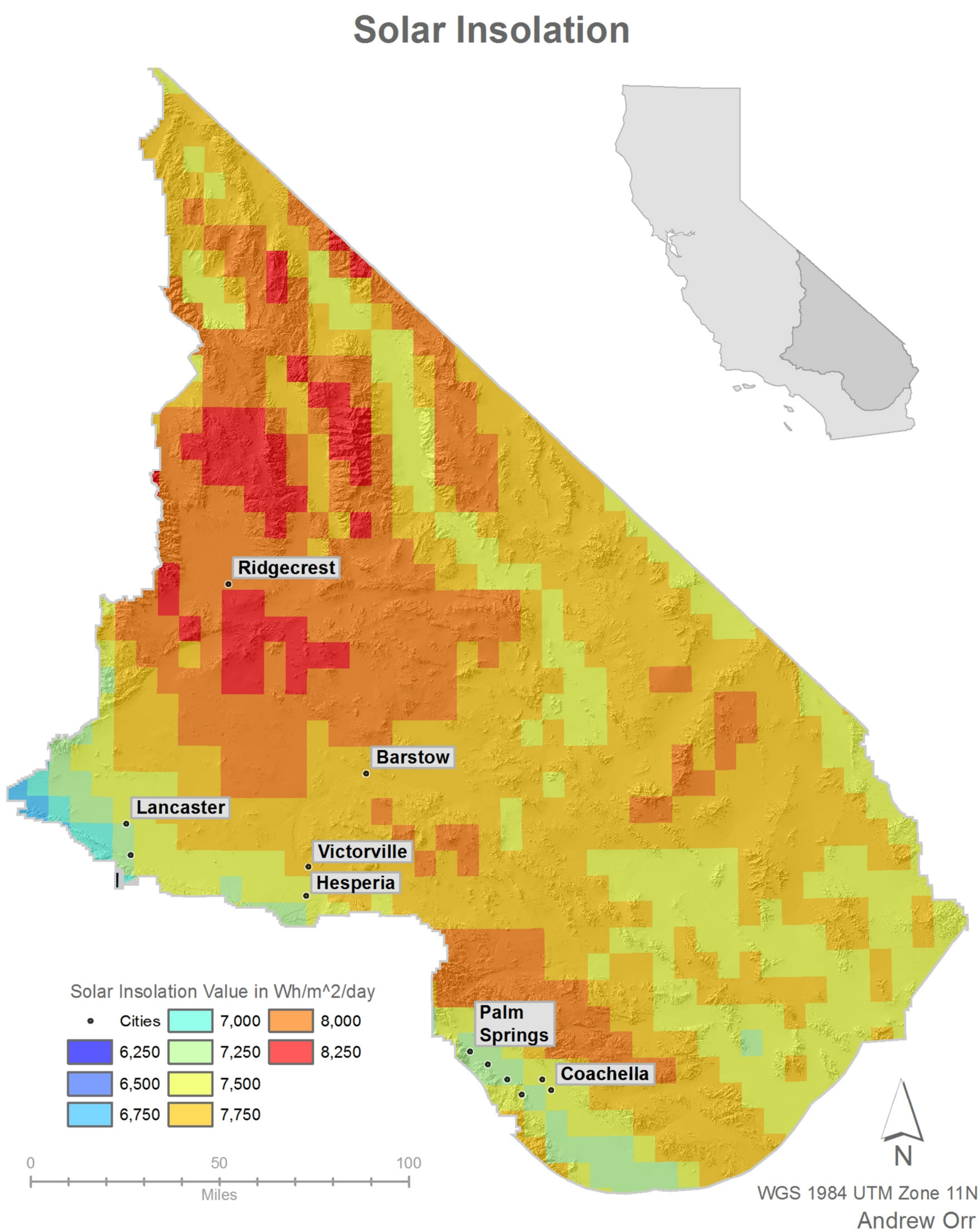

Figure 5-9 Map of the solar insolation raster.

As with the solar insolation raster, wind power class values are a critical element in a wind power siting model. Power class levels describe various levels of average wind speed with a unique scale for wind energy planning as Elliott, Holladay, Barchet, Foote, and Sandusky describe (Table 5-2, adapted from Elliott et al., 1986). The attribute that the cell values represent are wind power class levels (Figure 5-10). Figure 5-11 displays the raster created from this procedure.

Table 5-2 Wind power class levels.

Wind Power Class	Wind Power Density (W/m^2)	Speed* m/s (mph)
1	0 - 200	0 - 12.5
2	200 - 300	12.5 - 14.3
3	300 - 400	14.3 - 15.7
4	400 - 500	15.7 - 16.8
5	500 - 600	16.8 - 17.9
6	600 - 800	17.9 - 19.7
7	800 - 2000	19.7 - 26.6
	2000 +	26.6 +
Speeds are for 50m (164') height		
**** Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.***		

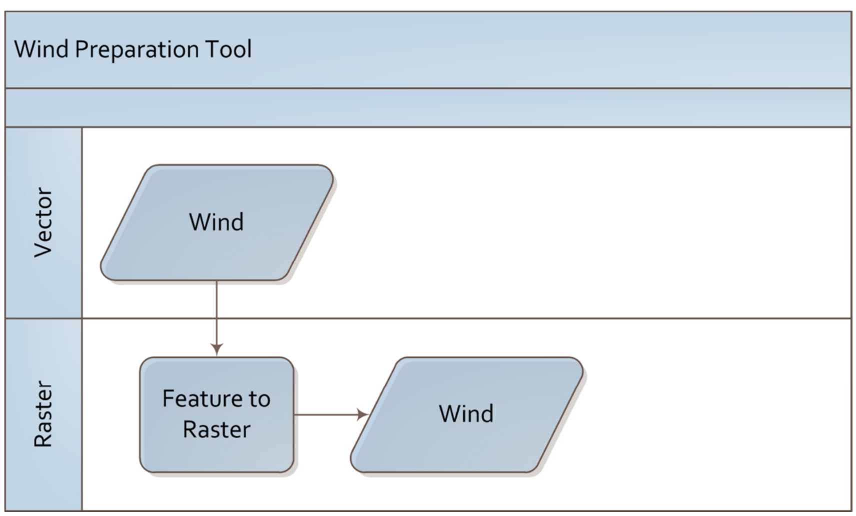

Figure 5-10 Model of the average wind power class raster creation process.

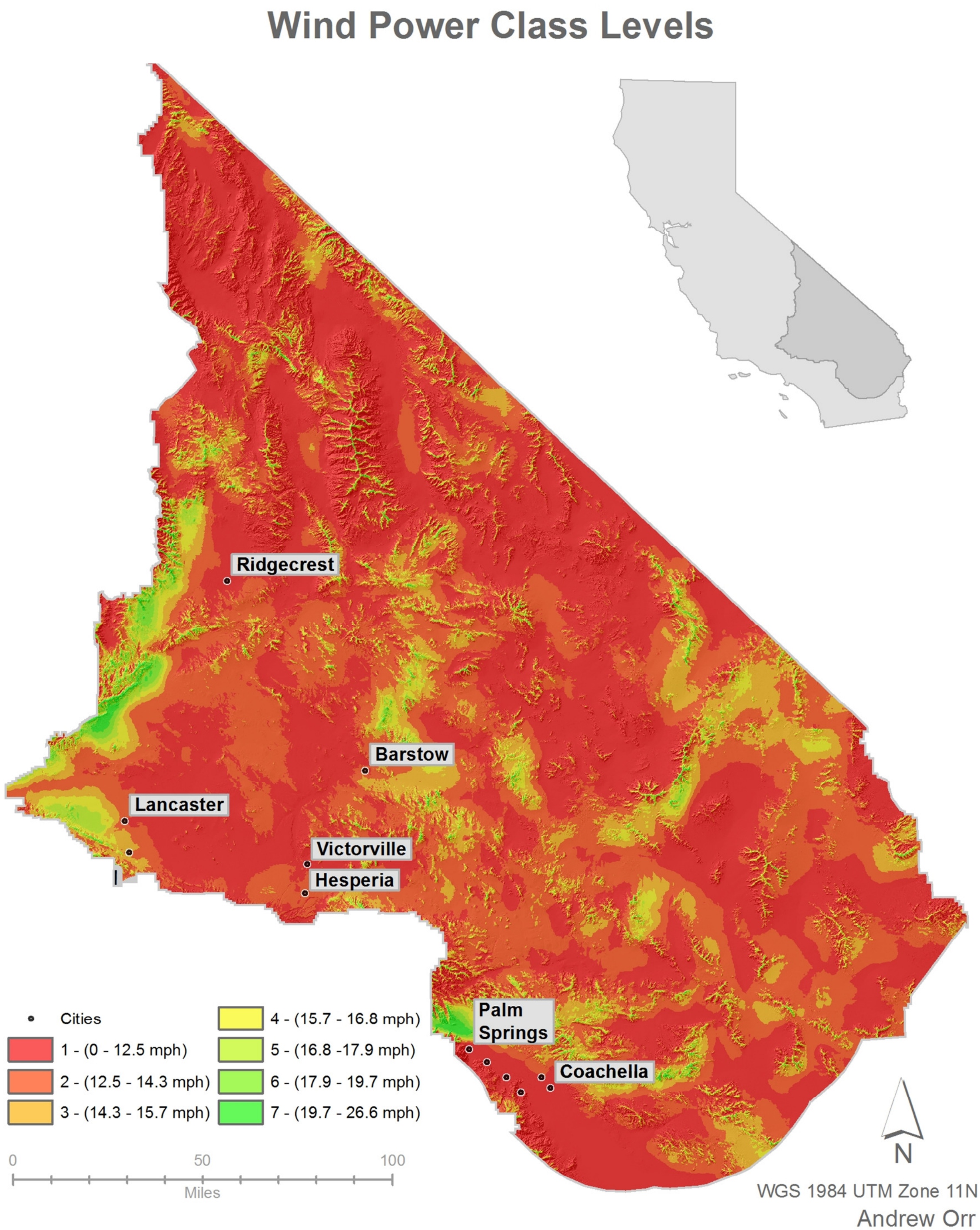

Figure 5-11 Map of the wind power class raster.

The distance to the nearest electrical transmission line was an important consideration when siting power facilities, because of the expense that line construction adds to a project. To create a raster that represented this problem, a Euclidean distance operation was performed to an electrical line vector data set (Figure 5-12). The Euclidean distance tool took each pixel of a raster grid and calculated the distance to the nearest feature. The cell units were then converted from meters to miles. Cell distances were reclassified to represent five mile increments away from the nearest line. Figure 5-13 depicts the generated raster. A visual examination of the data revealed the electrical lines represented in this data set are the main artery lines.

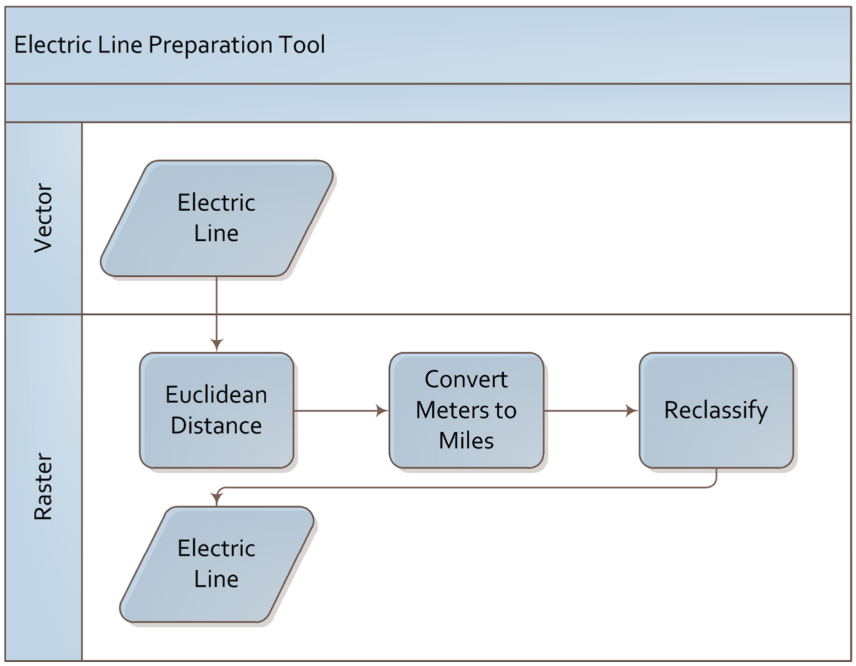

Figure 5-12   Model of the distance to nearest electrical line creation process.

