# CONCENTRATED SOLAR THERMAL FACILITIES:

# A GIS APPROACH FOR LAND PLANNING

by

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ABSTRACT

In recent years, concerns about fuel costs, environmental degradation and climate change have prompted consideration of alternative methods for electrical power generation. Studies have revealed that solar technology offers an environmentally sensible alternative to traditional electrical generation methods. However, in order for this technology to take effect, rules, regulations, and geospatial requirements must be met. Site selection becomes more problematic and the restrictions regarding land development can delay a project by months or even years. This study demonstrates how a geographic information system can be effectively used to spatially reconcile select prospect facility locations in a given region based on pre-existing geographic constraints. Prior literature, in conjunction with expert opinion, was used to define the appropriate search criteria. Area, slope, location, proximity to utilities, direct insolation, and critical habitat were just a few of the geographic criteria taken into consideration. By using Esri's *Spatial Analyst* and other data driven inquiries, regions of undesired terrain were omitted leaving only the available sites favored for CSP solar development on BLM lands within San Bernardino County, California.

# CHAPTER 1

# INTRODUCTION

## 1.1 Renewable Energy Planning: Background and Need

In recent years, concerns about fuel costs, increasing population, environmental degradation and climate change have prompted consideration of alternative methods for electrical power generation. It is argued that solar thermal technology offers an environmentally sensible alternative to the traditional 'clean coal' generation methods of recent past (Campbell et al., 2009). However, in order for this technology to take effect, rules, regulations, and geographic requirements must be met. Site selection becomes more problematic and the restrictions surrounding land development can delay a project by months or even years. Justifying the costs associated with implementing these technologies has long deterred developers from seriously pursuing solar power generation as a viable option. To entice America's utility sector towards a greener tomorrow, state and federal governments have offered financial support to companies pursuing the development of renewable energy facilities.

Beginning in 2007, the California Public Utilities Commission [CPUC] offered a combined $3.3 billion incentive for implementing new utility scale facilities powered by renewable energy. To further California's push towards renewable energy, Governor Arnold Schwarzenegger signed Executive Order S-14-08 requiring that California utilities reach the 33 percent renewables goal by 2020 (www.energy.ca.gov/renewable). With these goals in place, and the addition of the federal government supporting the renewable energy initiative, other states have offered incentives for companies pursuing renewable resources. In the last several years both foreign and domestic developers have looked to the Southwestern United States as an ideal region for utility scale solar development. Increased interest in prospective solar lands, with the addition of government funding have driven developers to comb arid regions searching for properties suitable for future solar energy projects.

Developers have found using Geographic Information Systems [GIS] as a tool for identifying potential solar facility locations has been beneficial to the siting process. Mark Zahn, land developer and planner for Oakland based BrightSource Energy, explains that the competition in locating and gaining control over potential sites for development has been intense. "The ability to quickly and efficiently vet sites and their geographic characteristics is absolutely critical to beating the competition… The use of Geographic Information Systems has been essential to our efforts and success" (M. Zahn, personal communication, October 29, 2010). According to Zahn, current mapping techniques have provided a quantum leap in terms of finding suitable sites; however, improvements are still needed regarding accuracy, efficiency, and reliability. Other freely available geographic tools such as 'Google Earth' and Microsoft 'Bing Maps' have been used by developers to site potential lands, but often fall short when taking into account unforeseeable obstacles or boundaries. The inability to identify these variables for inclusion in the siting process has often led to inaccurate or non-feasible site location designations, resulting in the unnecessary expenditure of both time and resources.

Vice President of Land Planning, Dave Perkins of Meridian Energy, has experience researching and identifying lands for future power generation facilities, not just in solar power generation, but in the thermal power generation and petroleum sectors as well (D. Perkins, personal communication, November 18, 2010). Perkins explains that a multitude of factors come into play when trying to site proper locations and pursue project completion of a proposed power generating facility. The location of and information about electrical infrastructures, topography, insolation values, flood information, environmentally sensitive areas, federal lands, and land conservation units, are all critical factors when considering a potential site. GIS offers the ability to take these and other layers of information into account when searching for optimal regions for solar development.

Negative environmental impacts can also be associated with large scale solar farms. A traditional rule used by planners equates eight acres of land being needed to produce one megawatt [MW] of electricity. This means roughly 800 acres would be consumed in the establishment of a common 100 MW solar facility. In areas of high biodiversity, this becomes a sensitive issue. Much of the solar activity underway in California has occurred in the Mojave Desert. "The Mojave Desert is home to diverse species and ecosystems… Of the 2,500 species of plants and animals that populate the area, more than 100 are considered in peril" (Bureau of Land Management, n.d.). It is also noted that among the desert flora about 25 percent of the species located in the Mojave Desert are endemics, meaning unique to the area and found nowhere else in the world. For these reasons, developers must proceed with caution when choosing potential sites due to the environmental implications that can be associated with future construction. With reliable data, GIS can be used to assess and reduce the environmental risks posed by forthcoming projects (Stephens et al., 2003; Thorne et al., 2009).

### 1.2 Geographic Information Systems

According to the Environmental Systems Research Institute [Esri], a GIS "integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information." Essentially GIS is mapping software that allows the operator to use maps, charts, and reports to visualize and discover spatial trends, relationships, and patterns that otherwise may have been overlooked or taken substantial amounts of time to accurately comprehend and review. Geographic features are often associated with data tables populated with information pertaining to each individual feature. The significance of the software comes from the fact that multiple layers of data can be simultaneously analyzed requiring relatively short periods of time to produce and display answers to questions regarding geographic relationships (*see Figure 1.1*). These capabilities make GIS an attractive and viable tool for land planners and developers interested in prospective regions for future site development. GIS was the primary tool used in assessing future solar site suitability within this report.

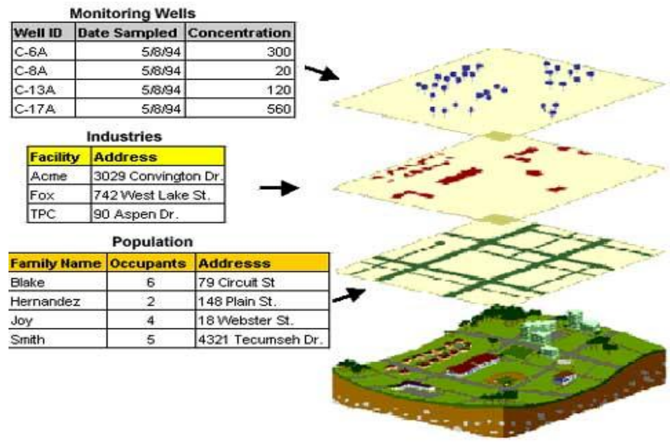


*Figure 1.1: GIS sample image - Attribute data associated with feature class layers (www.epa.gov, 2010)*

## 1.3 Solar Technology Under Investigation

In recent years, solar technologies have evolved, promising better electrical conversion ratios along with longer functioning lifespans (Viebahn et al., 2010). Larger utility developers such as Abengoa Solar, BrightSource Energy, and Iberdrola Renewables, have chosen power plants which use the power tower design, a form of concentrated solar power [CSP], because of its benefits over rival technologies (Campbell et al., 2009). Unlike photovoltaic solar cells that use semiconductor substances like silicon, CSP technology uses mirrors or lenses to concentrate the sun’s energy into high-temperature heat. The heat is then used to generate electricity (Mills, 2004). Because solar thermal plants can store heat before converting it into electricity, energy can be saved for later use and supplied during overcast weather (Quaschning, 2004). In the event that irradiance levels are too low for prolonged periods of time, natural gas can be used as an alternative to produce the heat needed to generate electricity.

The power tower (also known as solar power tower) design works best in areas of high insolation because of the extreme temperatures needed for electrical generation. Unlike traditional solar panels, this type of thermal technology needs significantly more acreage to produce optimal results when compared to its photovoltaic counterpart. "While CSP plants are large, some estimate they use less land area than hydroelectric dams (including the size of the lake) or coal plants (including the amount of land required for mining and excavating the coal)" (Solel, 2007, para. 5). These CSP facilities also have greater demands regarding distances to substations and function best when connected to major transmission lines. Despite these location limitations, there are two significant advantages to this electrical generation method: (1) long term cost effectiveness and (2) the ability to produce greater amounts of electricity than other solar technologies (National Renewable Energy Laboratory, 2009).

Power tower designs work differently than converting solar radiation into direct electrical current such as photovoltaic solar cells do. A stationary receiver (the tower), usually exceeding 500 feet in height is centrally located among an array of large mirrors, also known as heliostats (*see Figure 1.2*). The heliostats, which are mounted at ground level, redirect and concentrate the sun's rays to a boiler reservoir sitting atop the centralized tower. Each heliostat is mounted on a remotely operated base that allows the mirrors to track the sun's movement throughout the day. This tracking allows the mirrors to direct optimal amounts of reflected sunlight to the boiler, resulting in maximum electrical production hours per day. The boilers contained in these towers generate steam that runs through a closed loop cycle, much like the process used in traditional coal-fired power plants. The pressurized steam drives the turbines which generate the electricity. In the event rays from the sun cannot produce the needed temperatures, natural gas can be used to create the steam for electrical generation. Unfortunately, in order for this technology to be used as a viable power generation alternative, hundreds (if not thousands) of acres must be acquired before project inception (Mohammed & Hrayshat, 2009). Identifying these areas becomes problematic in that many spatial factors - be they political, environmental, geographical, or other - must be taken into account to assess site feasibility.

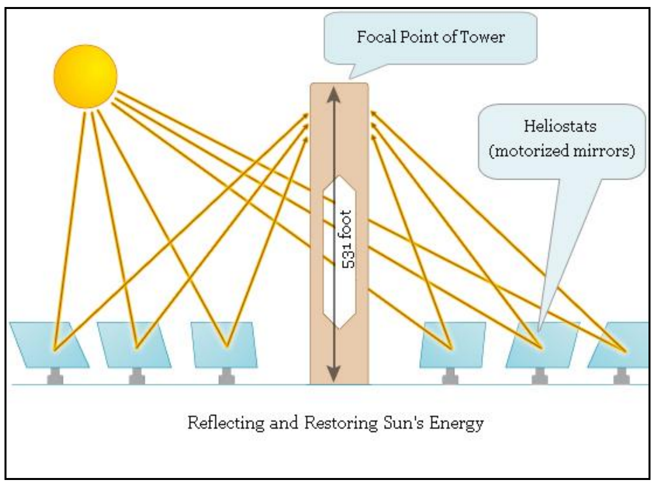


*Figure 1.2: Generic Solar Tower Design (Abengoa Solar, 2010).*

## 1.4 Research Objective

This paper demonstrates how a GIS can be used to shorten the process of identifying prime regions for solar electric generation facilities over 2,000 acres in size, on a countywide basis. San Bernardino County, California is the investigated study area.

This methodology draws from similar suitability models to design a comprehensive planning tool for project developers needing optimal site locations in the immediate future. The ideas and methodologies presented are tailored specifically to CSP utility scale solar development and elaborate on existing techniques used during the siting process. This form of solar technology is arguably the most taxing in terms of siting future locations based on its large facility footprint, required proximity to major transmission corridors, need for high irradiance levels, slope requirements, potential environmental risks, and other critical factors. The key contribution of this work is the creation of a site-suitability model adhering to the geographic requirements needed for a subject power tower facility being investigated by BrightSource Energy.

Other features of this research include:

- Creating an adaptable model for future implementation of similar site-search problems.
- Addressing a combination of environmental concerns not documented in previous research, to more thoroughly investigate the landscape.
- Utilizing insight from industry leading professionals for comprehensive land planning strategies.
- Geographically identifying competitor solar applications on federal BLM lands for future solar consideration and planning.

### 1.5 Outline of the Thesis

The remainder of this document is organized as follows (*see Figure 1.3*): **Chapter 2** provides an in-depth literature review of previous works relevant to the research conducted in this thesis, accompanied by thoughts and observations from leading industry professionals in the solar development field. **Chapter 3** provides an overview of the data that was acquired for site feasibility along with the data resources available at the time of research. This chapter also discusses the assessment and determination methods used when choosing relevant data for the suitability model. **Chapter 4** provides a step-by-step case overview analysis describing the concepts and methods used in creating the site suitability model. Explanation is given as to the design of the subject model and why existing models are not appropriate for the aforementioned protocol. **Chapter 5** analyzes the results and gives insight as to the reliability and accuracy of the chosen model. Here the findings are compared to existing solar applications for model validation. **Chapter 6** concludes the report by examining the strengths and weaknesses discovered in the model, describes potential future improvements, and touches on final thoughts.

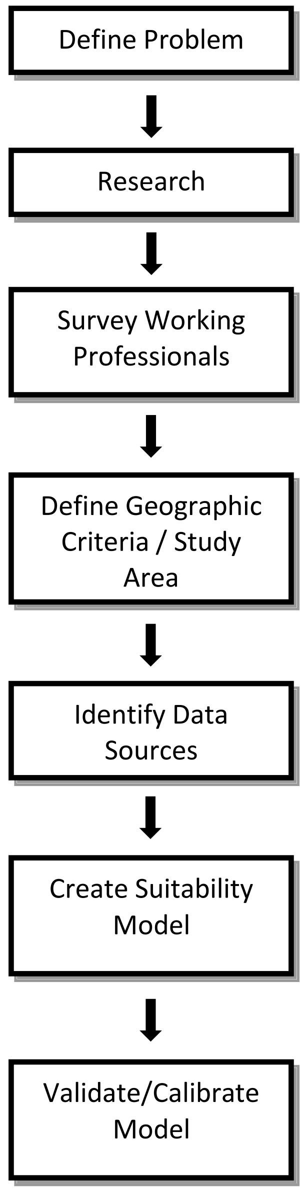


*Figure 1.3: Workflow of Thesis - The following diagram summarizes the general workflow of this thesis.*

# CHAPTER 2

# SITING TECHNIQUES AND PREVIOUS RESEARCH

## 2.1 History

Before the widespread availability of computational mapping technologies, planners relied heavily on hand drawn depictions derived from multiple sources often shown at varying scales (Steinitz et al., 1976; Collins et al., 2001). Rarely would a single map provide the needed information for future site assessment and selection. Information was often transposed to one source to more clearly identify geographic relationships relevant to the subject study area. This method posed problems in that:

1. Uncertainty of features within the map was unknown
2. Critical information may have been unintentionally omitted
3. Attributes may not be clearly defined
4. Accurate reproduction of the map may be difficult, if not impossible.

Even if a comprehensive map of the subject area was attained, a practical way was needed to evaluate site suitability.

Much like traditional cartographers and land planners, professionals involved in energy planning faced similar issues. Essential data often existed in varying forms, housed by different sources (i.e. power distribution information from the utility company, parcel maps and zoning districts from the county, environmental studies from private agencies, etc.). Once acquired, data had to be presented in a way that could show geographic relationships relevant to prospect energy regions. However, in the utility sector, both budget and timeframe are essential to project inception and vital to a company's ability to remain competitive. To save time and money during initial site selection, layers of information would often be transferred to a single base map by hand. This made the information easily transportable for field observation while giving developers a better understanding of the spatial relationships encountered in the subject region. Yet the same aforementioned issues lingered; the maps contained incalculable levels of uncertainty, and the inability to systematically identify suitable site locations remained. To more accurately and readily identify select regions for potential development, a method was developed known as land-use suitability analysis.