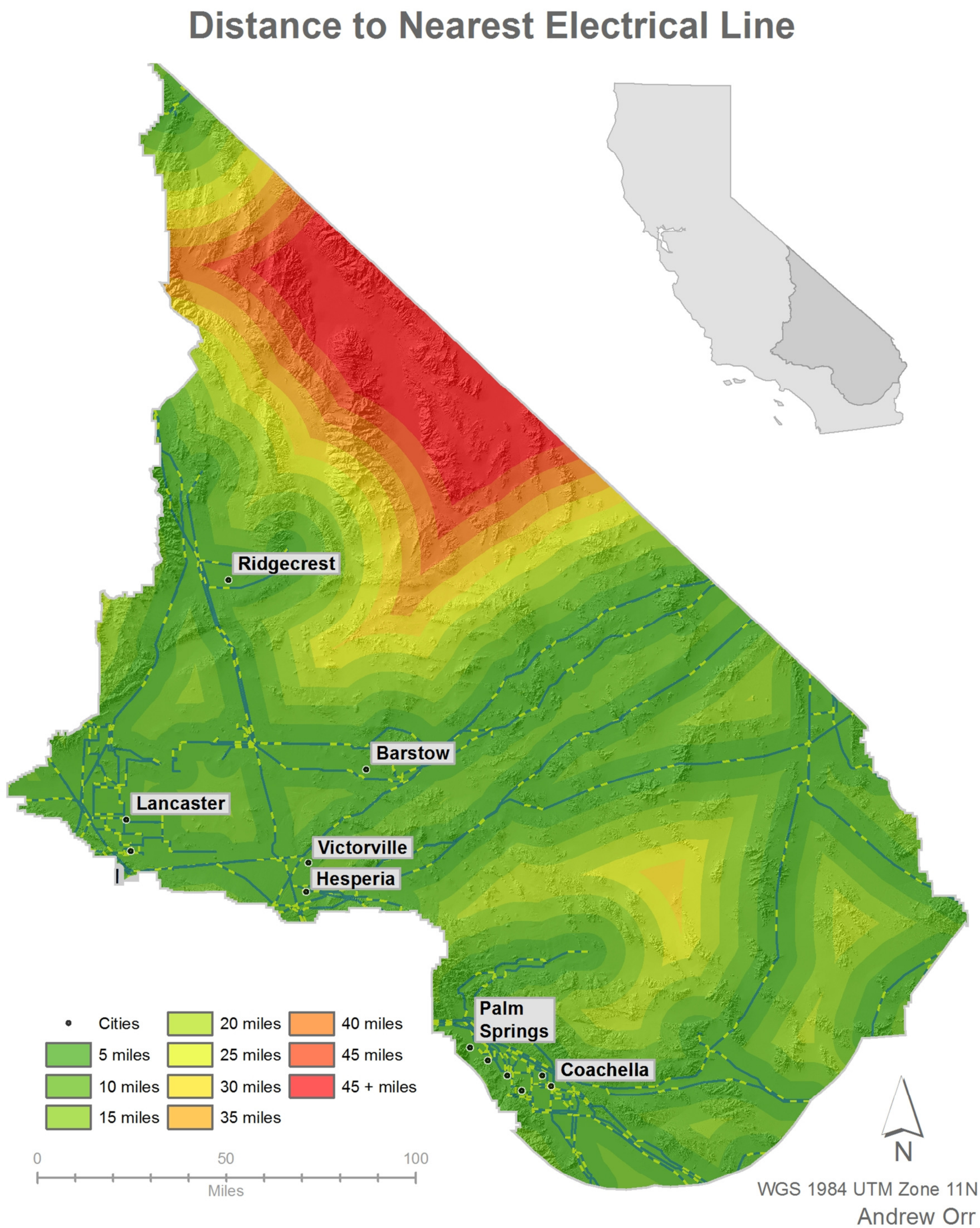

Figure 5-13 Map of the Euclidean distance to nearest electrical line raster.

CSP technology may make use of water as the heat exchange fluid in facility design implementation. Consequently, the distance to the nearest water source is a factor in some suitability studies. Like the Euclidean distance operation for creating an electrical line distance raster, the procedure for the distance to nearest river raster was the same and generated the raster depicted in Figure 5-14. Suitability studies also consider the distance to existing roads. This information is summarized in a roads Euclidean distance raster (Figure 5-15) which was generated as the distance to electrical and road rasters.

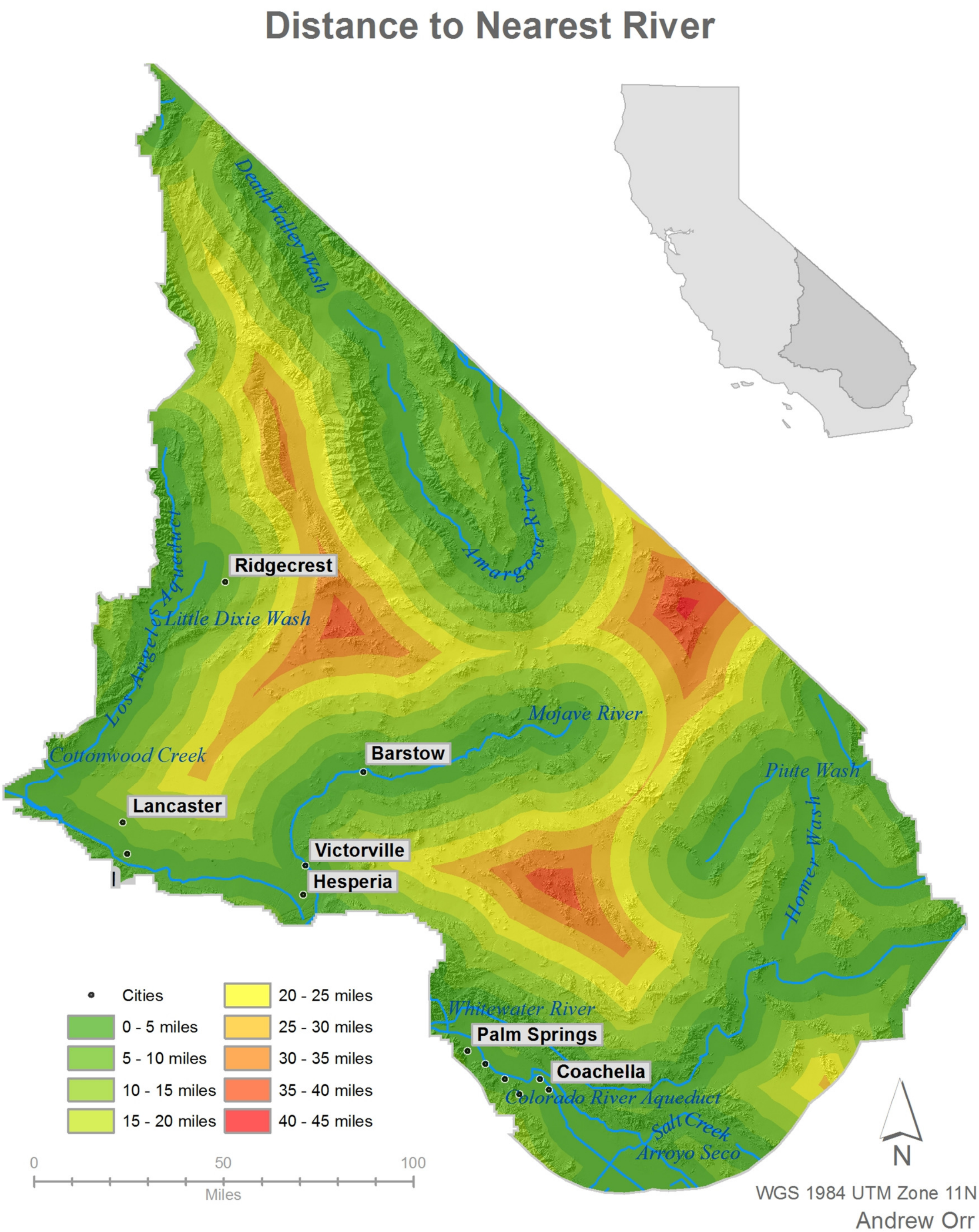

Figure 5-14   Map of the Euclidean distance to nearest river raster.

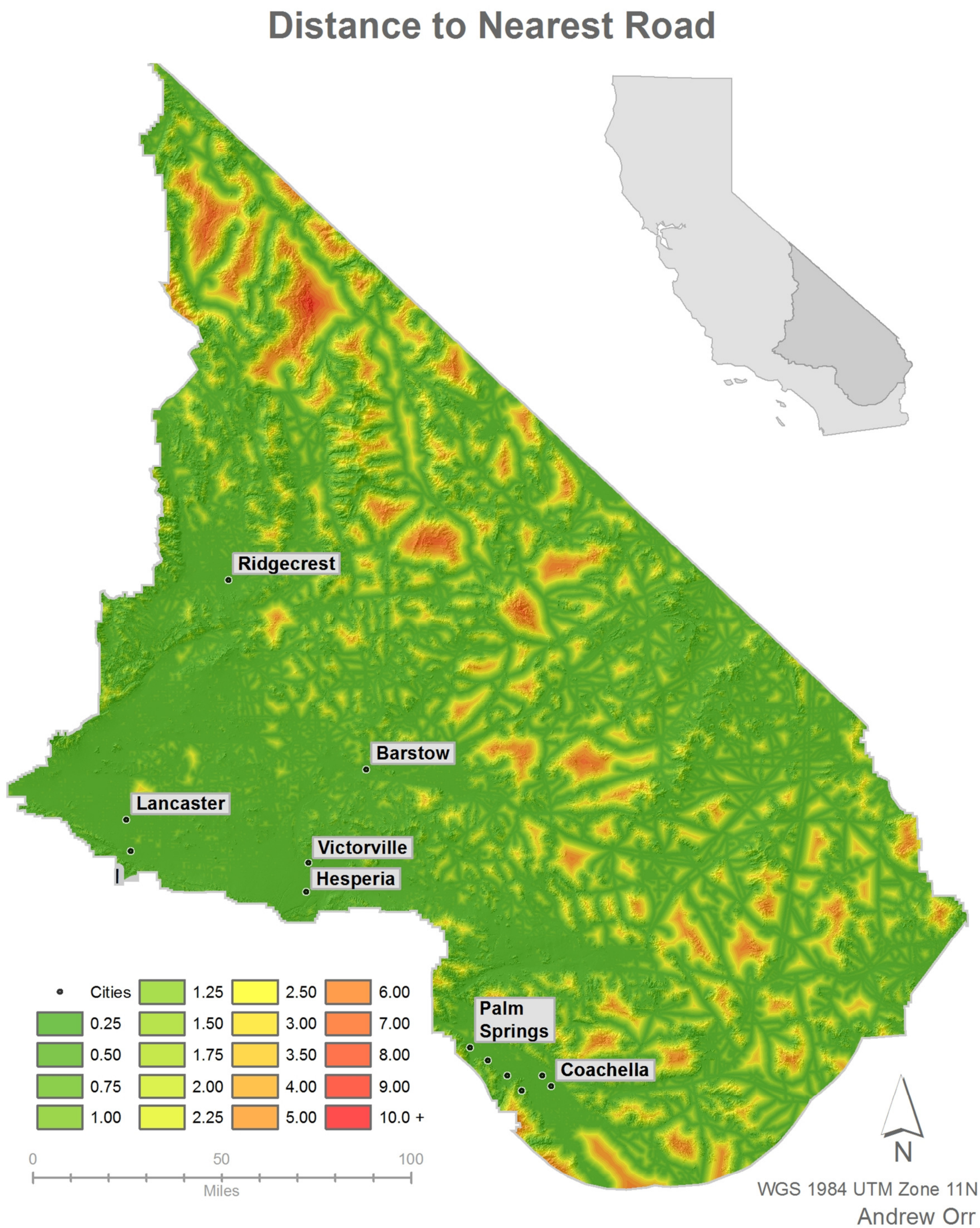

Figure 5-15 Map of the Euclidean distance to nearest road raster.

Tabor (2006) discussed the impact of wind facilities on military airspace encroachment. His conclusions suggested the proximity of wind power facilities to military air operation areas was significant and discussed the importance of considering minimum altitudes for airways near future wind farm sites.

The suitability tools in this project make use of his findings by the incorporation of a military airway raster, which used the minimum airway altitude as a raster cell value. The preparation tool used the ENR_ALT1 altitude attribute column to create the raster. This produced a raster set of numerical values which were then compared to the original vector data and a chart of which altitude goes with each raster value was compiled (Table 5-3). The raster cells lacked any form of intuitive description so the raster was reclassified with a more expressive coding shown in Table 5-3. Figure 5-16 shows the process of this data preparation process and is reflected in the raster seen in Figure 5-17.

Table 5-3 Military airspace feature to raster conversion codes

Description	Raster Value	Reclassified Value
SFC *	8	0
100 AGL **	10	100
150 AGL	4	150
200 AGL	9	200
300 AGL	7	300
500 AGL	5	500
1000 AGL	1	1000
2500 AGL	2	2500
7500 AGL	6	7500
SUAS ***	3	7777
DOD ****	11	8888
NoData – Suitable Areas	NoData	9999
* SFC = Surface	*** SUAS = Special use air space	
** AGL = Above ground level	**** DOD = Department of Defense	

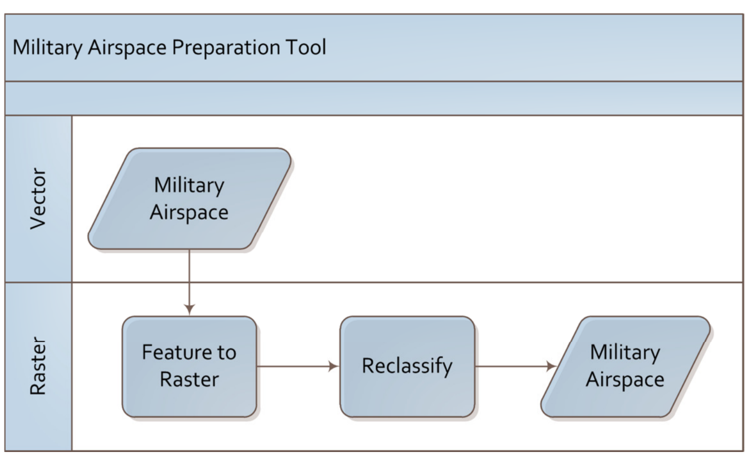

Figure 5-16 Model of the military airspace raster creation process

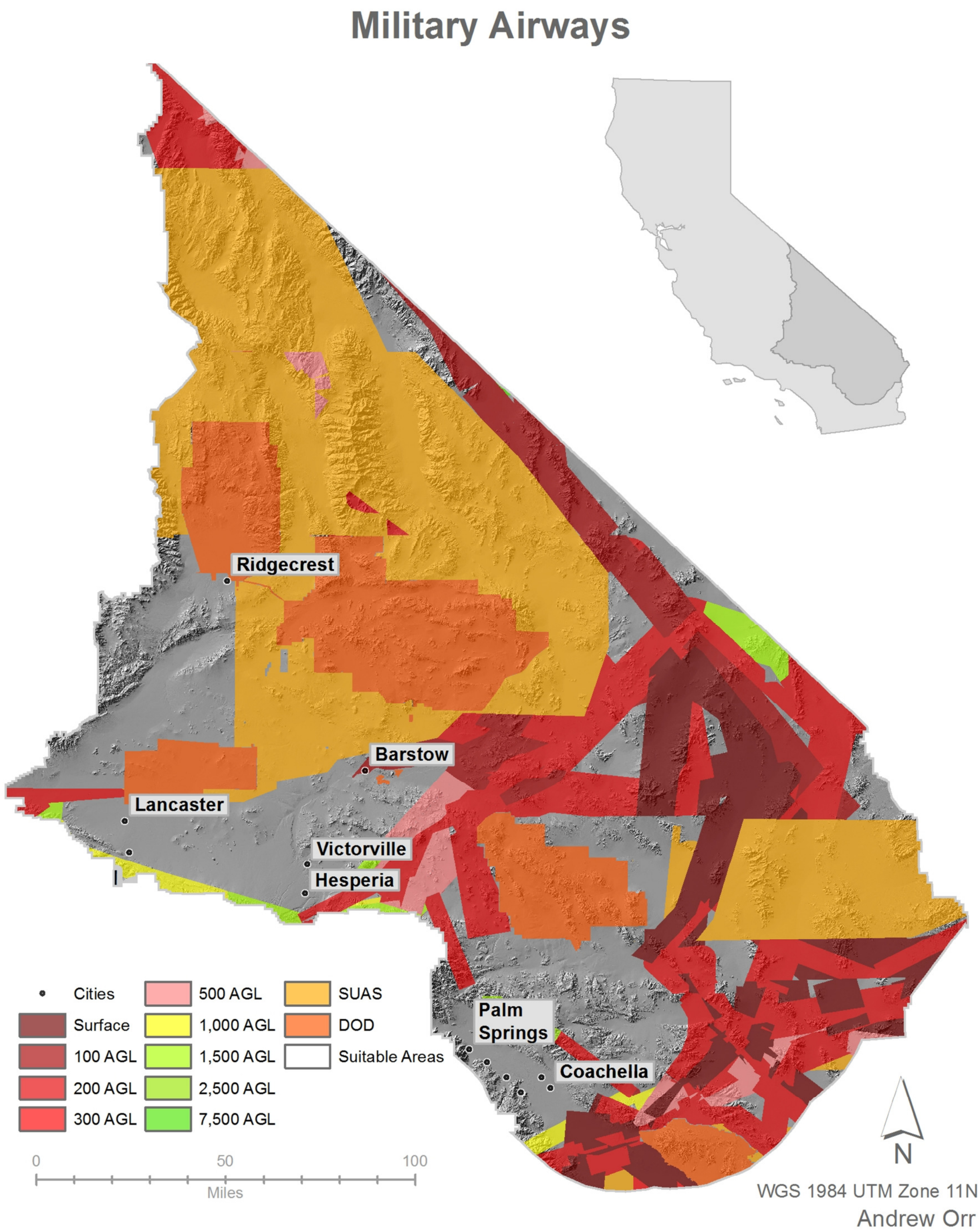

Figure 5-17 Map of the military airways raster.

The habitat extent of the desert tortoise is a controversial topic. The tortoise (*Gopherus agassizii)* is listed as threatened on the endangered species list and has decreased in population by 90 percent since the 1950s. With the federal and state governments' interest in the tortoise, relocation efforts are needed when development takes place in tortoise habitat regions (Defenders of Wildlife, 2011). The suitability tools incorporate a desert tortoise habitat dataset.

The desert tortoise data set exists in polygon form and outlines the known habitat of the tortoise. To create a file that the suitability tools could utilize, the feature was converted to a raster and reclassified with a unique structure. Areas considered suitable were given a value of "1", true, indicating acceptable. Areas where the tortoises reside were given a value of "0", false, indicating unsuitability. Originally the tortoise habitat was going to be a hard-coded operation in the exclusion operation of the suitability tools, but interest in allowing these areas to be considered led to it being a user-selected option. This also allowed a further element of tool customization to the tools. Figure 5-18 shows the model process. A table showing the tool reclassification is in Appendix A. A photograph of a desert tortoise shell found in the Mojave Desert by the author is displayed in Figure 5-19. The results of the desert tortoise preparation tool are shown in Figure 5-20.

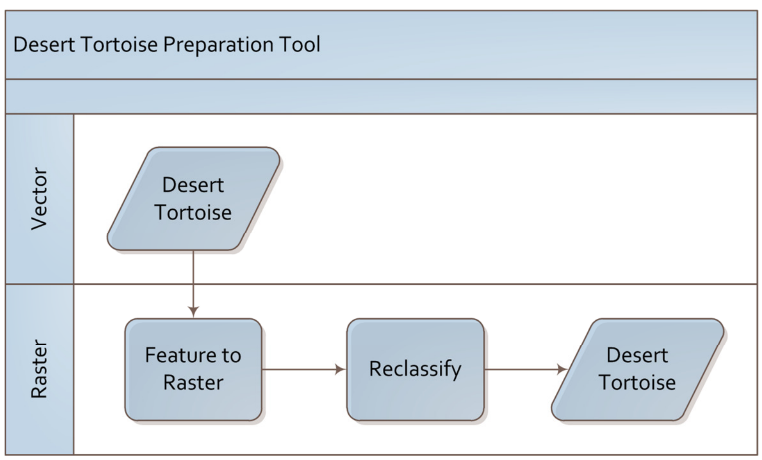

Figure 5-18 Model of the desert tortoise habitat raster creation process.

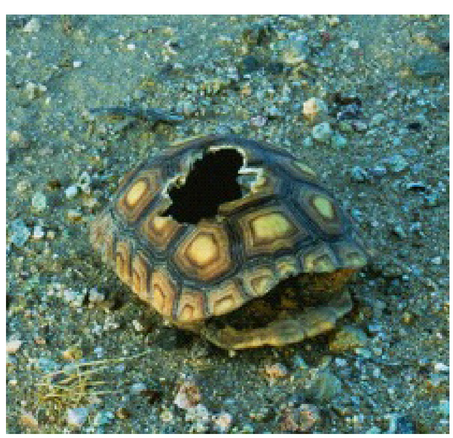

Figure 5-19 Photograph of desert tortoise shell near Barstow, California.

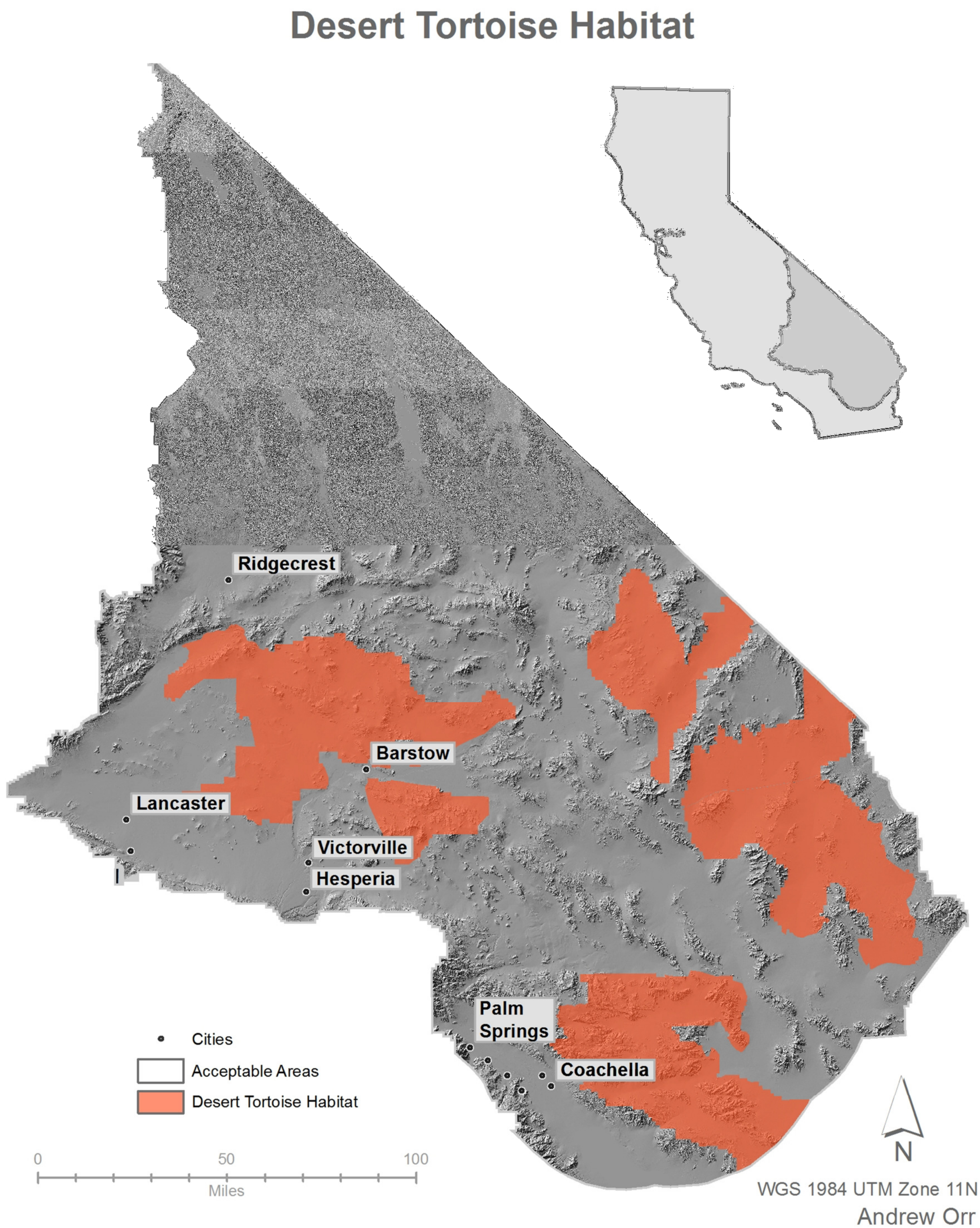

Figure 5-20   Map of the desert tortoise habitat raster.

The solar renewable energy suitability tools incorporate a set of hard-coded data in the form of an exclusion operation. This uses the ‘no site layer’ as a stamp to remove areas that were determined to be completely unsuitable. This was also one of the few data tools that had multiple operations take place in vector format. Two features that represented areas unsuitable for solar facilities were found: wilderness areas and lakes. Wilderness extents are stretches of land set aside to protect them from human intervention so development is unlikely to take place there. Lakes, too, are unsuitable locations for solar facilities because panels are generally placed near the ground and birds frequent areas of water, creating unwanted panel cleaning requirements. A union operation was added to the model which allowed additional land swatches of unsuitable areas to be merged in easily within Model Builder. An examination of the wilderness data revealed that there were blocks of private land within the wilderness feature class that are not excluded from the wilderness polygons. To represent this phenomenon, a clip operation was executed leaving a cutout of private land falling within wilderness areas. After a conversion of all layers to raster format, a raster calculation was performed to create a merged file. This operation added the cell values of each of the three rasters together and, with an investigation of the raster output, a chart was developed which shows how each cell corresponds to the original data sources (Table 5-4). This was made possible by a unique set of raster codes given to the features as they were converted from vector to raster format (Table 5-5). In the reclassified format, the raster was ready for use as an exclusion operation in the solar suitability tools. The creation of this raster is summarized in Figure 5-21 and Figure 5-22.

Table 5-4 The association of raster calculations with features represented.

Raster Value	New Classification	Description
0	0	No Feature
1	NoData	Lake or Wilderness
2	NoData	Lake and Wilderness
46	0	Lake or Wilderness and Private Land
47	0	Lake and Wilderness and Private Land
NoData	NoData	NoData

Table 5-5 Unique cell codes for the solar no site raster preparation tool.

Wildness (Object_ID field)		Land (Value field)		Lakes (OBJECTID_1 field)	
Description	Cell Code	Description	Cell Code	Description	Cell Code
0 - 10000	1	0	0	0 - 10000	1
NoData	0	20	0	NoData	0
		24	45		
		45	45		
		60	0		
		73	0		
		83	0		
		84	0		
		100	0		
		103	0		
		105	0		
		122	0		
		NoData	0		

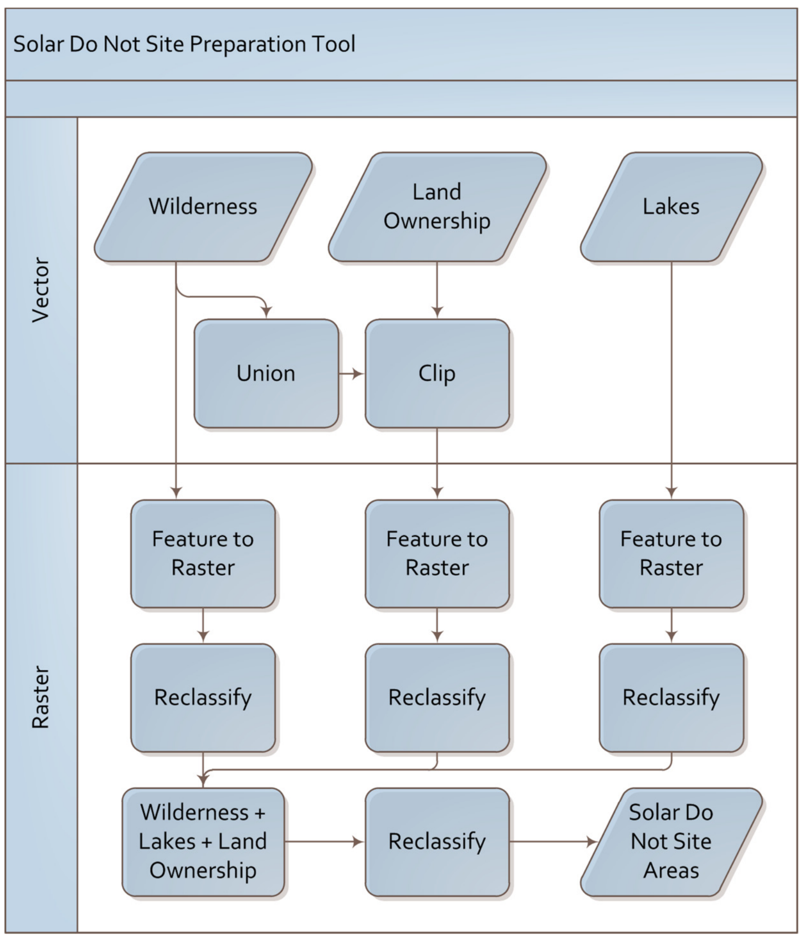

Figure 5-21 Model of the solar no-site areas raster creation process.