### 2.1.1 Defining Land-Use Suitability

A land-use suitability analysis aims to consider conditions such as specific requirements, preferences, or predictors, to identify the most appropriate spatial pattern for future land uses (Hopkins, 1977; Collins et al., 2001; Malczewski, 2004). For purpose of this study, the term land-use refers to the manner in which the physical state of the earth's surface, along with biophysical attributes, are considered and possibly manipulated for the employment of human use. When considering a land-use suitability model, it is important to make the distinction between the site selection problem and the site search problem (Cova & Church, 2000). In a site selection analysis (site selection problem), characteristics such as location, size, relevant attributes, etc. are already known for pre-determined candidate sites, and ranked accordingly so that the best site can be identified (Malczewski, 2006). If candidate sites have not yet been identified, the question then becomes a site search problem. The aim of a site search analysis (site search problem) is to explicitly identify the boundary of feasible site locations within a given study area. Both the site search problem and land suitability analysis assume that there is a given study area wherein area elements are represented as basic units of observation such as points, lines, polygons or raster (image) data. These area observation units can then be classified and ranked in order of desirability and importance for the application at hand.

### 2.1.2 GIS-Based Land-Use Suitability

GIS has become increasingly popular to developers needing to categorize, classify, and spatially analyze data. Using GIS as a tool for site suitability is not a new concept. The GIS-based approach to land-use suitability analysis stems from the application of hand drawn overlay techniques used by American landscape architects in the late nineteenth and early twentieth century (Steinitz et al, 1976; Collins et al., 2001). McHarg (1969) is credited with advancing these overlay techniques by proposing a procedure that involved mapping attributes of the study area on individual transparent layers. The attributes were represented as variations of light and dark shading to identify high and low regions of suitability. The transparent maps could then be superimposed over one another to assess multi-layered regions of shaded boundaries, resulting in an overall suitability map for intended land use (*see Figure 2.1*).

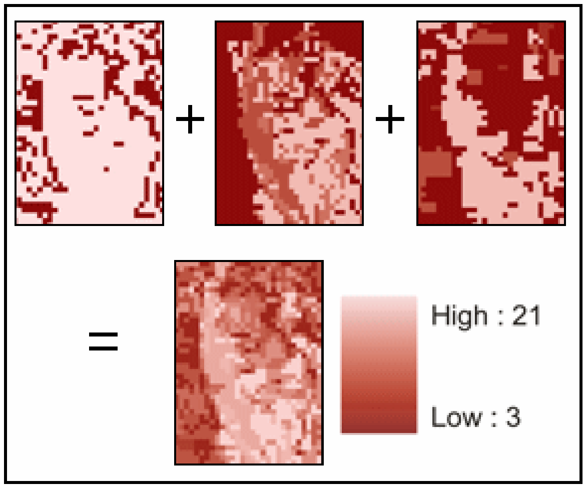


*Figure 2.1: Land-Use Suitability Analysis (Esri, 2010).*

In the 1980s, as digital computing power increased and hardware prices fell, computer-aided siting methods became a viable option for land-use planning. Although suitability analyses could essentially be performed by any software having basic GIS capabilities, affordable flowchart-based processing designs became commercially available (Malczewski, 2004). Most notably ‘Spatial Analyst’, a GIS software published by Esri, allowed users the ability to systematically analyze layers of data using two basic classes of overlay techniques - Boolean overlay and weighted linear combination [WLC]. The Boolean overlay performs two types of operations in relation to land-use suitability. The Boolean *intersection* operation classifies areas as suitable only when every suitability map meets the particular land-use threshold value. On the other hand the Boolean *union* operation will identify any suitable area that meets at least one suitability threshold value of any given layer within the analysis. The WLC approach, also known as weighting, differs from Boolean operations in that values are assigned to each suitability layer based on relative importance to overall site selection. Once classified, the WLC approach combines and averages the weights to obtain an overall suitability score. In using this method, a high score on one criterion can compensate a low score on another. This is valuable in that all factors of site selection can be assessed simultaneously, each with a varying influence on the selection process. The model used in this study draws from the WLC approach in determining the suitability of subject regions within the study area.

## 2.2 Evaluating Solar Conditions

When evaluating potential sites for CSP projects, planners must consider solar radiation levels. Direct normal irradiance [DNI] is the term often associated with the measurement of direct solar radiation. Renewable consulting group 3TIER defines DNI as “the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky”. Other types of measurements include Diffuse Horizontal Irradiance [DIF] and Global Horizontal Irradiance [GHI] (*see Figure 2.2*). These measurements (DIF & GHI) are more commonly associated with photovoltaic solar technology. DIF takes into account radiance that has been diffused by geographic and atmospheric conditions that are multi-directionally received on a normal surface. GHI represents the measurement combining both DNI and DIF values. All three values (DNI, GHI, DIF) are primarily assessed by data collected from weather measurement, instrumentation centers or high-resolution satellite imagery observations using broadband wavelength signals (National Renewable Energy Laboratory, 2009). In all cases, uncertainty remains present in these datasets due to the algorithmic modeling performed to estimate missing value information overlooked or undetected by instrument and satellite.

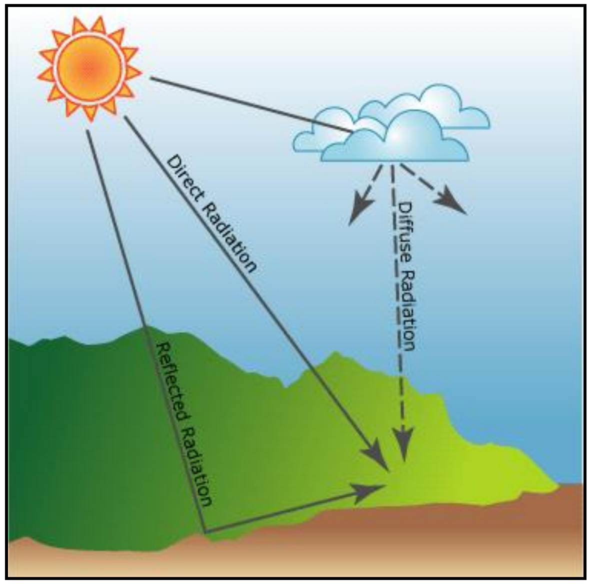


*Figure 2.2: Incoming Solar Radiation (Esri, 2010).*

GIS has been used as a primary tool for assessing solar radiation values by analyzing Digital Elevation Models [DEM] taking into account slope gradient, aspect and cell surface area (Corripio, 2003). A critical requirement for attaining dependable results relies heavily on an accurate georeferenced DEM dataset. Esri's ArcGIS *Solar Analyst* tool provides functions exclusively aimed toward calculating the estimated solar radiation values for any geographic region. Specific calculations can be made based on the latitude of subject location, along with date and time to provide estimated insolation values to the hour. In using this process, the solar map can take into account the position of the sun as well as any shading effect caused by surrounding buildings or objects located within the subject area. This concept model for solar assessment, used by Esri, was derived from Pinde Fu and Paul Rich from the Helios Environmental Modeling Institute (HEMI, 1999).

### 2.3 Land Planning for Solar Development

Before candidate sites can be chosen, developers must be familiar with the geographic limitations of the chosen solar technology, along with any rules and regulations that accompany energy development in the subject region. Although California supports the development of renewable energy, its passion for environmental conservation is equally robust. When dealing with minimum site requirements of 2,000+ acres, the loss of wildlife habitat is nearly inevitable. One challenge faced by developers has been finding locations with suitable geographic characteristics that have minimal impact on native species yet are close in proximity to existing utility infrastructure. In recent years, studies have addressed utility grid models geared specifically toward energy planning considering real world obstacles faced during project development (Clifton & Boruff, 2010; Gastli & Charabi, 2010; Janke 2010). However, a majority of the existing literature illustrates only simplistic site analyses that produce generic results commercially feasible only in ideal scenarios not typically found under realistic circumstances.

Although photovoltaic and concentrated solar thermal technologies differ in electrical generation methods, many site requirements remain the same. Utility sized plants need high solar radiation levels, a way to transport the electricity (i.e. power lines), and an assortment of acreage comprised of somewhat flat land. From there, additional geographic criteria must be considered and assessed given the chosen technology. For example, close proximity to an airport might not impact the use of PV systems but would prohibit power tower structures because of the potential conflict with fly zones and Federal Aviation Administration [FAA] regulations. To further identify what is needed in a siting model, this thesis investigates literature addressing both PV and CSP technologies.

### 2.3.1 Modeling Photovoltaic Potential

Much of the current literature regarding GIS has been structured toward the site modeling of photovoltaic technology. From modeling solar potential on city rooftops (Hofierka & Kanuk, 2009; Chavez & Bahill, 2010; Wiginton et al., 2010) to locating suitable land acreages (Carrión et al., 2008; Janke, 2010), finding these areas has been less challenging due to fewer siting limitations posed by photovoltaic panels. A common PV panel used in the utility sector typically measures 15 feet wide by eight feet tall. The obvious advantage to siting this type of technology is its size. Placement is easier in that a PV unit can generate electricity without the need of additional components and the MW produced can be dictated by site size. For example, when locating land for a future PV solar farm, an area of 160 acres can be considered for a 20 MW facility. The exact formation and size of the acreage is not critical for the technology to be functional; if less acreage is acquired fewer MW will be produced. Another difference is that PV technology typically does not need to connect to large transmission lines 250 kVA or higher. Generally speaking, transmission lines of 69 kVA and higher will meet the technological requirements necessary for the said PV technology. This is beneficial because these smaller lines typically make up the majority of the utility grid - meaning significantly more options for the placement of these renewable systems.

As previously stated, the photovoltaic site studies under investigation have considered only basic site requirements within their suitability models. Most did not go beyond analyzing elevation, aspect, slope, solar radiation, distance to transmission lines, or ideal land covers. However, an exception to this is an article in the October 2010 issue of *Renewable Energy* that presented a relevant siting model for future renewable facilities. The study titled "Multicriteria GIS modeling of wind and solar farms in Colorado" by Jason R. Janke (2007), explored the concept of identifying which areas were suitable for potential wind and solar farms using the state of Colorado as the study area. Eight different layers were used in one suitability analysis that evaluated the future site potential. In addition to solar data provided by the National Renewable Energy Laboratory [NREL], wind data, ideal land cover, and proximity to transmission lines, the study took into account distance from cities, population densities, distances to roads, and federal lands (*see Figure 2.3*). Each layer was assigned a weighted value derived from questionnaire surveys conducted in both private and public sectors, and analyzed in ArcGIS Spatial Analyst 9.3. The final product resulted in a data layer that identified ideal solar farm locations ranked by percentage- 100 percent being the best site, 1 percent being the worst.

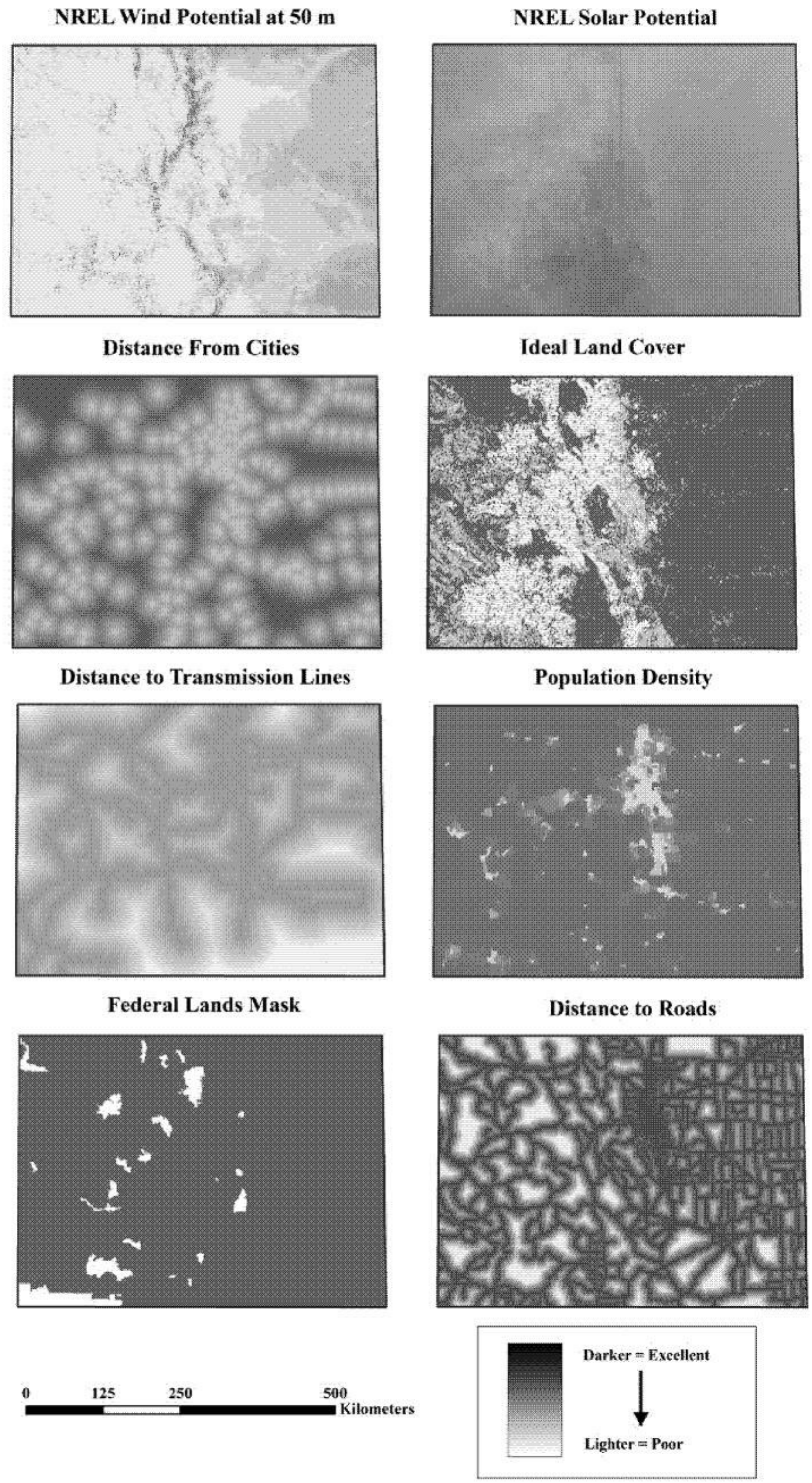


*Figure 2.3: Multicriteria GISModeling - GIS layers used to model ideal Locations for wind and solar farms in Colorado (Janke, 2010).*

Although the study formulated results for solar potential, much of the emphasis was placed on wind energy. The report did however compare the GIS results to the locations of existing solar farms in the state of Colorado. It was found that a majority of the existing solar installations were located in areas that received a 20 percent or less suitability ranking for potential solar site locations. It was determined by the author, that this was due in part to the fact that the NREL solar potential values did not significantly vary within the state of Colorado. The fact that multiple PV facilities were found in areas not highly recommended supports that although the analysis modeled optimal locations for solar potential, it probably did not model the most comprehensively feasible sites. The Janke report did not look at addressing additional information critical to project development and completion. In California, one area of concern has been environmental conservation. The study conducted by Janke lacked comprehensive environmental data that may have impacted the model's results. Realistically, the residence of endangered species or protected habitat can dismiss an entire region from further consideration during the development process. Therefore, it is important to incorporate this information into a viable land-use suitability model for more candid results.

### 2.3.2 Modeling Concentrated Solar Thermal Potential

The United States is in its infancy when compared to other countries that currently utilize the power tower design. Spain, Germany, Greece, Italy, and Middle Eastern Countries, have already ventured into the construction and implementation of power tower facilities with proven success (Salazar, 2008). In recent years, studies have been conducted analyzing the potential for the use of CSP in select foreign countries. Several studies evaluated regions in Australia due to high irradiance values and arid landscapes (Altman et al., 2005; Clifton & Noruff, 2010). Portions of India and Oman have also been prospected by use of GIS for siting future CSP facilities (Gastli & Charabi 2009; Purohit, I. & Purohit, H., 2010). A monumental study using GIS to evaluate the potential for CSP plants in Tunisa, Africa was published in a 1999 issue of *Journal de Physique* [Journal of Physics] (Vandenbergh et al., 1999).

The task of the Vandenbergh et al. (1999) study was to identify the minimal site requirements needed for the power tower design in conjunction with the economic feasibility of future development. The major geographic parameters taken into account were proximity to the national electric grid, direct normal radiation values, and amount of relatively flat lands with existing road access. Other key parameters included proximity to natural gas lines (for additional power generation in times of reduced insolation), and water availability (for the cooling of the Rankine cycle used in the electrical generation process). The economics under investigation were that of subject plant electrical production and the estimated utility transport losses encountered in the given study region. The initial capital investment of site construction was considered in addition to the predicted annual cost of operation. These factors were used as the basis for determining which geographic parameters were most crucial for maximum cost efficiency over a 30 year period.

The authors determined that the distance to the nearest natural gas line was the most critical factor, along with lands bearing a slope less than or equal to 4%. The calculated investment for constructing 1km of electrical line was roughly 50% that of constructing the equal distance of natural gas pipeline. All geographic layers under investigation were assigned weighted values based on estimated economic importance and analyzed within a GIS. In the study area of nearly 165,000 km², it was determined that roughly 23,000 km² (14% of the county) could successfully support the technology, however, the economic impact was detrimental. At the time the study was conducted, it was found that the solar electricity cost (8.3 c$/kWh) was nearly twice as high as costs associated with conventional coal power plants (4.4 c$/kWh). Furthermore when considering the low efficiency of the tested CSP technology, it was determined that the environmental benefits were inconsequential. When compared to rival fossil fuel combined cycles, the total carbon emissions of both plants were equal (Vandenbergh et al., 1999).

Of the existing literature, the aforementioned study "A GIS Approach for the siting of solar thermal power plants application to Tunisia" is most relevant to the model developed in this report (Vandenbergh et al., 1999). The 1999 article stated that similar technologies had proven cost effective for over ten years in regions of California. It is also noted that although the study developed a solar siting model within GIS, limited geographic parameters were used, with the key focus being economic feasibility. The model developed for this report identifies sites in San Bernardino County, and assumes economic feasibility, reduced carbon emissions, and local political support based on recent literature (Campbell et al., 2009; Purohit, I. & Purohit, H., 2010). The intent was to identify foreseeable factors that may deter development in prospect CSP regions and appropriately locate where a project has the highest likelihood of success.

### 2.4 Professional Insight

While considering relatively new technologies and aggressive competition within the utility sector; literature is scarce regarding any in-depth GIS analysis for solar planning. To compensate for the lack of information, land planners/developers from several energy planning firms with a working knowledge in the solar sector were contacted and interviewed. A series of questions were issued to those who agreed to help with the study. In total, seven candidates were interviewed verbally and presented with a written series of questions. Of the seven interviewed, five returned a completed questionnaire (see Appendix for individual responses to each of the questions listed below).

#### 2.4.1 Questions Presented to Industry Professionals

The following questions were provided to several Industry Professionals for their written response:

1. In order of importance - what geographic criteria are absolutely NEEDED for utility scale solar development? (i.e. transmission lines, % grade/slope, insolation values, etc)

2. In order of importance - what geographic criteria are DESIRED for utility scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictions)

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility scale solar development say 500 acres in size? Please estimate or explain.

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

5. What has been the biggest frustration when trying to site potential lands?

6. What would you change about current geographical siting techniques to make the overall process better?

7. What type of utility scale solar technology does your company use? What is the least amount of acreage needed for a future site? What is the most?

8. How much electricity can be produced from this technology?

9. Please add any useful comments not mentioned in the questionnaire.

### 2.4.2 Survey Participant Selection

Professionals were chosen from different fields in the solar development spectrum to establish comprehensive feedback in relation to solar planning. Three of the interviewed developers were from international solar companies familiar with the CSP power tower design. Two were from companies with solar experience focusing on photovoltaic technology. One was the GIS manager of an environmental consulting firm experienced in solar siting, and one was the GIS operations manager of a comprehensive land consulting firm which specializes in energy planning. Individual answers varied based on personal industry experience and type of solar technology. The results were reviewed and used to determine what criteria would ultimately be needed for designing the subject land-use suitability model. A master answer set was derived from responses given by the interviewed professionals. The individual's experience, company's credentials, method of siting, solar technology used, and independent research, were considered when formulating a final answer set. Those familiar with the power tower design or alternate CSP technologies were favored as applicable answers over responses directed at PV technologies. Once formulated, the final answer set was vital to identifying geographic criteria and siting extremities not mentioned or adversely explored in previously recorded studies.

### 2.4.3 Final Answer Set

Below is a summary of the responses provided by professionals from both interviews and questionnaires. The responses provided by professionals with CSP experience were favored over the responses provided by professionals who were unfamiliar with CSP.

1. In order of importance - what geographic criteria are absolutely NEEDED for utility scale solar development?

    a) Insolation/Irradiance Values
    b) Terrain slope less than 5%
    c) Close proximity to transmission line with appropriate voltage
    d) Close proximity to appropriate substation
    e) Close proximity to natural gas pipeline
    f) Location and information about any existing/future electrical infrastructure
    g) Water availability for close loop Rankine Cycle
    h) Known land designations (i.e. Federal Lands, Conservation Units, Zoning etc.)

2. In order of importance - what geographic criteria are DESIRED for utility scale solar development?

    a) Site size of at least 1,000 contiguous acres
    b) Known areas of environmental sensitivity
    c) Absence of conflicting surface uses (such as mining, oil or gas production)
    d) Absence of conflict with FAA flight paths, DOD flight training or operational routes
    e) FEMA flood zone information
    f) Competitor site application information
    g) Land parcel information with ownership data
    h) Information on soil types
    i) Existing land cover information

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility scale solar development 500 acres in size? Please estimate or explain.

   The process could be measured in months. In most cases extensive travel was needed either by plane or automobile (a big carbon foot print), lots of legwork and phone calls needing to be made. Traditional site vetting involved an extremely labor-intensive and inefficient sorting and culling process, condensing this information into a visually useful form was likewise inefficient and time consuming.

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

   The competition in gaining control over solar sites has been intense. The ability to quickly and efficiently identify characteristics of candidate sites has been absolutely critical to beating out competition. The known locations of competitor applications has been key in establishing existing rights to desired sites and evaluating opportunities to secure joint ventures with such parties. Keeping costs low has also been important in remaining competitive in that your company may get "selected" by the utility for a future project due to low prices.

   In terms of opposition, many times it comes down to limiting foreseeable obstacles and listening to the concerns of project opponents and proponents. Once everything is on the table all parties must work together to resolve the issues, whether it be modifying the overall design of the project or being flexible on other matters.

5. What has been the biggest frustration when trying to site potential lands?

   Environmental and/or political restrictions have been taxing on the siting process. The relatively low amount of sufficiently large private parcels with the needed site characteristics has also been challenging. Finding existing electric transmission capacity for the private tracts and its lack of flexibility to move large amounts of renewable energy to regions outside the desert southwest has also been extremely frustrating.

6. What would you change about current geographical siting techniques to make the overall process better?

   Beyond using GIS as strictly a siting tool, the next step would be combining current capabilities with a way to determine available transmission capacity and flexibility to deliver power to regional and national markets. Also a larger availability of accurate low/no-cost data to incorporate into the model would be extremely beneficial.

7. What type of utility scale solar technology does your company use? What is the least amount of acreage needed for a future site? What is the most?

   The technology under investigation is a form concentrated thermal power utilizing the 'power tower' design. 8 acres are needed for every Megawatt. A minimum of 1,200 acres is needed for a 150 MW facility. There is no maximum limit other than what is imposed by the transmission system. Sites as large as 10,000 acres have been prospected for the construction of at least three 250 MW facilities.

8. How much electricity can be produced from this technology?

   The typical rule of thumb for most solar technologies is 8 acres needed for every 1 Megawatt produced.

# CHAPTER 3

# DATA

## 3.1 Study Area and Data Availability

San Bernardino County was chosen for the study area based on its vast size and ideal conditions for solar development. The county encompasses over 18,000 square miles of relatively flat terrain, and according to the NREL solar database, has annual average irradiance values higher than 7,000. Most of the arid regions found in San Bernardino have limited vegetation and are uninhabited by residential communities. Furthermore, the County is geographically situated to serve large metropolitan areas in Southern California along with portions of Nevada and Arizona. Because of these prominent advantages, developers are pursuing the potential offered by this seemingly perfect locale. According to the Bureau of Land Management [BLM], San Bernardino currently has the most pending solar applications of any California county on public land. Over 25 commercial developers are competing for mass quantities of acreage in these desert regions. Because of heightened regional competition, escalated environmental opposition, and other deterring factors, this County was chosen as the study area to demonstrate how GIS can benefit developers facing overwhelming circumstances.

The data used for this study was collected from a broad range of multiple sources. Some information was available free of charge, while other information was hard to find and acquired only after financial compensation was delivered. The sources from which data were gathered were determined based on expert recommendation and current industry practices, in conjunction with sources mentioned in past literature and independent research.  In total 21 layers of data were analyzed within this model for siting potential CSP sites on BLM lands within San Bernardino County.   As previously stated, the site specific requirements used in this study were modeled after a 200 MW facility currently being investigated by BrightSource Energy.  Drawings of the facility layout were acquired from the engineer department to identify the acreage needed in the event a candidate site was selected (*see Figure 3.1*).  A potential site must be minimally 1,951.5 acres in size to support one 200 MW facility.

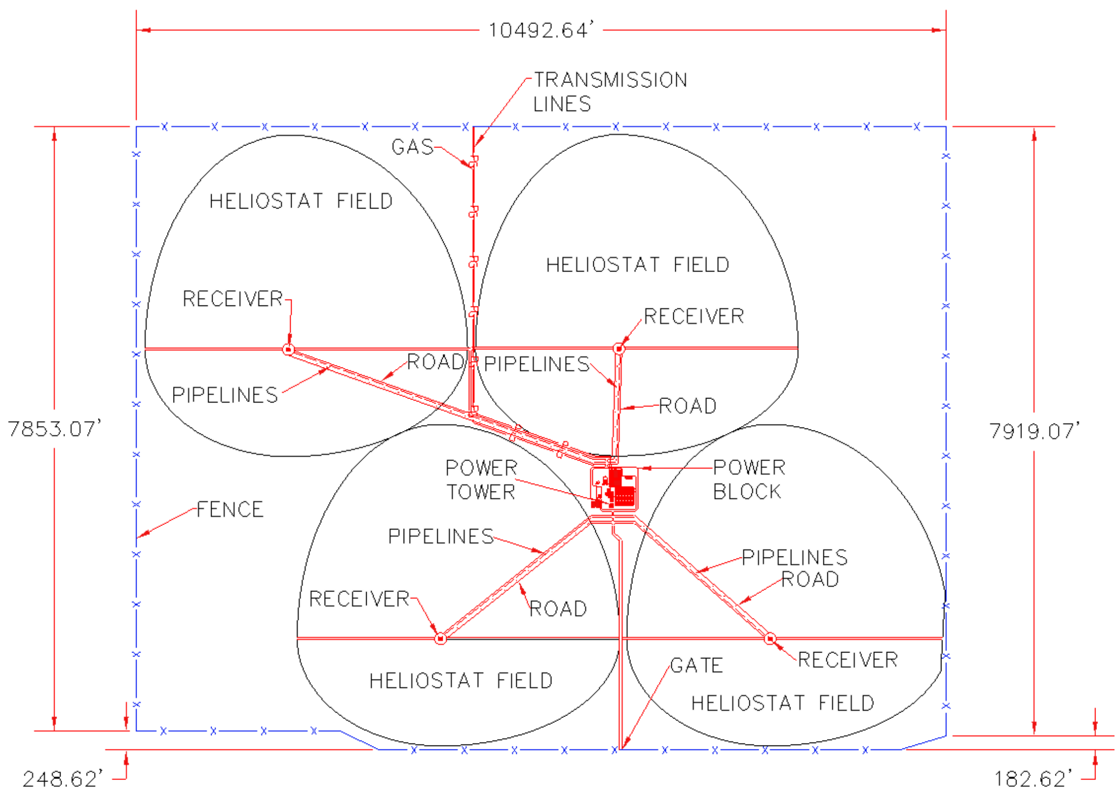


*Figure 3.1: 200 MW CSP Facility (BrightSource Energy, 2010).*

### 3.2 Terrain Data

A viable data set was needed to determine the elevation changes present within the study area in order to calculate terrain slope. The DEM raster, which constituted the county of San Bernardino, was selected as a means for calculating these needed slope values. Unlike orthoimagery or linear contour data, DEMs are digital representations of the earth's surface defined by a regularly spaced grid of elevation points. There are several techniques available for acquiring and creating this data. Most notably the United States Geological Survey [USGS] has collected digital elevation data using a number of production strategies such as onsite land surveying, remote sensing, and stereo modeling of contour data. This data can be purchased from the USGS at varying scales, resolutions, and projections, for most every region in the United States.

Another process gaining popularity in the creation of DEMs has been a remote sensing technique known as Light Detection and Ranging [LIDAR]. Of its many functions, LIDAR can create more accurate terrain models based on its ability to interpret characteristics of a contiguous surface based on reflected light waves (Koukoulas & Blackburn, 2004). More realistic terrain values can be attained through LIDAR as opposed to the computer generated values that likely populate a DEM created by stereo modeling or triangulation methods (*See figure 3.2*).

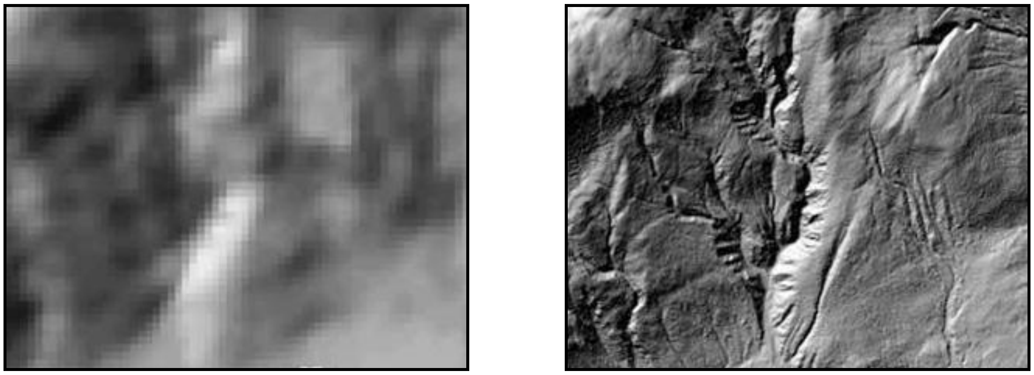

*Figure 3.2: USGS vs. LIDAR - These DEMs are depicting the same geographic location at the same extent. The image to the left displays surface cells at 20 meter resolution, while the image on the right was captured using LIDAR and displays surface cells at 3 meter resolution. (www.fs.fed.us, 2010)*

Given the size of the study area and cost associated with obtaining LIDAR data, USGS DEM elevation data was chosen for use in the suitability model. The digital elevation information was obtained from the USGS at ten meter resolution. At this resolution, there is a chance that certain features (such as small man-made structures or abrupt elevation changes) may be undetected by the DEM. The USGS provides a good explanation as to the expected accuracies associated with DEWs. "DEM data accuracy is derived by comparing linear interpolation elevations in the DEM with corresponding map location elevations and computing the statistical standard deviation or root-mean-square error (RMSE)… [For the DEMs used it is estimated that] 90 percent have a vertical accuracy of 7-meter RMSE or better and 10 percent are in the 8- to 15-meter range" (U.S. Geological Survey, 2000, para. 6).