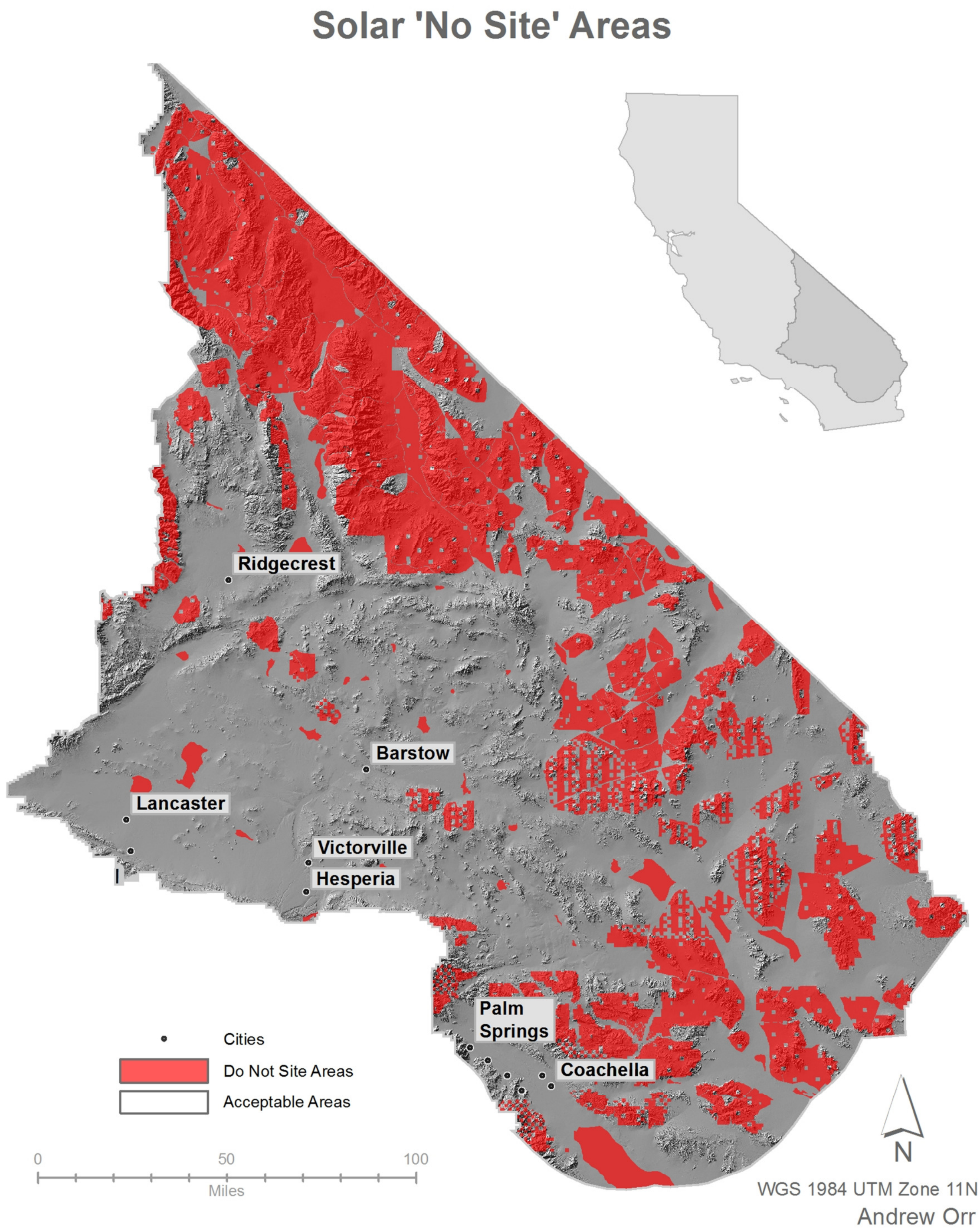

Figure 5-22 Map of the solar no site areas raster.

The process of preparing the wind no site raster was similar to the solar no site operations above. However, lakes were no longer considered unsuitable locations. Having a wind farm in an intermittent lake is feasible, so a lakes feature no longer exists in the no siting model. Additionally, Department of Defense (DOD) areas are likely to have low flying aircraft in the vicinity so these areas were considered unsuitable. The DOD no siting areas were identified as the Chocolate Mountains Aerial Gunnery area, Twentynine Palms, Edwards Air Force Base, Fort Irwin, and Naval Air Weapons Center China Lake. The DOD areas, along with wilderness areas, were combined in a union operation and merged with the public land layer (Figure 5-23). Figure 5-24 represents the resulting raster image.

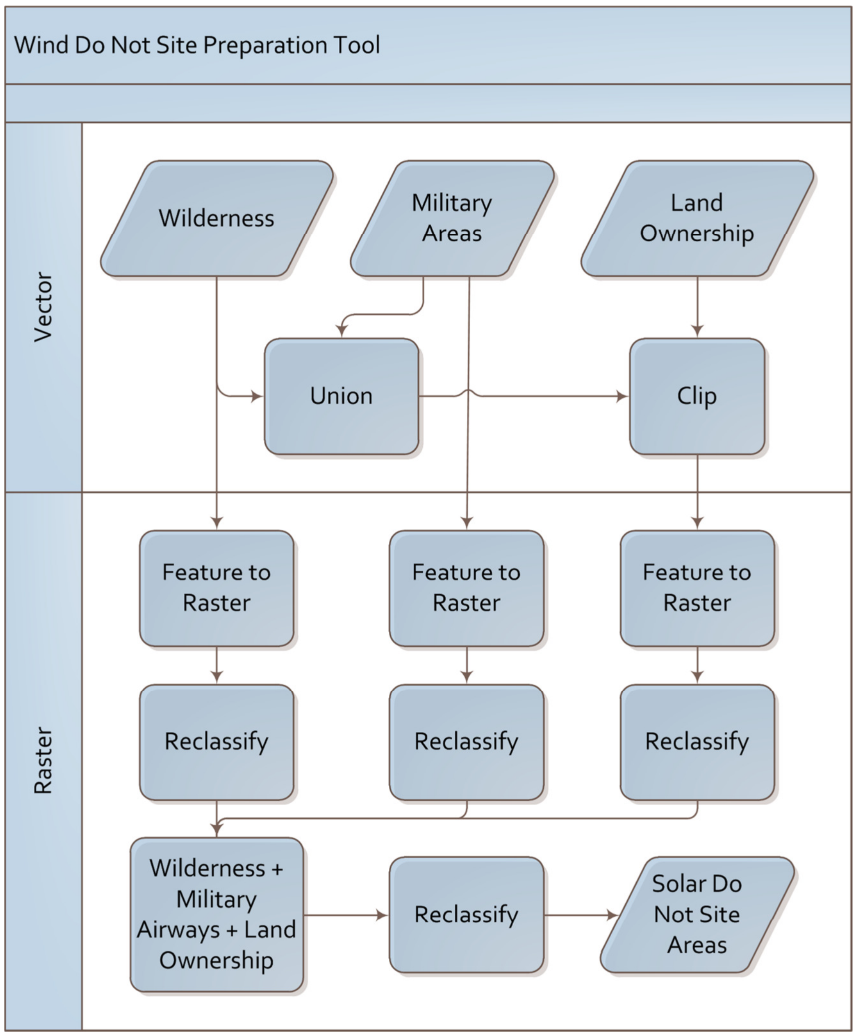

Figure 5-23 Model of the wind no-site areas raster creation process.

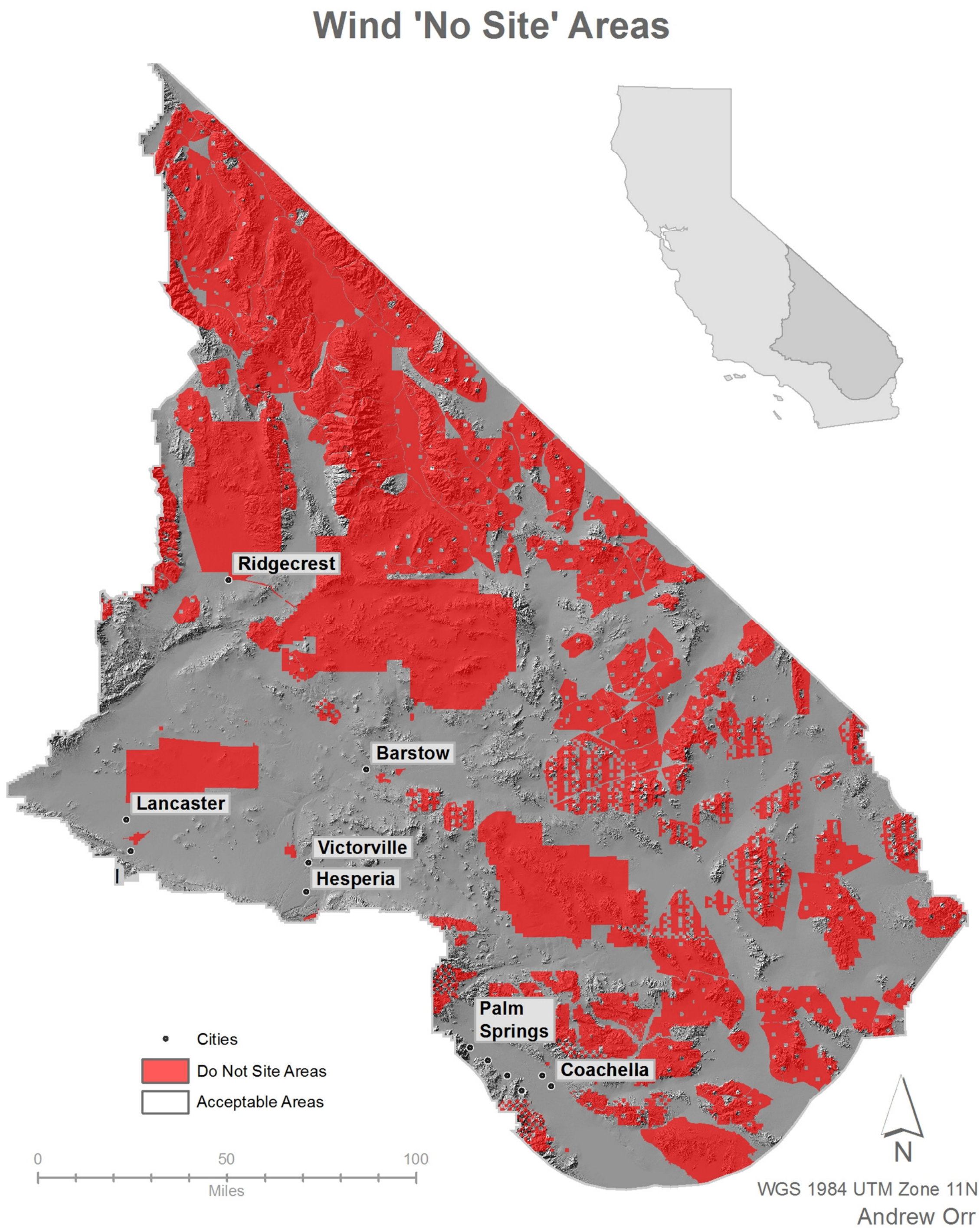

Figure 5-24 Map of the wind no site areas raster.

5.1.2 Creating Suitability Tools

The platform for creating the suitability tools in ArcGIS 10 also took place in Model Builder. After researching the tools in the spatial analyst toolbox, it was determined that the weighted overlay tool would provide the necessary customization and functionality. This was customized by adding several further processes to the pre-weighted overlay and post overlay operations (Figure 5-25).

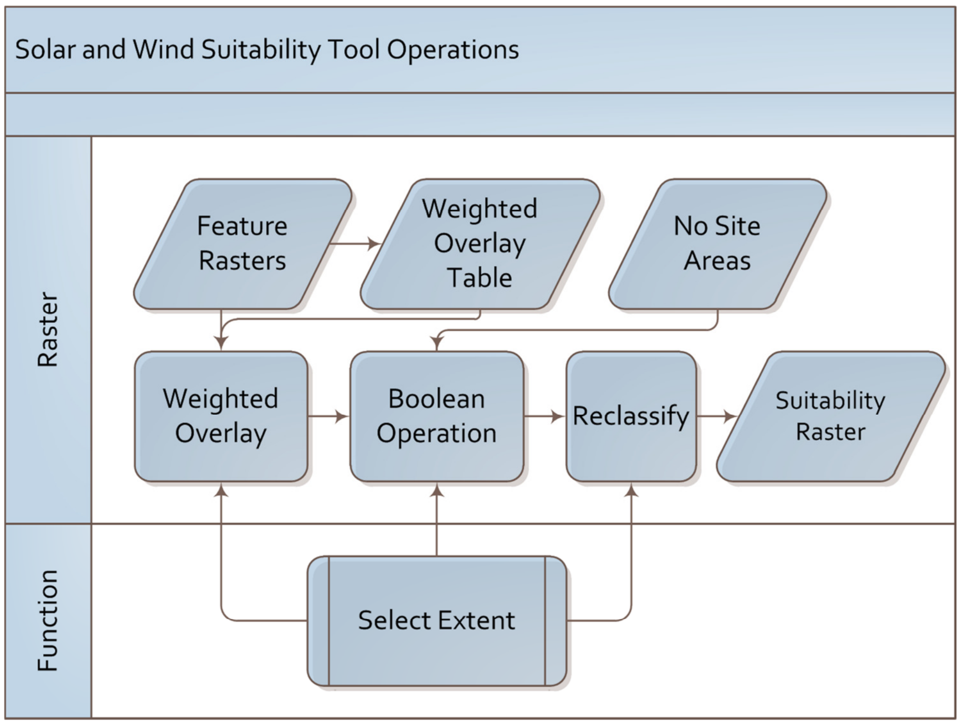

Figure 5-25 Model of the solar and wind suitability tool operations.