Even with this added uncertainty, the ten meter USGS DEM was elected based on project scope and comprehensive coverage of the study area. Open source LIDAR data was found on the internet; however, the regions available for San Bernardino County only amounted to approximately five percent of the county's total acreage.  In the event LIDAR was available for the entire study area, a USGS raster set would still be elected due in part to digital size advantages and objective practicality.  If dealing with a smaller study area with varying geographic formations (i.e. geology, tree canopies, etc.) or manmade structures, LIDAR would be highly desired, however it was not required to execute this study.

### 3.3 Solar Data

With issues like renewable energy and global warming becoming increasingly prevalent around the globe, numerous agencies have invested in weather pattern and solar condition research.  Once gathered, this information is tabulated into geographic databases to provide files in vector or raster format, which can be viewed and manipulated within GIS.  When dealing with solar data, there are different levels of functionality and reliability at which it can be acquired.  Private agencies such as 3TIER or DeLorme sell costly GIS data bundles that offer high functionality with purported industry leading accuracy.  Other agencies have collected the information and made GIS shape files available free to the public. Of the many organizations providing free information, the most notable is the National Renewable Energy Laboratory.

For the purpose of this study, solar radiation data was obtained from the NREL for several significant reasons:

1. The NREL is an industry leader regarding the development and implementation of renewable energies and is a credible data provider being referenced in literature both foreign and domestic.
2. Although the data acquired is estimated as being within 15 percent of a true measured value within any given 10km grid cell, it is commonly agreed that the best available solar datasets still contain an estimated six to eight percent uncertainty rating (National Renewable Energy Laboratory, n.d.). Given the vast study area, similar region DNI values, and excessive site acreages needed, it is assumed that the presence of this level of uncertainty does not jeopardize the results.
3. The data is updated regularly and available to the public free of charge.

Because of these three factors, the NREL irradiance data was selected for solar site analysis.

**3.4 Utility Information**

Although utility infrastructure information is legally free to the public, attaining a reliable GIS dataset can often prove challenging. This is one of the most critical factors in regards to energy planning. A site may be perfect for solar development, but in most cases, will not be pursued if a feasible way for accessing the energy grid does not exist. Some have exploited this concept by investing man hours into creating GIS utility data and selling the information for a sizable profit. That said, data integrity becomes a critical factor when considering which source(s) the information is acquired from. Some firms charge a nominal fee for data layers that are ambiguous with few if any populated attribute fields. These layers are often derived from generic information such as utility maps provided by the California Energy Commission or U.S. Department of Energy. In either case, most are simplified maps unfit for development purposes, showing general utility corridor locations in vast undefined regions.

Other options are available with regard to obtaining higher accuracy and comprehensive attribute information; however, these usually come at a high price. Firms such as Platts.com and HTSI, Inc. sell different utility layer bundles from prices ranging from several hundred to several thousand dollars. The firm Ventyx (www.ventyx.com) claims to have the most comprehensively accurate utility dataset for the continental United States. This was not confirmed due to the large price needed to acquire the dataset (in the tens of thousands of dollars). The utility data used for this study were purchased from HTSI Inc. The pipeline and transmission line data acquired for the study area were estimated at having a positional accuracy of 500 - 2,500 feet. This estimate was confirmed upon visual inspection; referencing both aerial imagery and USGS topographic quadrants (*see Figure 3.3*). The third utility infrastructure layer received from HTSI was a point file containing the locations of substations within the County boundary. The geospatial accuracy of substation locations was unknown. Upon visual inspection approximately 60 percent of the substation points were within 2,500 feet of the actual location. Accuracy of the remaining substation sites were unconfirmed.

*Figure 3.3: Validating Utility Data - The solid yellow line depicts the transmission data used. The red arrows indicate the transmission towers found on California NAIP aerial imagery. In this instance a polyline depicts one corridor housing two transmission lines (2010).*

### 3.5 Land Designation Data

One key factor not addressed in previous literature was the incorporation of appropriate land-use designations within a siting model. Without this information, it cannot be determined who has the rights over prospect locations and if the project is feasible. The results of an analysis can be easily misinterpreted if the proper data is not factored into the equation. A vast arid region such San Bernardino County may look free for the taking, but after further investigation many pre-established land designations can restrict future development. This has been a common problem faced by developers currently pursuing lands for renewable energies in the continental Southwest. This present study sees to address this issue by not only considering areas where solar facilities can be placed; it also considers where they cannot be placed.

### 3.5.1 Background Data

The base layer used for background data was provided by the 2010 Esri database "USA_Base_Map.lyr". This dataset included many boundaries and site designations found on a typical road atlas map. The layers incorporated for analysis included: military installation boundaries, wilderness designations, national forests, state parks, urban areas/city limit boundaries, airports, and bodies of water. Each layer was treated differently based on prospect facility requirements, federal regulations, and desired site assets. When cross referenced with other sources (i.e. GIS data provided by other sources, paper maps, etc.) the geospatial accuracy of the data far exceeded the minimum requirements needed for the large study area of San Bernardino County.

### 3.5.2 Bureau of Land Management

The U.S. BLM online database (www.blm.gov/lr2000/) provides a great resource for land planners in the renewable energy sector. Approximately 6,000 square miles of San Bernardino County [30%] consists of public lands owned by the USA, not including parks and designated wilderness. Solar developers have been attracted to these regions because of space abundance and the lack of conflicting land-uses. The BLM online database was chosen to represent public lands within the suitability model over the layer provided by Esri due to data currency. The BLM updates their information regularly, and given the importance of this layer within the analysis, the most current version was needed. Another critical piece of information provided by the BLM is the renewable energy application layer. It can be determined who, where, and when an application was filed to develop BLM land for renewable energy projects on a section by section basis. This layer provides attribute data as to the applications that are authorized, pending, closed or withdrawn. Competing applications were used to identify which companies have priority over subject regions, as well as validate the suitability model created for site analysis.

### 3.5.3 San Bernardino County GIS Department

In the computerized age of geospatial information, many counties around the nation have opted to convert paper records to digital format (*U.S. Department of Agriculture, 2001).* Roughly half of the counties in California currently house internal GIS departments. This information is available to the public; however, the cost associated with receiving this data varies by county. Fortunately, San Bernardino County provides an online FTP site where layers of data can be downloaded free of charge. Although many data layers were provided by the County only three were considered when creating the land-use suitability model. The first was zoning designations. This is important when considering private lands for potential development because the current land-use can be determined to indicate project feasibility. It is important to note that although zoning boundaries are previously assigned by county planning, they can potentially be changed assuming proper procedures are followed. The next layer considered was the tax assessors' parcel data set. The main reason for needing this information was to identify parcels, acreages, and the owners associated with those parcels, in the event private lands were chosen for future development.

Another layer of information regarding agriculture conservancy is one that can often go unnoticed. “The California Land Conservation Act of 1965 - commonly referred to as the Williamson Act - enables local governments to enter into contracts with private landowners for the purpose of restricting specific parcels of land to agricultural or related open space use” (State of California, 2007, para. 1). Meaning, lands designated for conservation under the Williamson Act cannot be used for industrial or commercial purposes. Many landowners participate in this conservation contract due to tax relief benefits offered by the state government. Knowledge pertaining to which private lands are classified as invalid parcels for development could save time in the search process by eliminating the sites from the land-use model. In the event one of these conservation parcels was chosen for development, a parcel of equal size and soil type would be needed for mitigation purposes. The event of this happening is uncommon, but not unheard of.

### 3.5.4 California Department of Oil and Gas

Another concept often bypassed during the planning phase of solar development is an investigation of the minerals that lie beneath the earth’s surface. In the state of California, mineral and surface rights can be severed and belong to multiple owners. Whoever controls the minerals has the right to access those minerals despite who or what is on the surface (B.M. Boone, personal communication, October 19, 2009). The real issue of concern for solar developers is the subsurface activities that have previously, currently, or potentially will be taking place below a potential site. For example, if a 1,000 acre solar plant is currently in operation and an oil reservoir is located directly below the facility, whoever controls the minerals has the right to access the oil - even if it means disturbing the existing solar structure. In reality, a similar situation is unlikely to happen. Usually an agreement can be made avoiding excessive damage and limiting negative impact, but the underlying point remains - it is imperative to know the status of the subsurface estate.

Fortunately California's Department of Oil and Gas [CA DOG] provides database files of geologic boundaries and recorded well sites. This information can be used to determine what known geological surveys and above ground facilities are present near potential sites. The presence of geologic activity will not necessarily discard a chosen site; however it can caution project developers of the potential site risks and instigate additional research. Before any project embarks on construction, it is critical to properly identify both the surface and mineral interests. Third party firms such as PPC Land Consultants can offer support for additional mineral research, title work, document preparation and contract negotiations associated with acquiring legal access to subject properties.

### 3.6 Environmental Data

As previously stated, the power tower design used in this study can have a negative environmental impact on existing vegetation and native wildlife. The nearly 2,000 acres used to produce 200 MW of electricity will eventually harbor above ground structures that can undeniably change the dynamics of the ecological community. To minimize environmental impact, developers need to abide by the rules and regulations set forth in the California Environmental Quality Act (2010), often referred to as CEQA. The 2010, 354 page report can be viewed online via PDF at ceres.ca.gov/ceqa/docs/2010_CEQA_Statutes_and_Guidelines.pdf. It outlines most of the environmental procedures associated with commercial development in the state of California. After developers consider state laws concerning the environment, they must also consider and assess the negative environmental impact the chosen project will have on the subject premises.

### 3.6.1 The California Desert Protection Act of 2010

On December 9th, 2009, Senator Diane Feinstein introduced to the U.S. Senate the California Desert Protection Act of 2010 [CDPA 10]. This environmental bill was created to protect scenic views and natural habitat, mainly along the historic Route 66 corridor near the Mojave Desert.

> "The Mojave Trails National Monument would prohibit development on 941,000 acres of federal land and former railroad company property along a 105-mile stretch of old Route 66, between Ludlow and Needles... The smaller Sand to Snow National Monument, about 45 miles east of Riverside, would cover about 134,000 acres of federal land between Joshua Tree National Park and the San Bernardino National Forest in San Bernardino and Riverside counties" (Sahagun, 2009).

The bill also leaves out vast sections of the Colorado Desert, such as Chuckwalla Valley, specifically designated for energy developers. Nearly one million acres of the two pending national monuments are located within San Bernardino County. The ability to avoid these areas entirely can save wasted efforts in the development process. This land-use suitability model took into account these pending boundaries as to omit them as viable site locations (*see Figure 3.4*).

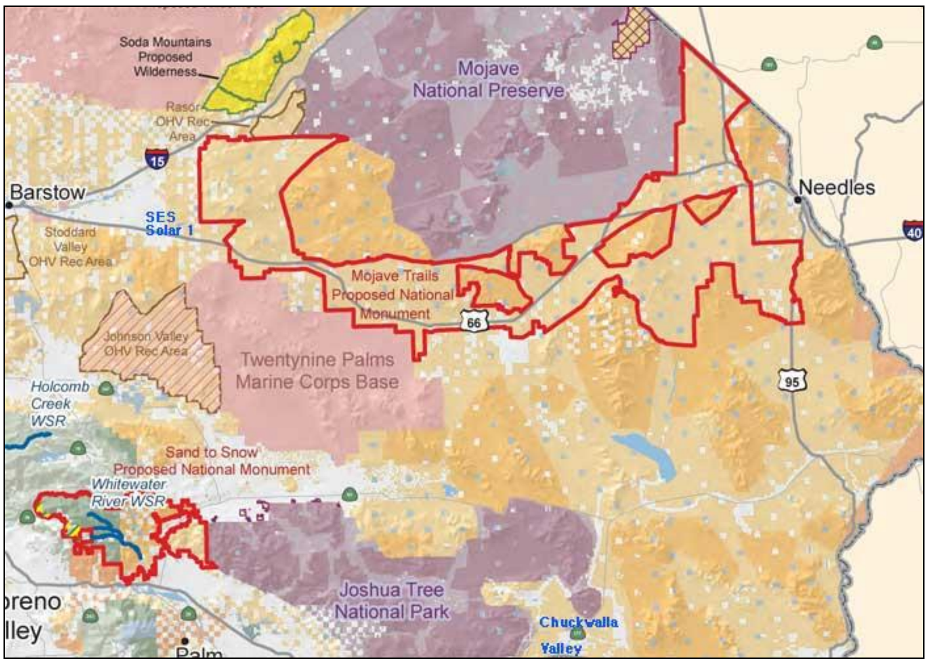


*Figure 3.4: Proposed National Monuments [Outlined in Red] (CDPA, 2010).*

### 3.6.2 California Department of Fish and Game

The California Department of Fish and Game [CA DFG] provided wildlife information not found in the Esri or County zoning districts database. Regions in San Bernardino County have been approved for designated wildlife conservation projects.

The CA DFG offers this information as downloadable data in the form of shapefiles. It can be obtained free of charge and gives developers added information regarding regions that may not be suitable for solar development due to future conservation. As of December 2010, roughly 5,655 non-contiguous acres within San Bernardino County were set aside for Wildlife Conservation Board projects. Although project sizes varied from upwards of 2,200 acres to as little as half an acre, knowing the locations and site boundaries of these projects is beneficial to developers looking to construct facilities in the near future. Although having an approved conservation project near or within a prospect solar site will not eliminate the possibility of development, it could likely raise controversy. For these reasons the data provided by the CA DFG was considered for use in the suitability model.

**3.6.3 US Fish and Wildlife Service**

Additional wildlife information not available through the CA DFG database was sought and obtained from the United States Fish and Wildlife Service [US FWS]. An increasingly critical factor in all land development has been the project's impact on existing wildlife habitat. With utility agencies racing to claim mass quantities of acreage for solar development, natural habitat can quickly diminish if not properly regulated. Similar research studies have not emphasized the importance of this variable into the land-use suitability models demonstrated for site selection. An on-going issue currently effecting solar applications in Southern California has been the habitat loss of the Desert Tortoise. In recent years, Desert Tortoises of the Mojave Desert have been federally listed as a threatened species. State and federal wildlife management agencies are actively involved in conservation programs aimed at increasing tortoise numbers in the Mojave (Burge & Royo, 2010). The core areas listed as critical habitat for the Desert Tortoise fall primarily within San Bernardino, covering nearly one-third of the County. Although Desert Tortoise populations account for most of the critical habitat regions in the study area, according to the US FWS, 20 other species are either threatened or endangered within San Bernardino County. Merriam's Kangaroo Rat, the Southwestern Flycatcher, the Inyo California Towhee, and San Bernardino Bluegrass are just a few of the species on this list.

### 3.6.4 FEMA - Flood Zone Data

It is not commonly thought that an area chosen for solar electric generation can be prone to flooding, but the possibility needs to be considered. One of the site requirements for the chosen technology is having a large flat area to build on. Considering the region, flat land is typically lower in elevation and can be prone to flooding. Even in arid regions, flash floods may occur unexpectedly and have an undesired effect on a planned facility. To combat the unknown, many developers rely on the flood zone data provided by the U.S. Federal Emergency Management Agency [FEMA]. Incorporating this data into the land-use suitability model cannot predict which areas will flood, but can be a good indicator as to which areas are at higher risk. This data for San Bernardino County was obtained and considered for use within the land-use suitability model created for this study.

### 3.7 Federal Aviation Administration - Flight Data

The Federal Aviation Administration closely regulates the flight traffic throughout North America and provides the most comprehensive information available regarding designated flight paths and no fly zones.  Although San Bernardino County does not house any large commercial airports, small commuter airstrips and mass military aviation operations occur within this region.  The issue posed by potential power tower facilities are the central receivers that can reach upwards and beyond 500 feet to the sky. Although cruising altitudes are generally higher than 500 feet, an obstruction of this size can pose serious implications regarding aircraft takeoffs and landings.  For that reason, this issue is considered detrimental to a chosen site.  Flight paths, military training areas, existing airports, and no fly zones were all implemented into the land-use suitability model designed for this study.  Table 3.1 lists the data collected and considered prior to site analysis.