The three suitability tools have the same flow of operations. The first operation is depicted on the bottom section of Figure 5-25. This process, select extent, is responsible for specifying that the tool will only run in the user's screen view. This is key in preserving tool performance requirements (Section 6.1). The extent area is transferred to the weighted overlay, Boolean, and reclassify operations to insure each takes place only within the view extent.

Next, the weighted overlay table and features are input to the weighted overlay operation. The tables exist as a set of default values which allow an operator to quickly redefine selected variables. The values used as defaults were based on a review of the literature (Section 2.2). The next process, the exclusion operation, merges the no site raster on the weighted overlay raster, removing any areas that were considered not suitable. Reclassifying the results after the weighted overlay and exclusion operation takes any cells labeled as NoData and sets them to zero so they display in red. This changes any areas that may have not had data associated with the entire view extent and classifies them as red so the user does not consider them suitable. This functionally displays the outside regions as red when operating the tools on the edge of the project area

Since all three tools have the same design processes, the differences exist only in the set of feature rasters and the weighted overlay tables used to weigh the feature rasters. Appendix B lists the default values for the weighted overlay tables.

The last phase of project implementation required building a map document file (also referred to as an .mxd file) in ArcMap. The map document contains five groupings of layers: reference, do not site, completed rasters, original data, and base map layers. Within the reference grouping, layers represent project area roads, boundaries, and cities. The do not site grouping contains the breakdown of files used in the do not site rasters. These are intended to show the user why certain areas are identified as not suitable. All rasters used in the suitability tools were added to the complete rasters grouping. The original data grouping contains the original vector files after projection to WGS 1984 UTM Zone 11N. The base map grouping houses the project DEM with a hillshade raster as a visual reference for the operator.

5.2 Interface

The interface for the suitability tools (Figure 5-26) is straightforward. The first option at the top shows the extent at which the user wishes to run the tool. For best performance, Same as Display is selected, which runs the tool on the currently displayed area. Below the display extent is the weighted overlay table with four columns: the name of the feature layer the other columns describe; the percent weighting of the feature layer mentioned in the first column; the sub-features in their coded form (see Appendix B or tool help for references); and where the user inputs the sub-feature weighting scale. The default values provide a structure for user-specified weighting. In order to retain the weighting scale, the user must select the save icon at the lower right of the table. Existing tables can also be opened here. The evaluation scale is for advanced users and this allows one to change the scale from 1-9 for sub-feature weighting to another value. When a different scale is used, the resulting raster symbology must be reviewed and a color ramp applied to view the raster cells in their classified state. This is indicated by blue pixels when the results display. The last option is a save option which allows the user to specify the place and name of the results, useful for a comparative analyses.

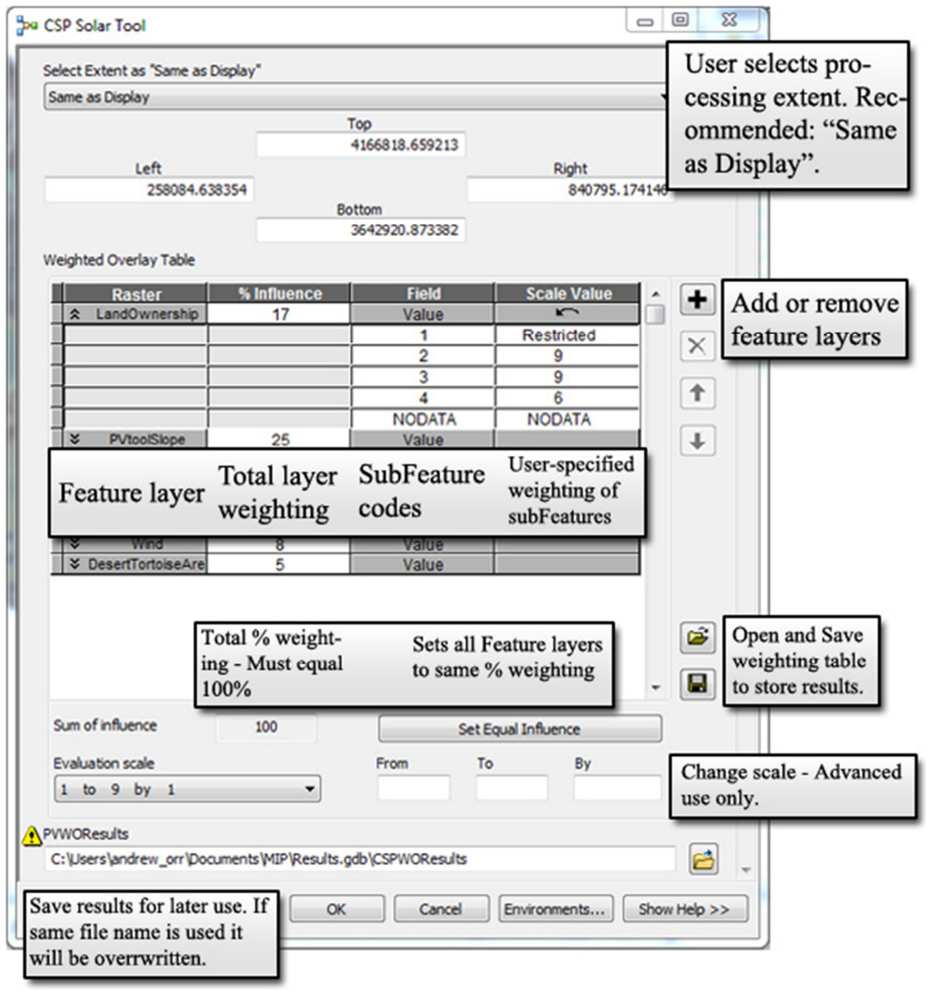

Figure 5-26 Tool interface for suitability tools.

5.3 Using the Suitability Tools

In order to use the suitability tools most efficiently, a set of directions is provided here. Using the tool help, accessed from the ArcGIS toolbox tools, can also help a user operate the tools properly.

In order to use the suitability tools, one must open ArcMap and create a map document that shows the extent of the Mojave Desert data region. Alternatively, a map document, titled Renewable Energy, has already been prepared for a working environment. The user must first locate the area of interest. The map document includes a set of bookmarks which show a few locations where renewable energy facilities exist. Once the area is located, note the scale of the map. For best results, choose a scale between 1:100,000 and 1:250,000.

Open the toolbox in the RenewableEnergy geodatabase from the catalog window. Double click the tool needed for the analysis. Once the tool displays, the first choice is to select the extent the analysis will be performed on. The user should choose Same as Display for this option. The extent is displayed in the four boxes below the extent dropdown button. The spreadsheet, below the extent boxes, displays the default-weighting scheme. Consult the tool help and Figure 5-26 for a description of how to interact with the spreadsheet. The default weighting scale is set to "one to nine by one" which indicates the user has an option to assign integer weights between one and nine in the spreadsheet. The tools use a value of one to indicate lowest suitability and a value of nine to indicate highest suitability.

The user can save the results raster using the last option on the tool interface, titled PVWOResults. The tool overrides the file name so unique names are not needed, but previous data will be lost if the name already exists.

A set of progress bars is displayed on the screen indicating the tool is running properly. Once finished, the results display on the screen. In the table of contents panel, one will see the scale of the data displayed in the data view. If a user changed the rating scale from one to nine to anything else, blue cell values will display. This indicates the color scale has to be recomputed. Double click the results raster in the table of contents panel to open the properties window. Click the Symbology tab. Click the button that reads Add all values and click okay to close the window. This will remove the blue cells and the table of contents should reflect the new suitability scale.

The map is now ready for analysis. Using the groupings of various layers in the map document, one can discern which layers came into play for each suitability analysis and decide what changes need to be made to the weighting values to reflect the most accurate set of data priorities for the area of interest.

5.4 Summary

The main phases of project implementation were: gather and re-project data into a geodatabase, create and run data preparation tools, and create three suitability tools. Creating the data preparation tools took considerable time and constituted the majority of the project.

Chapter 6 – Results and Analysis

The performance of the suitability tools exceeded the client's expectations (F. Duke, personal communication, May 15th, 2011). The client was excited to see the speed and accuracy of the results. At the time of this writing, the tool is under consideration for use in the Desert Renewable Energy Conservation Plan (DRECP) (F. Duke, personal communication, May 20th, 2011) who would use these tools in their study of area considerations for renewable energy facilities in the Mojave Desert region.

6.1 Tool Performance

Because the tool will ultimately be accessed via a geoprocess on an online map, speed considerations were crucial for the success of this project. The native resolution of the DEM matches a 1:113,386 scale and the intended performance of 30 seconds or less applies to scales below 1:250,000. It is suggested the tool be used within 1:100,000 to 1:250,000 for best accuracy and performance with an extent view of 24,000 meters to 18,000 meters to 60,000 meters to 45,000 meters respectively. Among the three tools, the operation speeds vary slightly, with the PV tool running the fastest, followed by the CSP tool, and lastly the wind tool. This is reflected by the number of layers used in the calculations. Table 6-2 shows an average set of times for the three tools, in three locations, with three trials of the tool at each location. The dimensions of the map scales are shown in Table 6-1.

Table 6-1 Map scale extents for speed performance results.

Map Scale	West / East Distance	North / South Distance
1:100,000	23,786 meters	17,913 meters
1:250,000	59,466 meters	44,781 meters

The computer used for these benchmarks was an Apple MacBook Pro running the 64-bit Windows Seven operating system in Bootcamp mode. The processor was a dual core Intel i5 processor running at 2.40 gigahertz. The system was equipped with 8 gigabytes of memory.

Table 6-2 Average tool performance times (in seconds) at various locations.

Tool	Scale	AVSR1	Ivanpah	San Gorgonio
PV	1:100,000	13.4		
	1:250,000	28.4		
CSP	1:100,000		14.1	
	1:250,000		30.3	
Wind	1:100,000			14.5
	1:250,000			30.1

6.2 Comparative Analysis

Three site locations were used for a comparative analysis of the tools' result rasters. The three sites were the photovoltaic facility AV Solar Ranch One, the concentrating solar power facility at Ivanpah, and the wind power facility at San Gorgonio Pass. Using these locations, each suitability tool was compared to a siting which could have utilized a tool like this when their locations were being considered.

6.2.1 AV Solar Ranch One

The first location examined was the AV Solar Ranch One (AVSR1) site in the Antelope Valley. Approved in July, 2010, AV Solar Ranch One will be a 2,100 acre, 230 megawatt photovoltaic power facility expected to be completed in December of 2013 (First Solar, 2011). The location is along Highway 138, 16 miles west of the Highway 14 intersection. Rosamond and Lancaster are the nearest cities.

The default values (Appendix B) of the PV suitability tool were used when creating the map below (Figure 6-1). With this siting criterion, the location of AVSR1 averaged a seven on the suitability raster scale. This indicated a good location. An analysis of the layers that went into making the location a seven and not something more prominent revealed that there was greater than ideal wind in the region, which negatively influenced the result. The wind for the project location was between a power class three and four, which means the average wind for the area was 14.3 to 16.8 miles per hour (Figure 6-1, lower left map). The solar insolation values for the site were less than other areas of the Mojave Desert, but still within the 6,750 cutoff limit expressed by Ignizio (2010) (Figure 6-1, lower center map). The slope of the area ranged from 0.75 to 1.50 percent slope within the site location, which is perfect to limit the amount of terrain disruption for construction (Figure 6-1, lower right map). In the case of this solar facility, the tool indicates the location was planned well given the input criteria the PV Solar Tool utilizes.

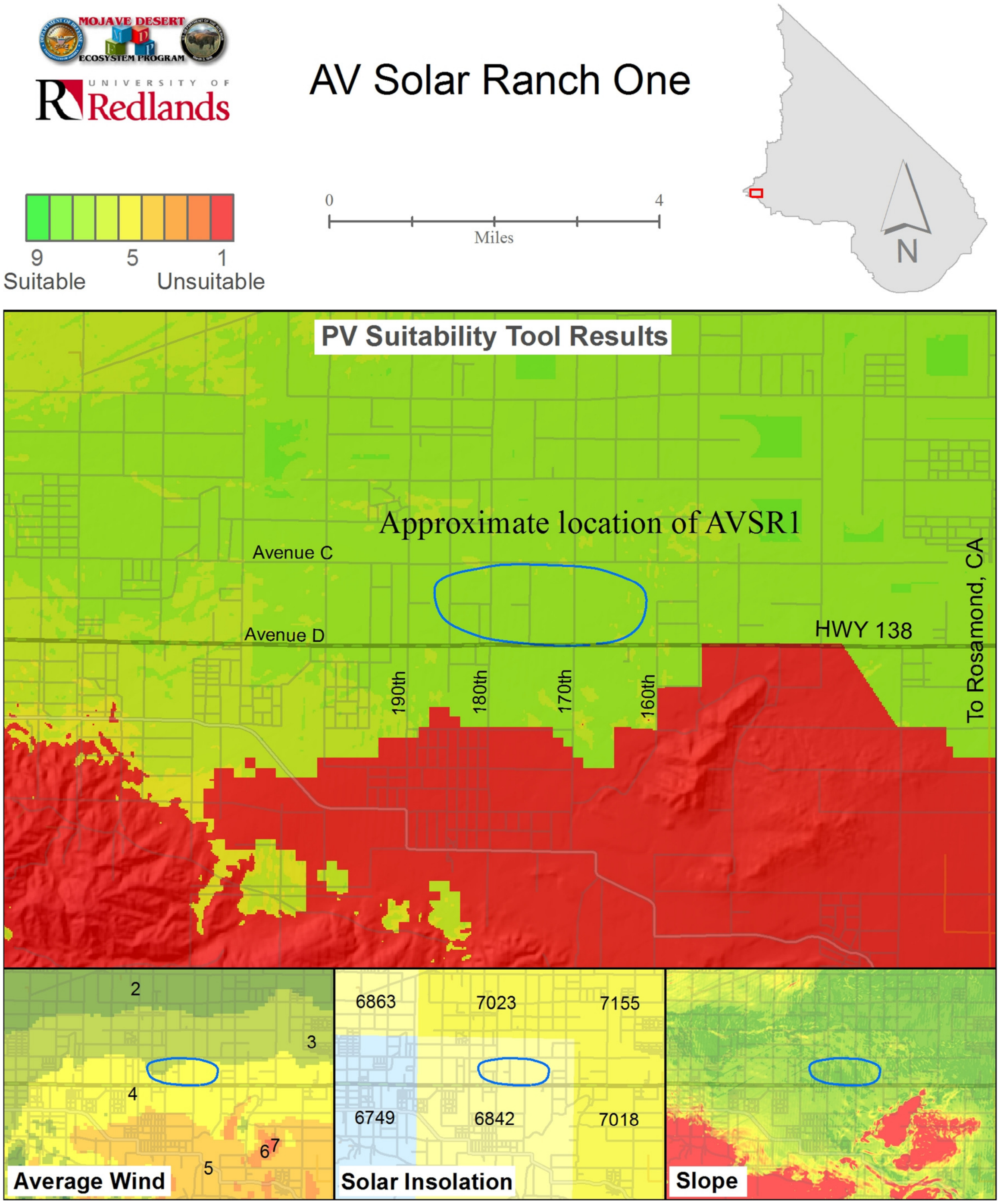

Figure 6-1 Maps of suitability results for PV facility, AVSR1.

6.2.2 Ivanpah

The location of the CSP facility is approximately five miles from the Nevada/California border and two miles from Interstate 15. This is known as the Ivanpah facility. Operated by BrightSource Energy, construction has been in process since October, 2010 and it is the largest solar plant project undergoing development in the world. The facility will be a 392 megawatt system with three centralized towers that have the sunlight reflected to each tower by arrays of mirrors on the ground (Figure 6-2) (Brightsource, 2010).

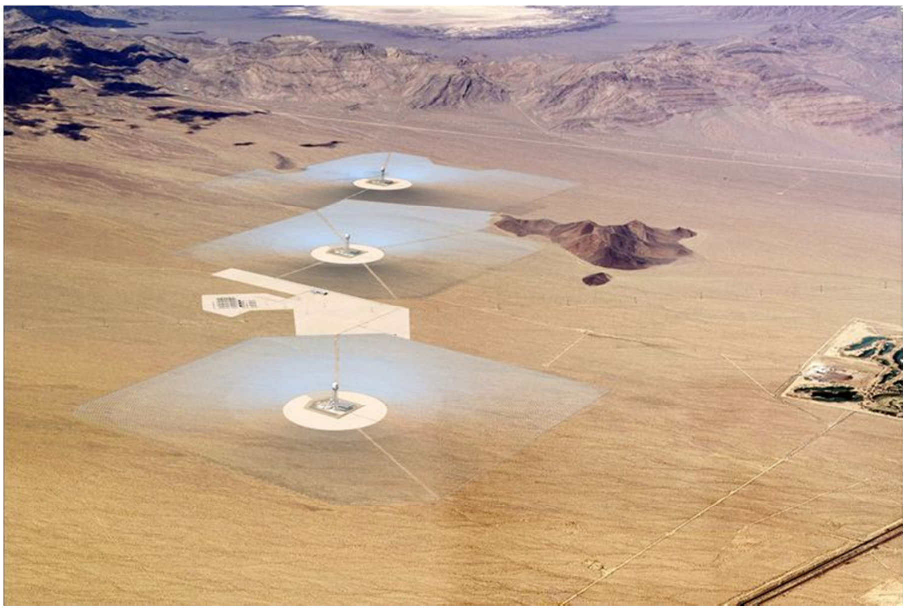

Figure 6-2 Rendering of the Ivanpah CSP facility (from BrightSource, 2010).

Figure 6-3 displays the CSP Solar Tool results achieved using the default values for the suitability analysis. The Ivanpah facility fell primarily in the green to yellowish green values, indicating a strong suitability. There were a few stretches of red in the northwest region of the area. These were a result of the banding effect discussed in Section 5.1.1 of the slope raster creation tool. Because the banding occurred in the slope derived from the DEM, and the errors are mostly negligible in amplitude, the red conflicting pixels were dismissed from negatively altering the positive results of the tool's assessment. The acceptable pixel values in the project area ranged from six to eight, with the majority being values of seven. The most suitable locations, displayed in a darker green with a pixel value of eight, were found in the southern extent of the blue polygon. Examining the data that were responsible for that area, it is evident that it came from the flattest slope values (Figure 6-3, lower right map). The location fell within very high areas of solar insolation. The insolation raster showed a project area value of 7402 $Wh/m^2/day$ (Figure 6-3, lower center map). The location picked for the Ivanpah facility is in a premium, low wind area of the Mojave Desert with wind speeds ranging from zero to 12.5 miles per hour. Given the close proximity the location has to I-15, the accessibility was clearly an advantage when picking the location. The suitability tool's proximity to nearest roads raster confirmed this location was premium in respect to this part of the analysis.

The siting of this facility was well chosen in terms of the suitability assessment the CSP tool provided. Possibly the only location that could have offered better siting would be to bring the facility a mile closer to the interstate in order to utilize some of the lower-average slope ground, indicated in the dark green color of the map.

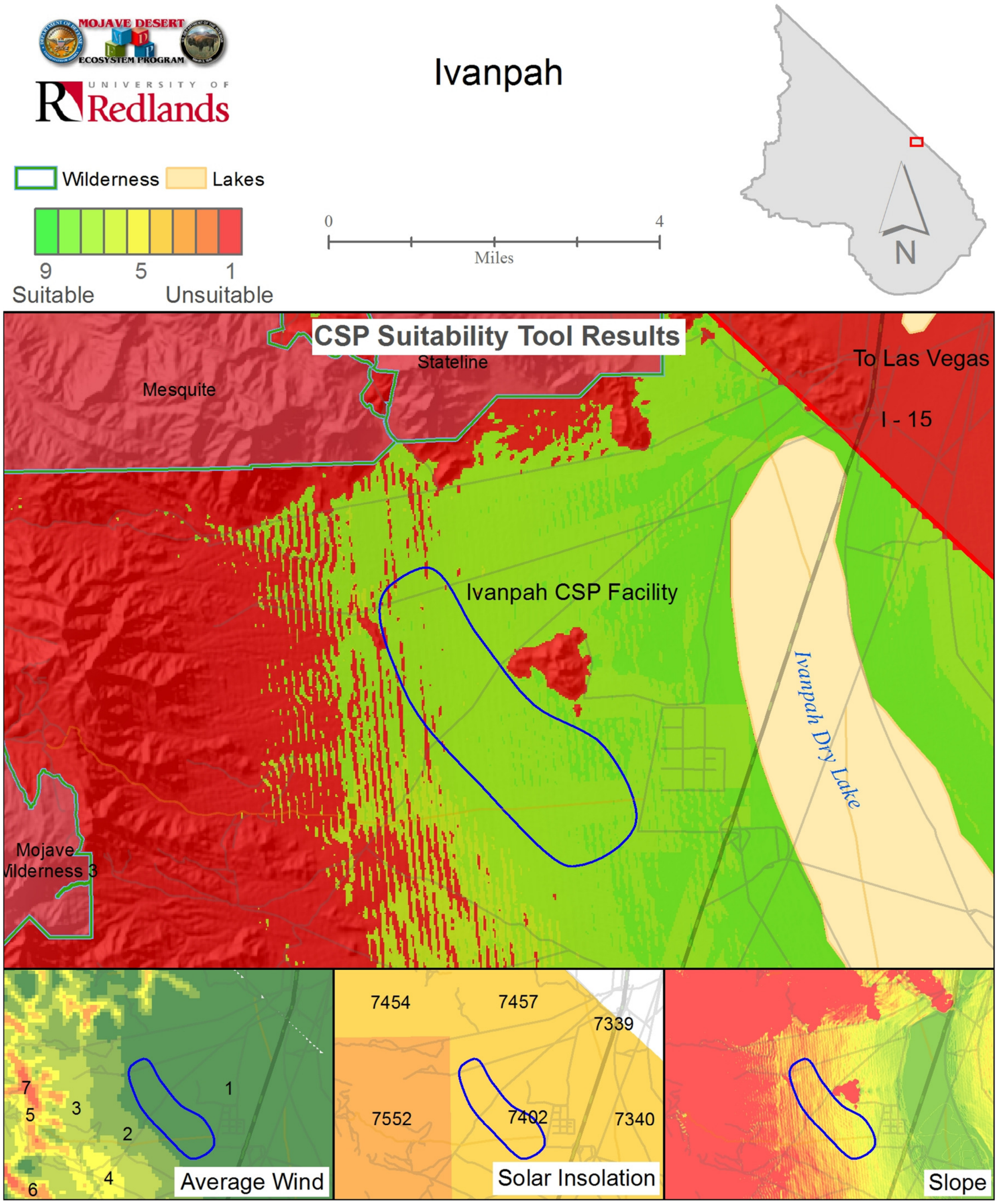

Figure 6-3 Maps of suitability results for the Ivanpah CSP facility.

6.2.3 San Gorgonio Pass

The final renewable energy location examined was the San Gorgonio Pass wind farm. In 2007, the farm consisted of 2,500 turbines with more being erected each year. The capacity at that time was 359 MW and accounted for 11% of global wind power (The Encyclopedia of Earth, 2007). Figure 6-4 is an Ikonos image of the wind farm (National Aeronautics and Space Administration [NASA], n.d.).

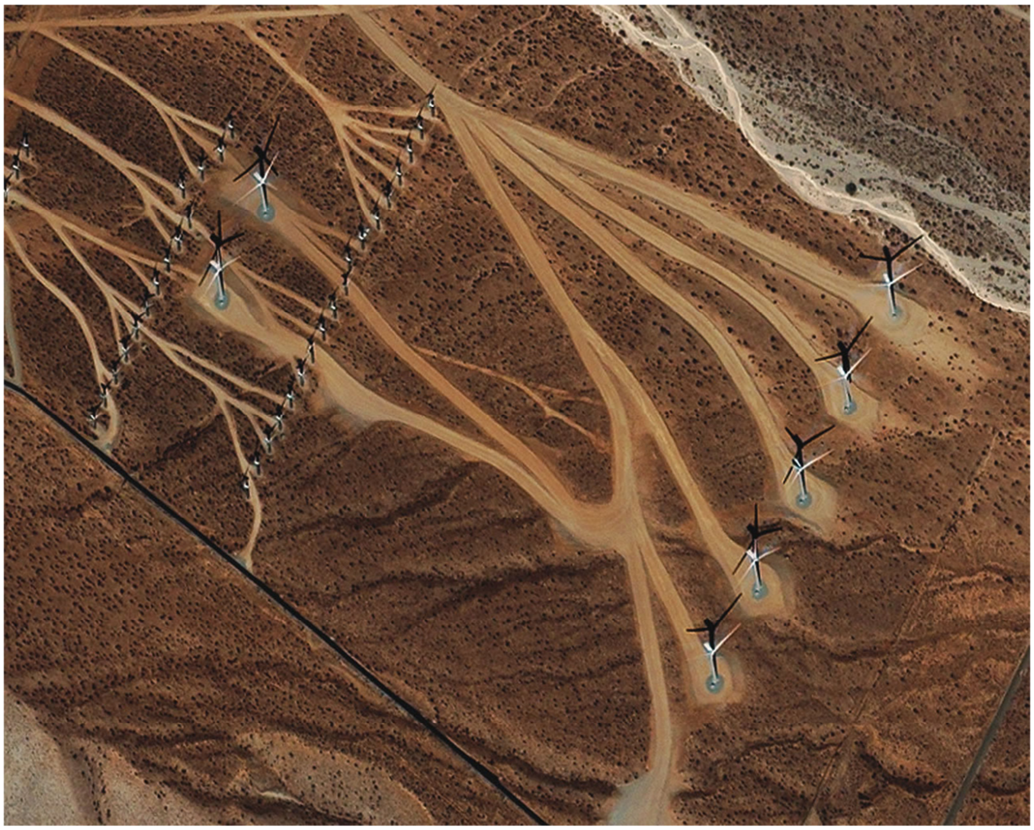

Figure 6-4 Ikonos image of the San Gorgonio Pass wind farm.

After running the wind suitability tool, a conclusion was reached that the tool correctly sited the San Gorgonio Pass wind farm (Figure 6-5). The tool creates a result raster with the project area suitability primarily rated an eight. Roughly a third of the area was rated very positively, with a value of nine. While the siting tool still used the default values, the wind was the prevailing factor for why the area was sited so positively. The wind power class was rated a seven here (Figure 6-5, lower right map). Land ownership also played a key factor in the high levels of suitability. The BLM owns much of the land at the location and this is a highly weighted value in the tool's suitability table. This is depicted in the lower center map of Figure 6-5. Private property in this map is illustrated in a lighter green. Many of the wind farms are on the mountainsides surrounding the canyon floor. The default values of the wind suitability tool prohibited siting at slopes over 14 percent. From field observations it is possible those wind turbines fall within red areas on the suitability map. This is a good example of where changing the values of the suitability tool to reflect a site-specific case is required.