**Table 3.1: Data Considered in the Siting Process.**

| Data Layer | Format | Description |
|---|---|---|
| Terrain | raster | Digital Elevation Model [DEM] used to calculate slope |
| DNI Solar Values | shape | Representing annual average Direct Normal Irradiance [DNI] values |
| Electrical Grid | shape | Representing electric transmission lines greater than 115 kVA |
| Substations | point | Representing locations of existing substation facilities |
| Pipeline | shape | Representing underground petroleum pipeline network |
| Land Use | shape | Representing county zoning designations for existing land use |
| BLM Lands | shape | Public Lands owned by the federal government and regulated by the Bureau of Land Management |
| Competitor Applications | shape | The latest pending solar applications filed on BLM lands |
| Military | shape | Boundaries of existing Military Installations |
| Wilderness-Forest-Parks | shape | Representing designated wilderness, national forests, and state parks |
| Cities | shape | Urban city limit boundaries |
| Water | shape | Representing bodies of water (i.e. rivers, lakes, streams) |
| Parcels | shape | Tax ownership boundaries for private lands |
| Williamson Act | shape | California Land Conservation Act of 1965 – Private parcels limited only to agricultural use |
| CA DOG | point | Existing oil and gas wells |
| Proposed Wilderness | shape | Representing lands selected for National Monument in California Desert Protection Act of 2010 |
| Approved Conservation | shape | Representing approved desert conservation projects |
| Critical Habitat | shape | Threatened and endangered species- sensitive areas designated by US Fish and Wildlife service |
| Flood Data | shape | Representing FEMA designated flood zones |
| FAA | raster | FAA flight paths and no fly zones |

# CHAPTER 4

# MATERIALS AND METHODS

## 4.1 Methodology Framework

This analysis followed the following steps:

1. Define the study area
2. Identify the core tools needed for conducting the site search analysis
3. Define the geographic features (selection criteria) needed at/near an ideal site and determine the importance to overall site suitability associated with each
4. Prepare data for use within the suitability model including determining how the selection criteria are to be identified and weighted given the available data
5. Identify the best candidate sites on existing BLM land using weighted overlay
6. Identify and geographically define the areas where subject CSP farms would not be feasible within San Bernardino County
7. Omit sites where solar development was unfeasible from the ideal candidate sites layer within BLM lands
8. Remove sites smaller than the needed 2,000+ acres
9. Compare sites larger than 6,000 acres to existing solar applications
10. Analyze suitability model outcome and calibrate *Weighted Overlay* tool to produce results reflective of existing solar applications
11. Repeat steps eight through nine, refining weighted values until satisfactory results are achieved

12. Once geographic processes have been appropriately calibrated and defined, run model from beginning to end and confirm geographic feasibility.

The steps listed above are further explained in the remainder of this chapter. Section 4.2 elaborates on defining the study area outlined in **Step 1**. Section 4.3 talks about the core tools referenced in **Step 2** identifying both *ModelBuilder* and the *Weighted Overlay* tool. **Steps 3 and 4** are outlined in greater detail in Section 4.4 explaining the process of establishing the geographic criteria and preparing data for analysis. Section 4.5 describes how the *Weighted Overlay* tool was arranged and executed for this study, as stated in **Step 5**. **Step 6** is explained in Section 4.6 where areas unsuitable for development are identified, and combined for use within the suitability model. Section 4.7 elaborates on both **Steps 7 and 8**, further refining the search area by omitting unusable sites by size and location. Section 4.8 addresses how the model results were further compared to existing BLM solar applications as stated in **Step 9**. The final section (4.9) of this chapter, illustrates the process used in both **Steps 10 and 11** for further calibrating the results produced by the suitability model. No section is dedicated to **Step 12** since this step was merely a computational confirmation that the geographic processes of the final model properly functioned from start to finish.

**4.2 Define the Study Area** ***[Step 1]***

The 20,098 square miles which make up San Bernardino County were defined as the study area used for analysis. The County boundary was employed as a template within which all other analyzed data needed to reside. Therefore, all the layers exceeding the County district borders were clipped prior to analysis to contain only regions delineated within San Bernardino County (*see Figure 4.1*). It was considered that data located in adjacent counties and/or states may have impacted the site selection process. However, it was elected to use data and find potential sites located solely within San Bernardino County, California due to laws and regulations associated with sites being located within two or more county jurisdictions,.

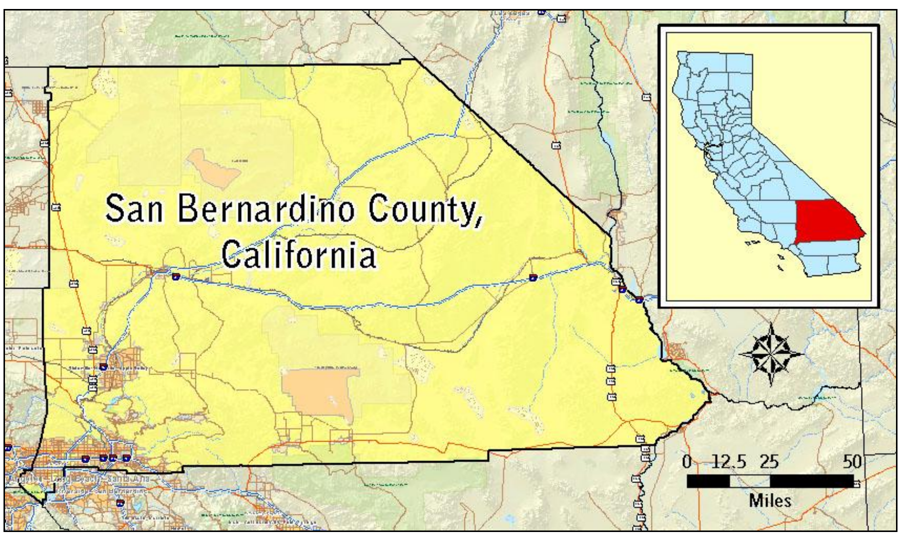


*Figure 4.1: San Bernardino County - The chosen study area is approximately 20,098 square miles in size.*

## 4.3 Core Tools *[Step 2]*

It was important to identify the spatial tools needed prior to creating the suitability model to determine (1) what role each tool would play in the analysis, and (2) at what junction each tool was needed. Although many tools offered by Esri were used within this suitability model, two tools served as the foundation on which the research was conducted. These tools are Esri's *ModelBuilder* and the *Weighted Overlay* tool, which are here described in greater length.

### 4.3.1 MoldelBuilder

While working with multiple spatial data layers and chronological mathematical processes, organization and documentation were prominent factors in creating a successful model. This site suitability model was designed to lend itself to virtually any prospect region with similar data availability and site parameters. A method was needed to quickly and efficiently manipulate data to foremost benefit potential users. *ModelBuilder* is a tool offered in Esri's ArcGIS that aids in the creation of spatial models for geographic areas. Multiple geographic processes can be combined and automated within *ModelBuilder* to be actualized as one large analysis. After the parameters within *ModelBuilder* have been properly configured, many geographic processes can be fashioned from start to finish with the push of a button. The *ModelBuilder* spatial model, represented as a flowchart diagram, has nodes that represent each component of a spatial process. Complex models can be built by connecting several processes together (*see Figure 4.2*). The suitability model for this study was created in *Modelbuilder,* and channels multiple datasets through predefined processes to find highly desired sites for CSP development.

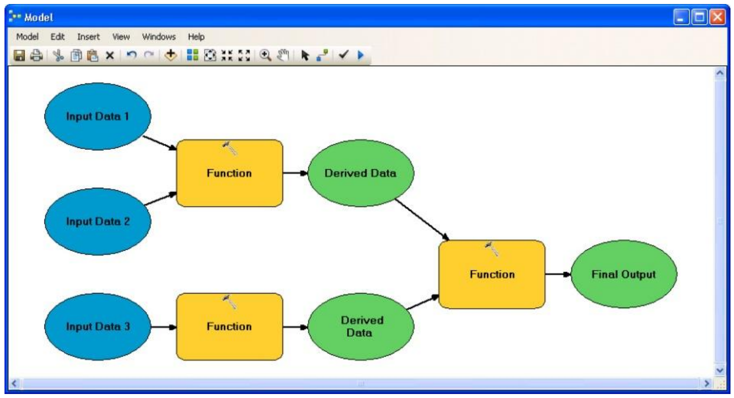


*Figure 4.2: ModelBuilder - Sample model within ArcGIS 10.0.*

### 4.3.2 The Weighted Overlay Tool

The *Weighted Overlay* tool, available in the *Spatial Analyst* extension of ArcGIS, can perform multicriteria overlay computations to assist in the site search process. This tool applies weighting techniques similar to the overlay siting methods outlined by McHarg (1969); however, multiple layers of raster data can be combined and weighted according to user defined importance. To perform the analysis correctly, each value for each criterion must be reclassified into a common numerical scale such as one to ten, with ten being the most favorable (as further described in section 4.5). Once the common scale is in place, the relative importance of each layer is assigned as a percent of the total sum. The sum of the percentage (assigned as the weighted importance values) must equal 100. For example, if four layers were placed within the overlay tool, and one layer was given an influence of 25 percent, then the remaining three layers would need to be assigned influence values that were equal to the sum of 75 percent [25% + 75% = 100%]. Additionally, these influence percentages can be readjusted to reflect the user's desired outcome. Once the proper influence values are assigned, the tool processes the information to provide numerical site desirability ratings. Prior to the *Weighted Overlay* analysis, proper raster information was initially acquired or mathematically generated within the GIS for model use.

### 4.4 Establishing Criteria and Preparing Data ***[Steps 3 & 4]***

The first step in building the solar citing model was determining which geographic criteria were to be used within the suitability model. To begin, it was possible to drop some potential criteria from the search problem. Since this study investigated potential sites on BLM land only, information pertaining to private parcels was not necessary for this task. Therefore, zoning data, assessor's parcel data, and agricultural conservation parcel information was not included in the siting process. Additionally, some layers did not provide the necessary variability within the County boundary and therefore would not influence the results. According to the FEMA data, 90 percent of the flood risk within San Bernardino County is undetermined. Also, the only discovered oil fields and existing wells were located on the extreme southwest region of San Bernardino County. For these reasons the FEMA data and CA DOG data were not included in the initial site search investigation.

Multiple datasets at varying scales and accuracies were collected and assimilated into the land-use suitability model created for this study. The layers used for analysis were transformed into one common projection, so as to minimize data misalignment that may have affected the final results. State Plane Zone IV NAD 83 (US feet) was the spatial reference selected for the study area because:

1. San Bernardino County maintains and distributes data in this projection
2. State Plane Zone IV displays less distortion in the chosen study area than other commonly used projections
3. Many engineering firms, surveyors, and developers actively use and are familiar with the State Plane coordinate system.

### 4.4.1 Converting Data

Once the data was integrated into the GIS and given the defined projection, each layer was appropriately formatted for inclusion within the suitability model. Of the collected data, two layers were manually converted to a format necessary for use within the suitability model. Low altitude flight paths and proximities within flight landing strips were converted from raster image to vector features. Digitized vector objects were created considering only features relevant to this study. The centerlines of low altitude Class E flight paths were digitized and buffered a distance of 500 feet, creating a 1,000 foot corridor for potential air traffic. All air strips were buffered with a 5 mile radius to represent the airspace needed for incoming and departing air traffic. The remaining layers to be used in the suitability model were acquired in the desired format for initial site analysis.

### 4.4.2 Calculating Slope

The subject solar facilities were to be located on relatively flat land, so calculating the slope of the terrain was necessary for site analysis. The study area was composed of eight adjoining terrain datasets that represented elevation values within the region. The *Mosaic* tool was used to combine these eight separate rasters into a single raster. This eliminated any overlap occurring in the eight separate images, while representing one all-inclusive elevation model of the earth's terrain. Once one contiguous raster was established, the rise over run values (slope) of elevations within the study area could successfully be determined. "For each [raster] cell, *Slope* calculates the maximum rate of change in value from [one] cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell" (Esri, 2010, Para. 1).

The *Slope* tool found within the Esri Spatial Analyst Extension was used to calculate elevation variances occurring on the earth's surfaces within the County. Several parameters were considered prior to evaluation, as to minimize uncertainty in the results. When dealing with a two dimensional plane (such as a map) the x and y axis represent horizontal coordinates. When adding a third dimension (surface elevation) a z axis is needed. Often times z units will be expressed differently than the ground x,y units present within a map. When this occurs, false readings may be encountered due to the contrasting units of measurement. To ensure all x,y and z units were uniformly represented, a proper Z-factor was considered. The Z-factor is the number of ground x,y units in one surface of z unit (Esri, 2007a). Since slope measures the rate of maximum change for z values, it was beneficial to use the proper Z-factor within the analysis for optimal results. The terrain data used in this study was of the same units and projection of all other x,y data. For this reason a z-factor of one was used (because xy units were represented in feet and the elevation values were also in represented feet). The *Slope* tool was utilized and the degree of inclination was then identifiable. (*see Figure 4.3*).

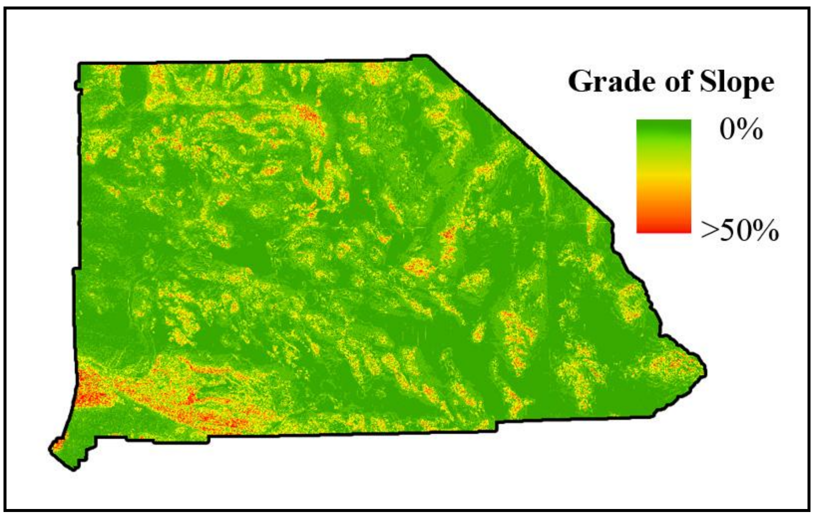


*Figure 4.3: Slope - Calculated output raster for San Bernardino County.*

$$[100\frac{rise}{run} = Grade\ of\ Slope]$$

### 4.4.3 Proximity to Critical Features

While prospecting the best possible regions for future solar development, certain features needed to be within close proximity to candidate facility sites. The proximity capabilities offered by *Spatial Analyst* were used to determine the distance from features within a given data layer.  A Pythagorean metric was used to identify which raster cells were within a given distance of subject feature class locations.  To do this, the *Euclidean Distance* tool was used to create an output raster classifying equal distance intervals from each subject feature (*see Figure 4.4*).  The extent was set to the San Bernardino County boundary polygon to ensure the function output would cover the entire study area.  The *Euclidean Distance* tool was used to divide the space emanating from the subject features to the furthest distances of the study area, into five mile wide concentric zones.  The distance values assigned to each zone in the raster output could then be numerically evaluated as to the suitability of each location.  This *Euclidean Distance* analysis was performed on transmission lines, substations, natural gas pipelines, and bodies of water (rivers, streams, lakes), as close proximity to these features was desirable for both project expense and technological success.