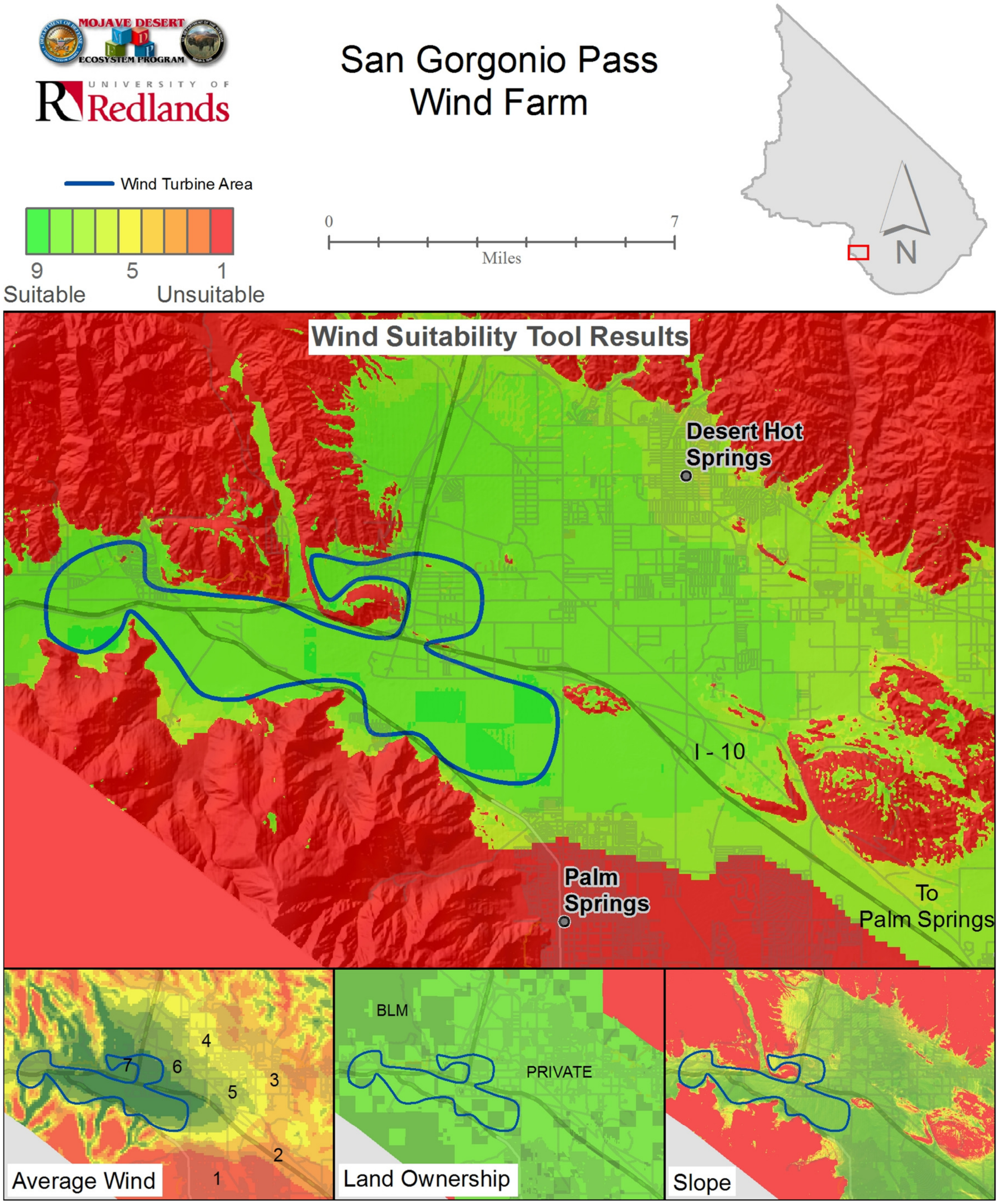

Figure 6-5 Maps of suitability results for the San Gorgonio pass wind farm.

6.3 Conclusions

These three examples demonstrate the usefulness of this tool to accurately locate areas of potential siting capability for photovoltaic, concentrating solar, and wind power applications. These results ensued from using the default values of the tools. More accurate results may be achieved by using specific criteria specified by the user.

Chapter 7 – Conclusions and Future Work

Developing an accurate geographic information systems (GIS) tool that can quickly site premium areas of potential renewable energy development through large expanses of terrain is feasible. The goals this project addressed were to develop a GIS tool which would run in ArcInfo 10 software which allowed a user to input their own data, assign a weighted scale of feature importance, and quickly export a graphic which depicted areas of highest suitability. This was achieved through development of 13 tools which prepared data for use in a set of three renewable energy tools: photovoltaic solar, concentrating solar, and wind power.

Through personal communication with the client, Schulz and Duke expressed that the tools did what they had requested and that they are excited to get the tools in the hands of agencies and organizations which can use them (R. Schulz, personal communication, April 8th, 2011) (F. Duke, personal communication, May 15th, 2011). The one concern, which Duke expressed, is that he had envisioned an easier-to-use interface. Creating a more user-friendly interface is possible in the second phase of the project: web implementation.

The client had expressed a need for the tools to be accessible in an online map. This was initially removed from the project scope in order to concentrate on the accuracy and development of the suitability tools. However, the web implementation is a critical piece of the project so work on this aspect will likely transpire quickly. This will be done by MDEP. During the web implementation, a cleaner user interface is a possibility. Using an application programmer interface (API) such as Flex, one could develop a Flex widget which parses the interface with the geoprocessing tool and allows an interface to easily include sliders to distribute weighted values for the suitability feature rasters.

Further customization might have been possible by coding the suitability tools in Python rather than Model Builder. Model Builder was chosen as the tool platform due to its ease of customization and the graphical elements are easy to understand and modify. However, by using the ArcPy module of Python, raster and cell mathematical operations could be custom fit to the tool's use. Instead of the arithmetically simple weighted overlay operations, one could tailor specific equations into the cell math to yield more advanced suitability modeling.

As the proximity rasters exist now, there is not a size or transmission capacity consideration of the roads, rivers, and electrical lines during the creation of the respective rasters. Incorporating this additional information into a raster may prove to be more difficult than using the current system of allowing the user to set the weighted values based strictly on the distance from nearest feature. One possibility could be to create a set of priority classes in which the user selects the suitability tool weights based on knowledge of what priority class they wish to use. These priority classes could be incorporated into the road, river, and electrical line rasters as showing features of greater capacity with longer distances since the value of the larger features allow for a cost difference to be less of an impact on the total cost of development. Figure 7-1 summarizes this idea where a small road (top) will have smaller priority areas because it is less prominent than the larger road below. Areas that overlap between multiple feature area buffers could be considered an even higher priority. While this is an idea of the process, more research would be required to make sure this is an acceptable way to represent the data.

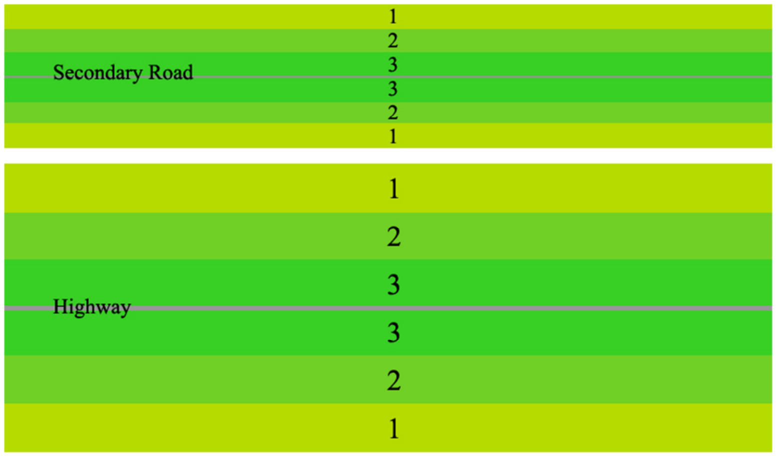

Figure 7-1 System for creating proximity rasters with favored features.

Incorporation of migratory bird flight paths into the wind suitability tool would also be a good idea. Wind turbines can approach heights of up to 500 feet, encroaching into the air space of migratory birds. This may be a serious issue for birds and needs to be researched and addressed for a proper analysis of a particular area.

The completion of this project came about through multiple attempts at creating a set of tools which would convert vector data into raster files and then incorporate them in a weighted overlay tool. Through trial and error, the procedures outlined in this paper evolved into their present state.

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Appendix A. Preparation Tool Descriptions

Table A-1 Properties of the project DEM and electrical lines raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
DEM	The DEM is the core raster component of the three suitability tools. While not a tool in and of itself, the DEM is responsible for creating a common ground for all rasters of the suitability and data preparation tools. Additionally, the DEM is responsible for deriving slope and elevation range rasters for PV, CSP, and wind suitability tools.	N/A	In order for the tool to work, all raster cells are based off of a DEM (Esri GRID format) that resides in the Geodatabase. The DEM must be titled strictly, "DEM" for the tools to read it by default. The tools request information from this DEM to specify cell size, extent of project area, and a reference of where new cells originate from (extent).	N/A N/A
Electric Data	Tool creates a distance to electrical line raster for use in the PV, CSP, and wind suitability tools. The distance to nearest electrical line is calculated with a reclassified Euclidian distance operation offering a speed advantage, and further flexibility, over creating a multi-ring buffer and converting it to a raster. The unit for the Euclidean distance operation is a meter so the raster undergoes an operation in the raster calculator which multiplies the value by 0.000621371192 to convert the unit to miles.	"Enter Rivers Hydrology Feature Class" "Reclassification"	Must be a vector file--preferred to be in line form. Reclassification is a parameter which allows the user to specify the classification range for which the electric line buffer distance raster will be built upon. The default is as seen to the right. The units are miles.	0 - 5 = 5 5 - 10 = 10 10 - 15 = 15 15 - 20 = 20 20 - 25 = 25 25 - 30 = 30 30 - 35 = 35 35 - 40 = 40 40 - 45 = 45 NoData = NoData

Table A-2 Properties of the land ownership and military airspace raster tools.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
Land Ownership Data	Tool creates a land ownership raster for use in PV solar, CSP solar, and wind power suitability tools.	"Enter Land Ownership Feature Class"	Must be a vector file--preferred to be in polygon form.	No Site = 1
		"Weighted Overlay Value Field"	Tool requires a "weighted overlay" field which specifies which classification value to use as seen to the right.	State = 2 Federal = 3 Private = 4
Military Airspace	This tool provides a raster for the wind energy suitability tool which restricts areas of various altitude airspaces for military operations.	"Enter Airspace Feature Class"	Must be a vector file--preferred to be in polygon form.	SFC = 0
		"Reclassification"	Reclassification is a parameter which allows the user to specify the classification range for which the military airspace raster will be built upon. The default is as seen to the right. The units are feet above ground level (AGL) for each airspace. Special use air space (SUAS) is an undefined class and thus it is an independent classification value. If it is not wanted to be considered useable area for the suitability model it can be set as a 'restricted' value. The same goes for Department of Defense (DOD) area. SFC is surface airspace defined as airspace from the ground, up.	100 AGL = 100 200 AGL = 200 300 AGL = 300 500 AGL = 500 1000 AGL = 1000 1500 AGL = 1500 2500 AGL = 2500 7500 AGL = 7500 SUAS = 7777 DOD = 8888 NoData = 9999

Table A-3 Properties of the solar slope raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
PV, CSP Slope Data	Tool creates a percent slope raster for use in PV and CSP solar suitability tools. Tool output is a raster with slope values, in integer form, of the original slope multiplied by 100. This is to preserve two decimal points of accuracy when integer function is applied. When reading the reclassified values, please note that the value read is the maximum of the interval between the previous value and value read. Example: the value 325 is a classified value from the previous entry, 300, through 325. *Also note, due to the 100 multiplication factor, the value 325 corresponds to 3.25% slope, 425 to 4.25% slope, etc.*	"Enter DEM to use"	Use DEM as specified from "DEM" restrictions listed above.	0 - 25 = 25
		"Reclassification"	The default classification breaks the percent slope into 1/4, percent slope intervals up to a maximum percent slope of 7 degrees. This allows the user to fine-tune the placement restrictions of the solar facility in the weighted overlay operation. The user can choose to use the default weighted values or preform a statistical approach of their own choosing to weight specific percent slope values independently.	25 - 50 = 50 50 - 75 = 75 75 - 100 = 100 100 - 125 = 125 125 - 150 = 150 150 - 175 = 175 175 - 200 = 200 200 - 225 = 225 225 - 250 = 250 250 - 275 = 275 275 - 300 = 300 300 - 325 = 325 325 - 350 = 350 350 - 375 = 375 375 - 400 = 400 400 - 425 = 425 425 - 450 = 450 450 - 475 = 475 475 - 500 = 500 500 - 525 = 525 525 - 550 = 550 550 - 575 = 575 575 - 600 = 600 600 - 625 = 625 625 - 650 = 650 650 - 675 = 675 675 - 700 = 700 700 - 100,000 = 100,000 NoData = NoData

Table A-4 Properties of the roads raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
Roads Data	Tool creates a distance to roads raster for use in the PV, CSP, and wind suitability tools. The distance to nearest road is calculated with a reclassified Euclidean distance operation offering a speed advantage, and further flexibility, over creating a multi-ring buffer and converting it to a raster. The unit for the Euclidean distance operation is a meter so the raster undergoes an operation in the raster calculator which multiplies the value by 0.000621371192 to convert the unit to miles.	"Enter Roads Feature Class"	Must be a vector file--preferred to be in line form.	0.00 - 0.25 = 25
		"Reclassification"	Reclassification is a parameter which allows the user to specify the classification range for which the roads buffer distance raster will be built upon. The default is as seen to the right. The units are miles.	0.25 - 0.50 = 50
				0.50 - 0.75 = 75
				0.75 - 1.00 = 100
				1.00 - 1.25 = 125
				1.25 - 1.50 = 150
				1.50 - 1.75 = 175
				1.75 - 2.00 = 200
				2.00 - 2.25 = 225
				2.25 - 2.50 = 250
				2.50 - 3.00 = 300
				3.0 - 3.5 = 350
				3.5 - 4.0 = 400
				4.0 - 5.0 = 500
				5.0 - 6.0 = 600
				6.0 - 7.0 = 700
				7.0 - 8.0 = 800
				8.0 - 9.0 = 900
				9.0 - >10 = 1000
				NoData = NoData

Table A-5 Properties of the insolation, solar no site areas, and wind raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
Solar Data	Tool creates a solar insolation raster for use in PV solar and CSP solar suitability tools.	"Enter Solar Feature Class"	Must be a vector file--preferred to be in polygon form.	5228 - 6250 = 6250
		"Reclassification"	Reclassification is a parameter which allows the user to specify the classification range for which the solar insolation raster will be built upon. The default is as seen to the right.	6250 - 6500 = 6500
				6500 - 6750 = 6750
				6750 - 7000 = 7000
				7000 - 7250 = 7250
				7250 - 7500 = 7500
				7500 - 7750 = 7750
				7750 - 8000 = 8000
				8000 - 8250 = 8250
				NoData = NoData
Solar Do Not Site Areas	Tool creates a raster used as a Boolean "false" raster which outlaws areas of no suitability from the suitability tool results. For use with the PV and CSP solar suitability tools.	"Enter Desert Tortoise Habitat"	Must be a vector file--preferred to be in polygon form.	0 - 1 = 1
		"Enter Wilderness Areas"	Must be a vector file--preferred to be in polygon form.	NoData = NoData
		"Enter Lakes Data"	Must be a vector file--preferred to be in polygon form.	
Wind Data	Tool creates a mean wind speed raster for use in wind suitability tools.	"Enter Wind Data Feature Class"	Must be a vector file--preferred to be in polygon form.	0.0 - 12.5 = 1
			The units outputted are wind "Power Class" values as described by NREL. The values are as seen to the right.	12.5 - 14.3 = 2
				14.3 - 15.7 = 3
				15.7 - 16.8 = 4
				16.8 - 17.9 = 5
				17.9 - 19.7 = 6
				> 19.7 = 7

Table A-6 Properties of the wind no site area and wind elevation raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
Wind Do Not Site Areas	Tool creates a file used as a Boolean "false" raster which outlaws areas of no suitability from the suitability tool results. For use with the wind suitability tool.	"Enter Desert Tortoise Habitat"	Must be a vector file--preferred to be in polygon form.	0 - 1 = 1
		"Enter Wilderness Areas"	Must be a vector file--preferred to be in polygon form.	NoData = NoData
		"Enter Military Operation Areas Data"	Must be a vector file--preferred to be in polygon form.	
Wind Elevation Range	Tool creates an elevation raster for use in the wind suitability tool. The elevation is expressed in feet for an easy association with US measurement standards. The factor used for converting meters (from DEM) to feet is 3.2808399.	"Enter DEM"	Must be a DEM with cell values representing meter elevation values.	-773.387695 = 500
		"Reclassification"	Reclassification is a parameter which allows the user to specify the classification range for the elevations one wishes to limit wind facilities to be built at. The default is as seen to the right.	500 - 1000 = 1000
				1000 - 1500 = 1500
				1500 - 2000 = 2000
				2000 - 2500 = 2500
				2500 - 3000 = 3000
				3000 - 3500 = 3500
				3500 - 4000 = 4000
				4000 - 4500 = 4500
				4500 - 5000 = 5000
				5000 - 5500 = 5500
				5500 - 6000 = 6000
				6000 - 6500 = 6500
				6500 - 7000 = 7000
				7000 - 7500 = 7500
				7500 - 8000 = 8000
				8000 - 8500 = 8500
				8500 - 9000 = 9000
				9000 - 14500 = 14500
				NoData = NoData

Table A-7 Properties of the wind slope raster tool.

Preparing Data tools	Description	Parameters	Requirements	Default Weighted Overlay Scale
Wind Slope Data	Tool creates a percent slope raster for use in wind suitability tool. Tool output is a raster with slope values, in integer form, of the original slope multiplied by 100. This is to preserve two decimal points of accuracy when integer function is applied. When reading the reclassified values, please note that the value read is the maximum of the interval between the previous value and value read. Example: the value 325 is a classified value from the previous entry, 300, through 325. *Also note, due to the 100 multiplication factor, the value 325 corresponds to 3.25% slope, 425 to 4.25% slope, etc.*	"Enter DEM"	Use DEM as specified from "DEM" restrictions listed above.	0 - 50 = 50
		"Reclassification"	The default classification breaks the percent slope into 1/4 percent slope intervals up to a maximum percent slope of 17 degrees. This allows the user to fine-tune the placement restrictions of the solar facility in the weighted overlay operation. The user can choose to use the default weighted values or preform a statistical approach of their own choosing to weight specific percent slope values independently.	50 - 100 = 100 100 - 150 = 150 150 - 200 = 200 200 - 250 = 250 250 - 300 = 300 300 - 350 = 350 350 - 400 = 400 400 - 450 = 450 450 - 500 = 500 500 - 550 = 550 550 - 600 = 600 600 - 650 = 650 650 - 700 = 700 700 - 750 = 750 750 - 800 = 800 800 - 850 = 850 850 - 900 = 900 900 - 950 = 950 950 - 1000 = 1000 1000 - 1050 = 1050 1050 - 1100 = 1100 1100 - 1150 = 1150 1150 - 1200 = 1200 1200 - 1250 = 1250 1250 - 1300 = **1300** 1300 - 1350 = 1350 1350 - 1400 = 1400 1400 - 1450 = 1450 1450 - 1500 = 1500 1500 - 1550 = 1550 1550 - 1600 = 1600 1600 - 1650 = 1650 1650 - 170000 = 1700 NoData = NoData

Appendix B. Suitability Tool Weighting Tables

Table B-1 Properties of the photovoltaic solar suitability tool.

Tool requires "extent" to be set with "Same as Display" for best performance. Tool can also run as other extents with an increase in tool calculation times.

The default settings for the weighted overlay table provide a close approximation to what a user may wish to input. Adjustments can be made to fine tune the parameters and allow the user to increase or decrease tool accuracies. The default weighted overlay scale is 1-9 with 1 being an unacceptable siting location and 9 being an optimal site location. The tool allows a user to utilize their own scale in the lower field of the window entitled "Set evaluation scale." When a new scale is used, you may not use a value larger than the highest number of categories within one data set. In this tool, the critical number is < 30. When using a user-defined scale, the tool will create an approximation of new values based on the defaults defined. Please note that the layer symbology will only work for a scale of 1-9 and that any other scale will create a raster with random color values. When using a different scale, an easy method to re-symbolize the new data is to simply click the "add all values" button in the layer Properties: Symbology tab. Blue denotes data that is not symbolized.

PVtoolSlope = 25% (Slope x 100)
25 = 9
50 = 9
75 = 9
100 = 9
125 = 8
150 = 8
175 = 7
200 = 7
225 = 6
250 = 6
275 = 5
300 = 5
325 = 4
350 = 4
375 = 4
400 = 3
425 = 3
450 = 3
475 = 3
500 = 1
525 = 1
550 = 1
575 = 1
600 = Restricted
625 = Restricted
650 = Restricted
675 = Restricted
700 = Restricted
100000 = Restricted
NODATA = NODATA

SolarInsolation = 20% (Wh/m^2/day)
6250 = Restricted
6500 = 1
6750 = 2
7000 = 3
7250 = 5
7500 = 7
7750 = 8
8000 = 9
8250 = 9
NODATA = NODATA

LandOwnership = 16%
(No Site) 1 = Restricted
(State) 2 = 9
(Federal) 3 = 9
(Private) 4 = 6
NODATA = NODATA

ElectricLines = 14% (Miles)
5 = 9
10 = 8
15 = 7
20 = 6
25 = 5
30 = 4
35 = 3
40 = 2
45 = 1
255 = Restricted
NODATA = NODATA

Wind = 5% (Power Class Level)
1 = 9
2 = 6
3 = 3
4 = Restricted
5 = Restricted
6 = Restricted
7 = Restricted
NODATA = NODATA

Desert Tortoise = 5%
(Habitat) 0 = 1
(Suitable) 1 = 9
NODATA = NODATA

Roads = 15% (Miles x 100)
25 = 8
50 = 9
75 = 9
100 = 9
125 = 8
150 = 8
175 = 8
200 = 8
225 = 7
250 = 7
300 = 7
350 = 6
400 = 6
500 = 5
600 = 5
700 = 4
800 = 3
900 = 2
1000 = 1
NODATA = NODATA

Table B-2 Properties of the concentrating solar suitability tool.

Tool requires "extent" to be set with "Same as Display" for best performance. Tool can also run as other extents with an increase in tool calculation times.

The default settings for the weighted overlay table provide a close approximation to what a user may wish to input. Adjustments can be made to fine tune the parameters and allow the user to increase or decrease tool accuracies. The default weighted overlay scale is 1-9 with 1 being an unacceptable siting location and 9 being an optimal site location. The tool allows a user to utilize their own scale in the lower field of the window entitled "Set evaluation scale." When a new scale is used, you may not use a value larger than the highest number of categories within one data set. In this tool, the critical number is < 30. When using a user-defined scale, the tool will create an approximation of new values based on the defaults defined. Please note that the layer symbology will only work for a scale of 1-9 and that any other scale will create a raster with random color values. When using a different scale, an easy method to re-symbolize the new data is to simply click the "add all values" button in the layer Properties: Symbology tab. Blue denotes data that is not symbolized.

PVtoolSlope = 25% (Slope x 100)	**Electric = 10% (Miles)**	**SolarInsolation = 15% (Wh/m^2/day)**	**Rivers = 10% (Miles)**
25 = 9	5 = 9	6250 = Restricted	5 = 9
50 = 9	10 = 8	6500 = 1	10 = 8
75 = 8	15 = 7	6750 = 2	15 = 7
100 = 8	20 = 6	7000 = 3	20 = 6
125 = 7	25 = 5	7250 = 5	25 = 5
150 = 7	30 = 4	7500 = 7	30 = 4
175 = 6	35 = 3	7750 = 8	35 = 3
200 = 5	40 = 2	8000 = 9	40 = 2
225 = 5	45 = 1	8250 = 9	45 = 1
250 = 4	255 = Restricted	NODATA = NODATA	NODATA = Restricted
275 = 4	NODATA = NODATA	**LandOwnership = 17%**	
300 = 3	**toolRoads = 10% (Miles x 100)**	(No Site) 1 = Restricted	
325 = 3	25 = 8	(State) 2 = 9	
350 = 2	50 = 9	(Federal) 3 = 9	
375 = 1	75 = 9	(Private) 4 = 6	
400 = 1	100 = 9	NODATA = NODATA	
425 = Restricted		**Wind = 8%**	
	125 = 8	**(Power Class Level)**	
450 = Restricted	150 = 8	1 = 9	
475 = Restricted	175 = 8	2 = 6	
500 = Restricted	200 = 8	3 = 3	
525 = Restricted	225 = 7	4 = Restricted	
550 = Restricted	250 = 7	5 = Restricted	
575 = Restricted	300 = 7	6 = Restricted	
600 = Restricted	350 = 6	7 = Restricted	
625 = Restricted	400 = 6	NODATA = NODATA	
650 = Restricted	500 = 5	**Desert Tortoise = 5%**	
675 = Restricted	600 = 5	(Habitat) 0 = 1	
700 = Restricted	700 = 4	(Suitable) 1 = 9	
100000 = Restricted	800 = 3	NODATA = NODATA	
NODATA = NODATA	900 = 2		
	1000 = 1		
	NODATA = NODATA		

Table B-3 Properties of the wind power suitability tool.

Tool requires "extent" to be set with "Same as Display" for best performance. Tool can also run as other extents with an increase in tool calculation times.

The default settings for the weighted overlay table provide a close approximation to what a user may wish to input. Adjustments can be made to fine tune the parameters and allow the user to increase or decrease tool accuracies. The default weighted overlay scale is 1-9 with 1 being an unacceptable siting location and 9 being an optimal site location. The tool allows a user to utilize their own scale in the lower field of the window entitled "Set evaluation scale." When a new scale is used, you may not use a value larger than the highest number of categories within one data set. In this tool, the critical number is < 33. When using a user-defined scale, the tool will create an approximation of new values based on the defaults defined. Please note that the layer symbology will only work for a scale of 1-9 and that any other scale will create a raster with random color values. When using a different scale, an easy method to re-symbolize the new data is to simply click the "add all values" button in the layer Properties: Symbology tab. Blue denotes data that is not symbolized.

WindtoolSlope = 18% (Slope x 100)	**Wind = 19% (Power Class Level)**	**Electric = 10% (Miles)**	**Military Airspace = 15% (AGL Altitudes)**
50 = 9	1 = Restricted	5 = 9	0 = Restricted
100 = 9	2 = 2	10 = 8	100 = Restricted
150 = 9	3 = 4	15 = 7	200 = Restricted
200 = 8	4 = 6	20 = 6	300 = Restricted
250 = 8	5 = 8	25 = 5	500 = Restricted
300 = 8	6 = 9	30 = 4	1000 = 5
350 = 8	7 = 9	35 = 3	1500 = 8
400 = 7	NODATA = NODATA	40 = 2	2500 = 9
450 = 7	**toolRoads = 5% (Miles x 100)**	45 = 1	7500 = 9
500 = 6	25 = 8	255 = Restricted	(SUAS) 7777 = 9
550 = 6	50 = 9	NODATA = NODATA	(DOD) 8888 = Restricted
600 = 6	75 = 9	**Wind Elevation = 15% (Feet)**	9999 = 9
650 = 6	100 = 9	500 = 7	NODATA = NODATA
700 = 6	125 = 8	1000 = 7	**Desert Tortoise = 5%**
750 = 6	150 = 8	1500 = 7	(Habitat) 0 = 1
800 = 6	175 = 8	2000 = 8	(Suitable) 1 = 9
850 = 5	200 = 8	2500 = 8	NODATA = NODATA
900 = 5	225 = 7	3000 = 9	
950 = 4	250 = 7	3500 = 9	
1000 = 4	300 = 7	4000 = 9	
1050 = 4	350 = 6	4500 = 8	
1100 = 3	400 = 6	5000 = 8	
1150 = 3	500 = 5	5500 = 7	
1200 = 3	600 = 5	6000 = 5	
1250 = 2	700 = 4	6500 = 4	
1300 = 2	800 = 3	7000 = 2	
1350 = 1	900 = 2	7500 = Restricted	
1400 = 1	1000 = 1	8000 = Restricted	
1450 = 1	NODATA = NODATA	8500 = Restricted	
1500 = Restricted	**LandOwnership = 13%**	9000 = Restricted	
1550 = Restricted	(No Site) 1 = Restricted	14500 = Restricted	
1600 = Restricted	(State) 2 = 9	NODATA = NODATA	
1650 = Restricted	(Federal) 3 = 9		
1700 = Restricted	(Private) 4 = 6		
NODATA = NODATA	NODATA = NODATA		