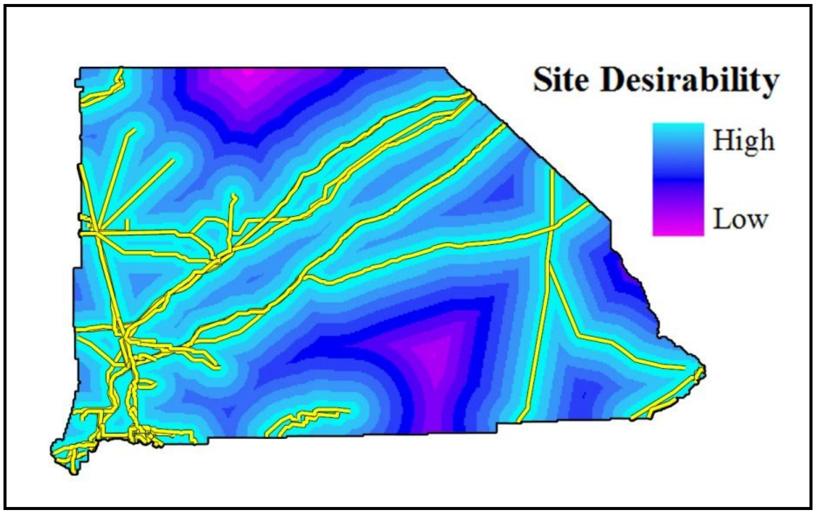


*Figure 4.4: Euclidean Distance - This tool was used to create equal distant increments emanating from transmission line features. These values were eventually reclassified and used for analysis in the Weighted Overlay tool.*

### 4.4.4 Assigning Suitability Values

Before data could be properly analyzed, raster cell values had to be reclassified to a common numerical metric for weighting purposes. For each raster layer used in the *Weighted Overlay* tool, cell values were reclassified to a scale of one to ten indicating their suitability for future solar development (ten being most suitable, one being least suitable). Each cell value represented a distance increment of approximately five miles. For those criteria where close site proximity was favored, the cell values in the most favorable range nearest to a desired feature were given a rating of ten, the second nearest range a rating of nine, the third nearest a rating of eight, and so on. The utilities datasets and existing bodies of water were classified in this manner in numerical order from ten through one.

Both the *DNI* raster and *Slope* raster were classified into ten separate classes by applying the *Jenks Natural Breaks Classification* method to the appropriate field data. This method is designed to determine the best arrangement of values into different classes, seeking to minimize each class's average deviation from the class mean while maximizing the differences between each class (Esri, 2007b). Once these raster values were categorically classified by the Natural Breaks method, they were reclassified according to site desirability. For example, areas with a slope of less than four percent were deemed highly suitable, whereas areas with higher slope percentages were deemed unsuitable. Areas with high annual DNI values were deemed highly desirable and given a rating of ten, whereas areas with the lowest annual values were given a rating of one. It is noted that all solar irradiance levels within the county of San Bernardino are considered sufficient for development; however, regions with values higher than 7,000 annual DNI were considered optimal for prospect site locations.

The final feature set reclassified for analysis was the *critical habitat* layer. It was decided to designate different habitats within San Bernardino County, so that each could be individually weighted within the overlay tool during model operation. The critical habitat boundaries were converted into a raster and the data was reclassified by assigning different critical habitat regions into one of nine categories. A tenth category was used to represent 'no data' (all remaining areas **not** defined as critical habitat). The final reclassified critical habitat raster identified ten numerical categories. The 'no data' values as well as areas delineating threatened and endangered species were successfully reclassified as numbers one through ten and placed into the *Weighted Overlay* tool.

Table 4.1 shows the threatened and/or endangered species included in the Critical Habitat layer and what value they were assigned.

**Table 4.1 Classes Assigned to Critical Habitat.**

| Class | Description/Species |
|---|---|
| 1 | **Desert Tortoise**<br>(Gopherus Agassizii) |
| 2 | **Amphibians**<br>(Arroyo Toad & Mountain Yellow-legged Tree Frog) |
| 3 | **Cushenbury**<br>(Buckwheat, Milk-vetch, & Oxytheca) |
| 4 | **Birds**<br>(Coastal California Gnatcatcher, Least Bell's Vireo, & Southwestern Willow Flycatcher) |
| 5 | **Fish**<br>(Bonytail Chub fish, Razorback sucker, & Santa Anna Sucker) |
| 6 | **San Bernardino Merriam's Kangaroo Rat**<br>(Dipodomys Merriami Parvus) |
| 7 | **Flora**<br>(Ash-Grey Paint Brush & Bear Valley Sandwart) |
| 8 | **Flora**<br>(California Taraxacum & Parish's Daisy) |
| 9 | **Flora**<br>(San Bernardino Bluegrass & Mountains Bladder pod) |
| 10 | **No Data** |

### 4.5 Executing the Weighted Overlay Tool *[Step 5]*

The *Weighted Overlay* tool was used by combining the derived data (with a common measurement scale of ten) to assess the most suitable locations within San Bernardino County. As opposed to making all weighted values equal, certain features were determined more important than others based on information from prior literature

(Vandenbergh et al., 1999; Janke, 2010) and the responses received from professional survey. Parameters were chosen within the *Weighted Overlay* tool to reflect ideal circumstances in a perceivably realistic environment. In total, eight raster layers were analyzed in the weighting process, with specific values restricted (i.e. removed from consideration) in areas where solar development was highly improbable or not greatly beneficial. Table 4.2 below shows an example of how these reclassified values might be scaled and how various weighted influences can be assigned to each layer. In finding optimal locations for future development, unsuitable distances from critical features were assigned a restricted scale value. Thus the scale values represent a subjectively optimized threshold placed on each raster layer to more precisely control the results produced by the suitability model.

**Table 4.2: Example - Weighted Feature Influence.**

| Raster | % Influence | Scale Value |
|---|---|---|
| Reclass Transmission Line | 20 | 10 – 8 (1 - 7 Restricted) |
| Reclass Pipeline | 15 | 10 – 9 (1 - 8 Restricted) |
| Reclass Substation | 15 | 10 – 5 (1 - 4 Restricted) |
| Reclass Slope | 15 | 10 – 8 (1 - 7 Restricted) |
| Reclass Critical Habitat | 15 | 10 (1 - 9 Restricted) |
| Reclass DNI | 10 | 10 – 4 (1 - 3 Restricted) |
| Reclass River/Streams | 5 | 10 – 1 (No Restrictions) |
| Reclass Lakes | 5 | 10 – 1 (No Restrictions) |

### 4.5.1 Finding Optimal Locations on BLM Public Lands

Once the parameters in the *Weighted Overlay* tool were adjusted to the desired specifications, a weighted output raster was created classifying all areas within the County with numerical values of one through ten. These values represented the weighted total derived from the assigned input layers ranking location suitability within the entire study area. To further refine the results, the *Conditional* tool was used to derive a raster containing only areas classified as nine or ten (sites rated 80 percent suitable and higher within San Bernardino County). To identify which of these locations fell within BLM public lands, the sites derived from the *Conditional* tool were converted to vector format for further analysis. The *Clip* tool was then used taking the BLM public lands feature layer and extracting those optimal sites that fell within the public lands boundaries. The final result showed the optimal CSP site locations found only on BLM public lands (*see Figure 4.5*).

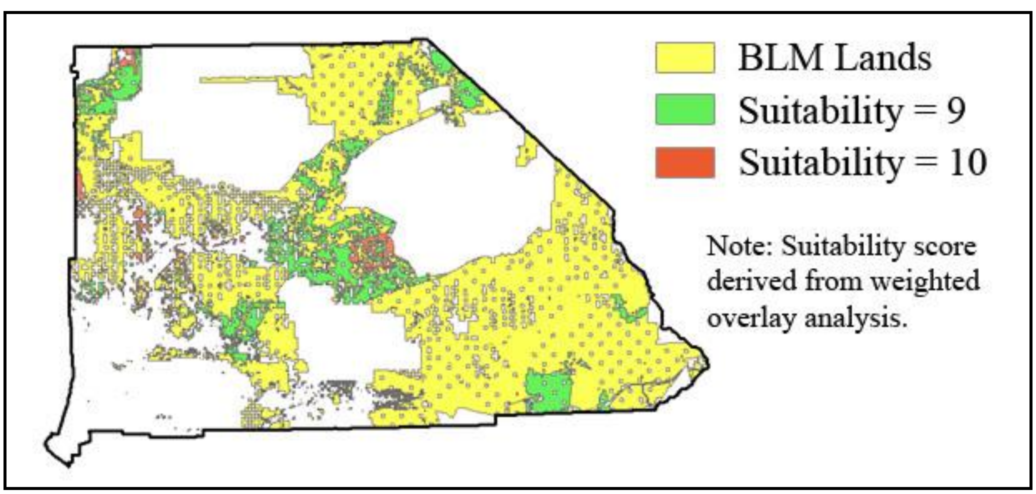


*Figure 4.5: Suitable Sites on BLM Public Lands – Shows regions receiving suitability scores of nine or higher on BLM public lands .*

## 4.6 Identifying Unsuitable Areas *[Step 6]*

Focus was placed on excluding features representing potential conflict and/or project opposition within this model. City limit boundaries, existing bodies of water (i.e. lake beds), national forests, designated wilderness, state parks, and recreation were all considered off-limits for large scale solar development. Other areas where close proximity may cause controversy were also treated as such. Vast regions in San Bernardino County are currently used for military operations. A four mile buffer was placed on all military installations to account for any flight traffic or related military actions that might deter the erection of a 500 vertical foot solar tower. Additionally a five mile buffer was placed on all airports and landing strips to account for incoming and outgoing air traffic. The four and five mile buffers were used from the airport traffic area boundaries depicted on the FAA raster data. The boundaries depicting low altitude Class E flight paths were also taken into account. Although there would most likely be no airspace conflict, flight paths were considered off-limits as an additional precaution. Table 4.3 lists the data compiled to create the *sites prohibited* layer. Note that flood data and CA DOG information, though listed, were excluded from the analysis due to lack of relevant data within the study area.

**Table 4.3: Areas Not Suitable for Solar Development.**

| Data Layer | Format | Description |
|---|---|---|
| Cities | shape | Urban city limit boundaries |
| Water | shape | Representing bodies of water (i.e. rivers, lakes, streams) |
| Wilderness-Forest-Parks | shape | Representing designated wilderness, national forests, and state parks |
| Military | shape | Boundaries of existing Military Installations |
| 4-Mile Military Buffer | shape | Areas within 4 miles of existing Military Installations |
| Existing Airports | shape | Airport landing strips in San Bernardino County |
| 5-Mile Airport Buffer | shape | Areas within 5 miles of existing airports (non-military) |
| FAA | shape | FAA flight paths and no fly zones |
| Proposed Wilderness | shape | Representing lands selected for National Monument in California Desert Protection Act of 2010 |
| Approved Conservation | shape | Representing approved desert conservation projects |
| Flood Data* | shape | Representing FEMA designated high risk flood zones |
| CA DOG* | point | Existing oil and gas wells |

** Layers* ***not*** *included due to lack of comprehensive coverage in the study area.*

Other information relevant to identifying unusable locations pertained to representing regions designated as planned future use. The largest were the proposed boundaries of Mojave Trails National Monument and Sand to Snow National Monument delineated in the 2010 CDPA. Desert areas for planned vehicle recreation were considered off-limits as well. A 100,000 acre BLM proposed wilderness site was also taken into consideration for exclusion within possible sites. The final feature boundaries added to the off-limits areas were conservation project sites that had been approved by the CA DFG. Once this data was collected, all polygon layers were merged into one *sites* *prohibited* layer. The *Dissolve* tool was utilized to make one polygon representing all areas where solar development was to be considered prohibited (*see Figure 4.6*).

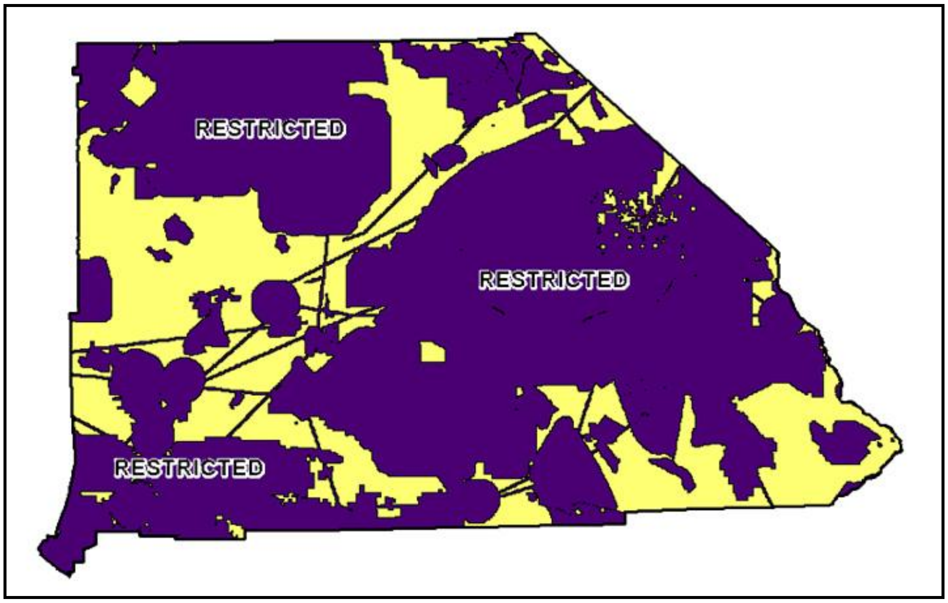


*Figure 4.6: Sites Prohibited Layer – Areas in purple indicate regions where solar development was considered off-limits.*

### 4.7 Refining the Search Area ***[Step 7 & 8]***

Once the prime locations on BLM public lands were found the sites where development was prohibited needed to be removed to prevent false indicators as to where future development could occur. To execute within the suitability model, a reverse clip function was needed to extract the optimal BLM public lands that resided outside of the *sites prohibited* layer. To do this, the *Erase* tool was used to remove any overlap occurring between the *sites prohibited* layer and optimal BLM public lands. What remained were optimal BLM public land sites (valued nine or ten) which did not encroach on areas determined off-limits for solar development.

The final step in identifying the best candidate sites was to make sure potential locations were of adequate size. The ideal site would have nearly 2,000 contiguous acres in a geometrically sensible layout. To eliminate polygons smaller than the specified acreage, the surface area and configuration of each remaining site needed to be known. Since the final BLM sites polygon layer had been derived from multiple processes, the area and perimeter of each feature was no longer present in the attribute table. To reestablish each sites' size, an additional field was added to the attribute table and titled 'acres'. The *Calculate Values* tool was selected to populate each feature's surface acreage. Once the acreage values were established within the attribute table, a definition query was executed to exclude sites that were too small for 200 MW facilities. The remaining sites were reviewed visually to confirm their configuration was sufficiently compact to contain the necessary development. In other words, although no such sites were identified, any site that was over 2,000 acres in size, but in a linear configuration with a maximum width of under 400 m, would have been eliminated. The final suitability model consisted of 27 processes (29 including populating the acreage field and querying site size) which were adjusted and refined until a desired outcome was reached (*see Figure 4.7).*

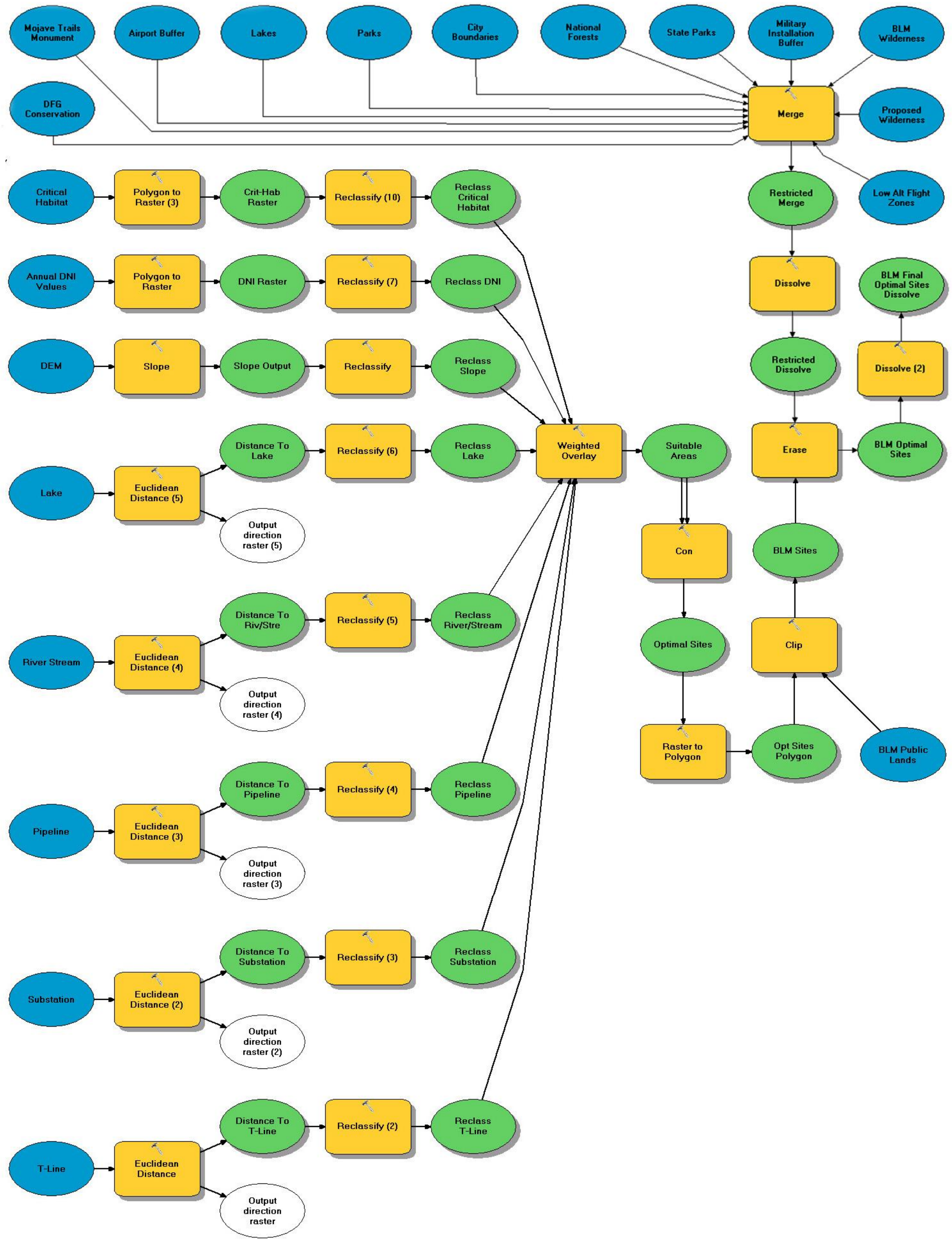


*Figure 4.7: Land-use suitability model created to identify optimal sites for CSP development on BLM public Lands.*

### 4.8 Comparing Model Sites to Existing Solar Applications *[Step 9]*

In addition to inspecting the results produced by the model with respect to the expected ideal geographic characteristics, the results were compared against existing solar applications as well. Since the existing solar applications in San Bernardino County account for only a small fraction of the available BLM lands, it is assumed that these filings were methodically placed due to the utility solar potential associated with each region. Sites larger than 6,000 acres produced by the suitability model were evaluated based on how well each location reflected that of an existing solar application. In the event an existing application did not overlap a result produced by the suitability model, further confirmation was sought as to why this had occurred. For example several existing applications were located in areas not attune with the minimum site requirements needed for the chosen CSP technology. For this reason, these sites were discarded as valid comparisons to the results delivered from the suitability model. This review of the findings with respect to the existing solar application sites is discussed further in the next chapter.

### 4.9 Calibrating the Suitability model *[Steps 10 & 11]*

After completing the suitability model, a method was needed for calibrating the results. It was decided that an effective means of calibration would be achieved by comparing the optimal sites' output by the model with the location of BLM approved solar applications since these decisions should reflect an integration of all the criteria included in the model. Ideally, therefore, the model should output these sites as part of the final set of optimal locations. The two components possessing the highest impact on the results were the weighted process and the restricted layers output. The *sites prohibited* layer was methodically composed of specific geographic criteria that eliminated the possibility of development, hence there was no flexibility for model calibration in that process. Essentially most of the variability came from adding or removing datasets from the final *sites prohibited* layer. Since these layers were intentionally chosen for site exclusion, focus was placed on fine-tuning the numerical weightings and scalings of individual layers within the *Weighted Overlay* tool.

In total 23 weighted trials were conducted until an acceptable outcome that (1) met ideal geographic conditions, (2) met technological requirements (i.e. fell within appropriate distances to utilities, received minimal DNI, etc.), and (3) most closely mirrored that of existing BLM solar applications, was reached. Table 4.4 shows several of the weighted process trials conducted. Note the change in influence percentages and scale values for each layer. The output of each of the weighted overlay trial runs was visually compared with the BLM sites. Once the trial which produced the best fit with the BLM sites was determined, the scaling used for each individual layer was reviewed to determine if any further adjustments could be made to incorporate additional parts of the BLM approved sites. The final model reflects the weightings and scaling that produced a result most closely reflecting the boundaries of the BLM approved solar application sites. The next chapter discusses in detail the analysis done to compare the model results to the BLM sites and produce the final model.

## Table 4.4: Calibrating Weighted Values.

*Weighted Process: Test 1*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 13 | 10 – 1 (No Restrictions) |
| Pipeline | 13 | 10 – 1 (No Restrictions) |
| Substation | 13 | 10 – 1 (No Restrictions) |
| Slope | 13 | 10 – 1 (No Restrictions) |
| Critical Habitat | 12 | 10 – 1 (No Restrictions) |
| DNI | 12 | 10 – 4 (1 - 3 Restricted) |
| River/Streams | 12 | 10 – 1 (No Restrictions) |
| Lakes | 12 | 10 – 1 (No Restrictions) |

*Weighted Process: Test 3*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 1 (No Restrictions) |
| Pipeline | 15 | 10 – 1 (No Restrictions) |
| Substation | 15 | 10 – 1 (No Restrictions) |
| Slope | 15 | 10 – 1 (No Restrictions) |
| Critical Habitat | 15 | 10 – 1 (No Restrictions) |
| DNI | 10 | 10 – 4 (1 - 3 Restricted) |
| River/Streams | 5 | 10 – 1 (No Restrictions) |
| Lakes | 5 | 10 – 1 (No Restrictions) |

*Weighted Process: Test 6*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 8 (1 - 7 Restricted) |
| Pipeline | 15 | 10 – 8 (1 - 7 Restricted) |
| Substation | 15 | 10 – 6 (1 - 5 Restricted) |
| Slope | 15 | 10 – 9 (1 - 8 Restricted) |
| Critical Habitat | 15 | 10 (1 - 9 Restricted) |
| DNI | 10 | 10 – 4 (1 - 3 Restricted) |
| River/Streams | 5 | 10 – 1 (No Restrictions) |
| Lakes | 5 | 10 – 1 (No Restrictions) |

*Weighted Process: Test 10*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 15 | 10 – 9 (1 - 8 Restricted) |
| Pipeline | 20 | 10 – 9 (1 - 8 Restricted) |
| Substation | 10 | 10 – 9 (1 - 8 Restricted) |
| Slope | 20 | 10 – 9 (1 - 8 Restricted) |
| Critical Habitat | 20 | 10 (1 - 9 Restricted) |
| DNI | 10 | 10 – 9 (1 - 8 Restricted) |
| River/Streams | 3 | 10 – 9 (1 - 8 Restricted) |
| Lakes | 2 | 10 – 9 (1 - 8 Restricted) |

*Weighted Process: Test 13*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 9 (1 - 8 Restricted) |
| Pipeline | 20 | 10 – 9 (1 - 8 Restricted) |
| Substation | 10 | 10 – 9 (1 - 8 Restricted) |
| Slope | 20 | 10 – 9 (1 - 8 Restricted) |
| Critical Habitat | 15 | 10 (1 - 9 Restricted) |
| DNI | 10 | 10 – 9 (1 - 8 Restricted) |
| River/Streams | 3 | 10 – 9 (1 - 8 Restricted) |
| Lakes | 2 | 10 – 9 (1 - 8 Restricted) |

*Weighted Process: Test 17*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 8 (1 - 7 Restricted) |
| Pipeline | 20 | 10 – 8 (1 - 7 Restricted) |
| Substation | 15 | 10 – 6 (1 - 5 Restricted) |
| Slope | 15 | 10 – 9 (1 - 8 Restricted) |
| Critical Habitat | 15 | 10 (1 - 9 Restricted) |
| DNI | 5 | 10 – 4 (1 - 3 Restricted) |
| River/Streams | 5 | 10 – 5 (1 - 4 Restricted) |
| Lakes | 5 | 10 – 5 (1 - 4 Restricted) |

*Weighted Process: Test 20*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 8 (1 - 7 Restricted) |
| Pipeline | 20 | 10 – 9 (1 - 8 Restricted) |
| Substation | 15 | 10 – 6 (1 - 5 Restricted) |
| Slope | 10 | 10 – 8 (1 - 7 Restricted) |
| Critical Habitat | 15 | 10 (1 - 9 Restricted) |
| DNI | 10 | 10 – 4 (1 - 3 Restricted) |
| River/Streams | 6 | 10 – 1 (No Restrictions) |
| Lakes | 4 | 10 – 1 (No Restrictions) |

*Weighted Process: Final Values*

| Raster | % Influence | Scale Value |
|---|---|---|
| Transmission Line | 20 | 10 – 9 (1 - 8 Restricted) |
| Pipeline | 20 | 10 – 9 (1 - 8 Restricted) |
| Substation | 10 | 10 – 5 (1 - 4 Restricted) |
| Slope | 15 | 10 – 9 (1 - 8 Restricted) |
| Critical Habitat | 10 | 10 (1 - 9 Restricted) |
| DNI | 10 | 10 – 6 (1 - 5 Restricted) |
| River/Streams | 6 | 10 – 1 (No Restrictions) |
| Lakes | 4 | 10 – 1 (No Restrictions) |

*Parameters within the Weighted Overlay tool were adjusted to examine how the final results were influenced.*

# CHAPTER 5

# RESULTS & DISCUSSION

## 5.1 Findings

All analyses were conducted using Esri ArcView 10.0 and the *Spatial Analyst* software extension. Eight datasets were used in the weighting process, one other was used to identify BLM locations, and an additional 12 were used to create the *sites prohibited* layer within the suitability model. Thus a total of 21 input layers were applied to the suitability model with five additional layers considered but intentionally omitted (DOG, agricultural conservation lands, tax parcels, current zoning designations, and FEMA flood zone data). Once the weighted parameters were properly adjusted, the model executed all the required processes, from beginning to end, within a ten minute time period. After the suitability model had identified optimal solar regions, model validation was accomplished by further analyzing and assessing the sites manually, based on: size, location, proximity to existing applications, etc. This validation process is described in this chapter.

### 5.1.1 Comparing the results to BLM Solar Applications

There were 99 BLM solar applications filed by 26 companies competing for federal lands within San Bernardino County at the time of study. Of the 9,310 square miles of public land, 1,003 miles [10.8%] were being petitioned for use by solar developers. It was found that 24 of the 99 applications [24.3%] were located inside the *sites prohibited* boundaries created within the suitability model. Three of these applications were actively pending, three had been withdrawn, two had been rejected, and the remaining 16 had been closed. Of the remaining 75 applications located outside the *sites prohibited* boundary, only three had been authorized for solar development. The three sites approved for solar development were located within the *sites acceptable* boundaries produced within the suitability model. Furthermore, the approved applications were geographically dispersed in that each site was at least 60 miles away from each other.

### 5.1.2 Validating Sites Produced by the Suitability Model

The implemented land-use methodology with the chosen weighted parameters *(see Table 5.1*) produced 33 potential sites (greater than 2,000 acres in size) ideally suited for solar development; 14 of which were larger than 6,000 acres. The sites greater than 6,000 acres were compared to existing solar applications within the study area to validate their geographic arrangement. This 6,000 acreage figure was investigated based on the economic benefit associated with constructing multiple 200 MW facilities at one specific location. Of the 18,000 square miles of level ground located within San Bernardino County, 14 sites greater than 6,000 acres accounted for approximately 346.8 [1.92%] of those square miles. Additionally these same 346.8 square miles accounted for just 5.78 percent of BLM public land. These sites were found throughout the County in all four quadrants of the study area.

**Table 5.1: Calibrated Values Yielding the Best Results.**

| Raster | % Influence | Scale Value |
|---|---|---|
| Reclass Transmission Line | 20 | 10 – 9 (1 - 8 Restricted) |
| Reclass Pipeline | 20 | 10 – 9 (1 - 8 Restricted) |
| Reclass Substation | 10 | 10 – 5 (1 - 4 Restricted) |
| Reclass Slope | 15 | 10 – 9 (1 - 8 Restricted) |
| Reclass Critical Habitat | 10 | 10 (1 - 9 Restricted) |
| Reclass DNI | 10 | 10 – 6 (1 - 5 Restricted) |
| Reclass River/Streams | 6 | 10 – 1 (No Restrictions) |
| Reclass Lakes | 4 | 10 – 1 (No Restrictions) |

Every site larger than 6,000 acres at least partially intersects an existing solar application. Furthermore, five of the 14 sites were located within the three BLM solar applications authorized for development thus far (*see Figure 5.1*). Of the authorized applications, both sites larger than 6,000 acres were operated by companies (Stirling Energy Systems and BrightSource Energy) utilizing CSP technology. The third authorized application was a 516 acre site operated by Chevron most likely designated for photovoltaic power generation. At just over 7,100 acres, the largest of the three sites was owned and operated by BrightSource Energy. Approximately 5,108 acres [71.9%] of the BrightSource site was located within the optimum site boundaries generated by the suitability model. Additionally 61.3 percent of the Stirling Energy application fell within the optimum sites boundary. The Chevron site was located entirely [100%] within one of the optimal site polygons produced by the suitability model. It was noted that FAA low altitude flight paths had bisected the optimum site boundaries associated with both the BrightSource and Stirling Energy sites. Had the FAA low altitude flight paths been removed from the *sites prohibited* layer, the approved application boundaries within the produced sites boundaries would raise to 84.5 percent (BrightSource Energy) and 92.5 percent (Stirling Energy Systems) respectively.

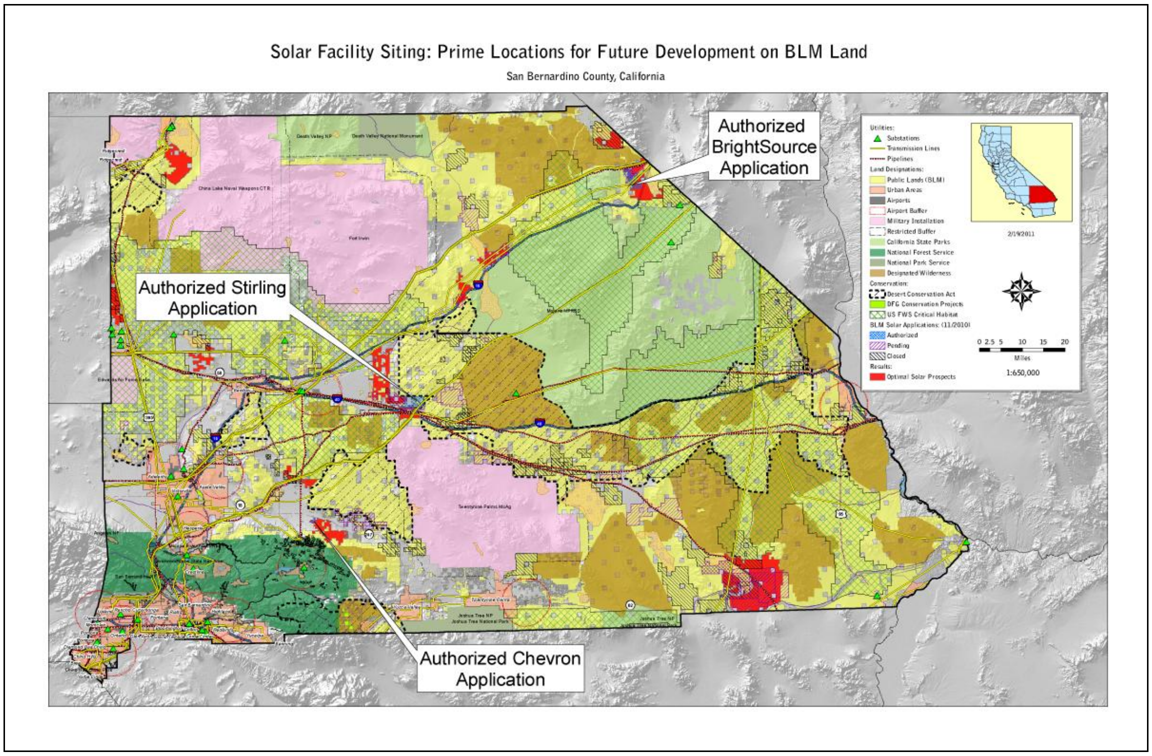


*Figure 5.1: Results - With so many layers of data, its easy to see how convoluted interpreting the informationcan be. Optimal solar sites larger than 6,000 acres shown in red.*

Of the pending solar applications within the *sites acceptable* boundary, only seven were not recognized as optimal sites by the suitability model. Conversely, there were seven areas larger than 6,000 acres produced by the suitability model delineating BLM lands where applications had not yet been filed. These sites had overlapped existing applications, but presented additional acreage near and/or adjacent to where existing applications had been filed. An investigation of sites larger than 4,000 acres revealed that four additional potential locations were identified where solar applications had not yet been filed. Based on further investigation regarding geographic parameters and proximities, there was no recognizable indication as to why these sites could not be used for future CSP development.

### 5.2 Evaluating the Results

The outcomes of these results were based heavily on the influence assigned to each layer during the weighted process. Additionally, some weighted classes were assigned restricted values to exclude areas where the solar technology could not be placed during the selection process. Restricted values were used to rule out the possibility of a site being produced where the subject CSP technology would not flourish. For example, slopes possessing steeper inclines than four percent were restricted to avoid the situation where all other criterion received a high rating, thus making the site appear optimal. The final weighted values were selected with both professional opinion and prior research taken into consideration. The last calibration of the weighted values within the model was based on how well the results matched up with existing solar applications and appropriate geographic features. For example, based on the economic statistics illustrated in the Tunisia study (Vandenbergh et al., 1999), close proximity to natural gas pipelines were considered a high priority for a potential site. The ordered significance of the remaining layers also corresponded with expert opinion and prior literature.

### 5.2.1 Problematic Criteria Choices

In an arid region such as San Bernardino County, existing water features may be little more than a barren area describing where water used to be. The selected criteria eliminated the possibility of sites being located on areas classified as lakes; however, a majority of the so-called lakes within San Bernardino County are actually dry lake beds. These areas can be extremely attractive to solar developers based on the terrain, location, and likelihood of no conflicting land uses. Several of the BLM solar applications were indeed filed directly over existing dry lakebeds. This model was designed to remove all lakebeds from the selection process based on its inability to efficiently assess other variables associated with these areas. Seasonal water shed, soil types, existing flora and fauna, and other environmental deterrents, were just a few of the factors that could not be assessed by the model given the available data. For that reason, all existing lakebeds were considered restricted for solar development.

As mentioned above, the addition of low altitude flight paths did have an effect on the boundaries of potential sites. Based on the applications authorized for development, the results show that low altitude flight paths did not inhibit the authorization of power tower facilities. However, adding military fly zones, buffers around military installations, and buffers on existing airstrips to the *sites prohibited* layer did appear to reflect areas where solar development was not acceptable. When compared to authorized solar applications, the success of this suitability model was improved when the FAA low altitude flight paths were withdrawn from consideration. It is also noted that the flight paths created were initially digitized from raster data, and undeniably contained additional uncertainty that could have impacted the results.

### 5.2.2 Layers Not Included in the Site Selection Process

Several criteria were considered but not included in the suitability model. Existing oil and gas data, flood zone data, parcel data, zoning data, and agricultural conservation data (The Williamson Act) were not included in the initial analysis. Upon investigation, the only discovered oil fields and existing wells were located on the extreme southwest region of San Bernardino County. This region was already deemed unsuitable for the chosen solar technology due to uneven terrain and abundant human population densities; therefore, the CA DOG data was excluded from this analysis entirely. If prospecting areas along the California coast and central valley where thousands of oil and gas wells reside, this layer would be beneficial; however, it was not needed for this particular analysis.

Little information was available as to the areas within San Bernardino County that are prone to flooding. Although a FEMA flood zone layer was acquired delineating all regions within the County, more than 90 percent of the study area was classified as having an undetermined flood risk. Most of the accessed flood risk regions were within city limit boundaries (which were considered off-limits in the chosen model). For this reason, the FEMA flood zone data was not included in this suitability model. To confirm the FEMA flood data would not have an impact on the results, the sites produced by the suitability model were investigated after initial analysis. It was found that one site larger than 6,000 acres encroached on an area zoned as having a one percent flood risk over a 500 year period. The remaining sites produced were established in the FEMA designated undetermined flood zones. It was confirmed that the flood data did not jeopardize the results; however, had more comprehensive information been available, the data would have been included in the weighting process within the suitability model.

The final three layers not included in this analysis (parcel data, land-use, and agricultural conservancies) were all related to private lands within the County. This model focused on identifying regions within BLM public lands for solar development. For this reason, they did not play an integral role in the established results; however, this information can be beneficial to developers after a site has been approved for development. For example, if a site of 4,500 acres was granted by the BLM for solar development, and private parcels were located adjacent to the site, developers would have the option of expanding their project onto private lands. Knowing the size and location of parcels, designated land uses, and agriculture status would aid in the decision making process of developers. Additionally, companies using the contrasting PV technology often consider private parcels due to the flexibility enjoyed by smaller site size and final acreage configuration. Had this study focused on private lands, these datasets would play a more substantial role.

### 5.2.3 Model Shortcomings

There are several factors within this analysis that can raise questions regarding the integrity of the final results. Some factors were unavoidable whereas others were inadvertently user induced. One obvious shortcoming comes from questionable data reliability. It was confirmed that the uncertainty within the substation data layer was unknown. Some points within shapefiles were accurately positioned, while others could not be identified when cross referenced with aerial imagery or topographic backdrop information. Furthermore, the DEM layer used was ten meter resolution and did not represent the earth's surface to true life standards. Some areas may possess features undetected by the DEM that would deter development, such as man-made structures or abrupt elevation changes. Both of these layers are essential to site development and were used in the weighting process. The misdiagnosis of these geographic feature properties, and others used in the study, can skew the results produced by this suitability model.

Additional model shortcomings arise in the design of the model and specification of criteria, and can be avoided in future case studies. The fact that authorized solar applications were located within low altitude flight paths signifies that (1) the initial flight pattern was inadequately digitized during the conversion process, or (2) the low altitude flight zones did not have a direct impact on the location CSP solar development. When low altitude flight zones were removed from the *sites prohibited* layer, the model averaged more than a 90 percent suitability rating while detecting the existing BLM solar applications that had been authorized for development.

The polygons present in the *critical habitat* layer were meant to identify the location of endangered and/or threatened species. In actuality, this is a fuzzy boundary and should be treated as such. Realistically, an invisible geographic line cannot signify the exact location of a species (Boroushaki & Malczewski, 2010). Therefore, a site located adjacent to a critical habitat region should be approached with caution. It was decided to add this information to the weighted process and not the *sites prohibited* layer to allow for future flexibility. The added flexibility allows the model to be adjusted in a situation where sites may encroach on the boundary of or in the vicinity of critical habitat. Unfortunately, because of raster conversion, critical habitat regions were no longer linked to an individual species and therefore could not be individually queried as such; however, the original critical habitat dataset could still be used in the event this scenario became an issue. The original critical habitat dataset can be placed under the optimal sites layer and queried by species. This allows the user to identify which threatened or endangered species (if any) exist near or on a project site. Given the fact that the original critical habitat layer can be further examined, this issue is not expected to jeopardize the results.

As with any geographic evaluation, the results will only be as reliable as the data used for analysis. When investigating multiple layers of data, the uncertainty presented in the results can increase exponentially. For these reasons, it is essential to obtain the most reliable data for the investigation at hand. It is important to note that more comprehensive datasets were available at time of study, but were not incorporated into the model due to high costs associated with obtaining the information. Also, several critical processes such as initial data set up and final site queries were not automated within the suitability model. These tasks are to be performed at user discretion and because of this reason, can adversely affect the final outcome produced by this siting process.

# CHAPTER 6

# CONCLUSION

## 6.1 Model Validation

This suitability model was designed to expedite the siting process encountered by developers seeking BLM land for CSP site development larger than 2,000 acres in size. Multiple elements regarding the land development process and technological feasibility were considered during site assessment. After the appropriate geographic datasets and parameters were configured, the suitability model produced encouraging results within a ten minute time period. The sites generated from the suitability model correlated closely to existing solar applications, while still identifying areas not yet claimed by solar developers. Identifying these additional areas can be valuable in that the suitability model may be used to identify regions still open for development. In addition, the model identified existing applications that were not suitable for development and were classified by the BLM as such (i.e. withdrawn, closed, or rejected). Aside from validating potential solar sites, this tool may also be used as an audit instrument for the compliance of existing sites. Although this model displayed a data collection and geographic processes directed at producing sites capable of supporting CSP power tower technology, it can also be used as a template by solar developers investigating other various types of renewable power generation.

This study was conducted in San Bernardino County, California to demonstrate how a GIS can be used to analyze copious amounts of data in an extremely competitive marketplace. The strict environmental policies and land-use laws surrounding utility sized development can pose complications when trying to identify suitable locations for solar development. This model took these and other criteria into account while finding the optimal sites for facilities over 2,000 acres in size. This model may be beneficial when applied to alternate counties and/or study areas for users seeking similar results. Nevertheless, it is good to keep in mind the limitations presented by the model and methodology. As previously mentioned, higher accuracy datasets were not incorporated into this model due to attainability issues. However, based on the results achieved with the current implementation, it is not suspected that the lack of these data greatly compromised the location of the produced sites. Although, several actions within the methodology may limit the overall functionality of the suitability model (i.e. removing dry lake beds as possible areas for development), valid results were still produced.

Based on the size of the study area and large acreages being sought, it is believed that the suitability model presented in this research can greatly benefit the initial selection process. Although unknown variables will inevitably hinder these results, the model's purpose remains valid. A search area of nearly 20,000 square miles was reduced to approximately 14 sites totaling 346.8 square miles within a matter of minutes. Furthermore, the candidate sites produced by the suitability model highlighted the regions where the solar applications within San Bernardino County were authorized for solar development. Approximately more than 90 percent of the authorized application sites fell within the candidate site boundaries produced within the suitability model. Additionally, the fact that all 14 candidate sites greater than 6,000 acres in size intersected existing solar applications suggests that the suitability model was successful in qualifying areas suitable for utility scale solar development. This does not however guarantee that a site will be authorized for development. Furthermore, additional deterrents not addressed within the model may be present at subject locations, and need to be assessed on a case-by-case basis. It should be noted that these findings do suggest this is an appropriate methodology that can be applied for identifying areas of interest. The subject site boundaries can be further analyzed after the initial findings.

### 6.2 Future Work

Although this study examined the CSP site search process within GIS, further analyses can be done to more appropriately identify suitable locations. One problem faced by utility developers in California has been finding the capability to adequately transport large amounts of generated electricity (D. Perkins, personal communication, November 18, 2010). Transmission lines have capacity limits as to the amount of voltage they can safely handle. With population growth and the push toward additional renewable facilities, most of these transmission lines have reached their maximum capacity. If data could be attained containing information as to line size, current electrical flow, and potential kVA availability, the site selection process could be enhanced. Using this information, a method could be used to identify the most suitable site locations based on: available space in transmission lines, user demand, and economic feasibility associated with delivering the electricity. Additionally, uncertainties affect the results produced by this model.  Future work may be conducted as to quantifying these uncertainties to more comprehensively evaluate the final results.

## GLOSSARY

**CDPA 10:** *Acronym for the California Desert Protection Act of 2010* - A Conservation Act proposed by Senator Diane Feinstein protecting wildlife areas within the Mojave Desert.

**CA DOG:** *Acronym for the California Division of Oil and Gas* - This Division oversees the drilling, operation, maintenance, and plugging and abandonment of oil, natural gas, and geothermal wells in California.

**CA DFG:** *Acronym for the California Department of Fish and Game* - This agency maintains native fish, wildlife, plant species and natural communities for their intrinsic and ecological value and their benefits to people. This includes habitat protection and maintenance in a sufficient amount and quality to ensure the survival of all species and natural communities.

**CSP:** *Acronym for Concentrated Solar Power* - power plants that provide solar power using mirrors to concentrate sunlight to create heat which is used to produce steam to drive steam turbines and electricity generators.

**CPUC:** *Acronym for California Public Utilities Commission* - Regulates privately owned utilities in the state of California, including electric power, telecommunications, natural gas and water companies.

**DEM:** *Acronym for digital elevation model* **1.** The representation of continuous elevation values over a topographic surface by regular array of z-values, referenced to a common datum. **2**. A format for elevation data, tiled by map sheet, producedby the National Mapping Division of the USGS.

**Esri:** *Acronym for Environmental Systems Research Institute* - The world's leading developer of geographic information systems [GIS] software.

**FEMA:** *Acronym for Federal Emergency Management Agency* - An independent agency of the United States government that provides a single point of accountability for all federal emergency preparedness and mitigation and response activities

**Georeferencing:** Aligning geographic data to a known coordinate system so it can be viewed, queried, and analyzed with other geographic information.

**GIS:** *Acronym for Geographic Information System* - An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes.

**Heliostat:** An instrument consisting of a mirror mounted on an axis moved by clockwork by which a sunbeam is steadily reflected in one direction.

**Insolation:** The rate of delivery of direct solar radiation per unit of horizontal surface.

**Irradiance:** the density of radiation incident on a given surface usually expressed in watts per square centimeter or square meter.

**kWh:** *[kilowatt hour]* - The standard unit of measure for electrical energy use. One kWh is used to light a 100-watt bulb for 10 hours.

**kVA:** *[kilovolt Ampere]* - A term for rating electrical devices. A device's kVA rating is equal to its rated output in amperes multiplied by its rated operating voltage.

**LIDAR:** *Acronym for Light Detection and Ranging* - A remote-sensing technique that uses lasers to measure distances to reflective surfaces.

**NREL:** *Acronym for National Renewable Energy Laboratory* - A notional laboratory of the U.S. Department of Energy, dedicated to the research, development, commercialization and deployment of renewable energy and energy efficiency technologies.

**Power Tower:** *(also known as 'Central Tower' power plants or 'Heliostat' power plants)* is a type of concentrated solar thermal facility using a tower to receive focused sunlight to generate a turbine. It uses an array of flat, movable mirrors (called heliostats) to focus the sun's rays upon a collector tower (the target).

**Raster:** A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and comprised of a single or multiple bands. Each cell contains an attribute value and location coordinates.

**Site Suitability Model:** A model that weights locations relative to each other based on given criteria.

**Vector:** A coordinate-based data model that represents geographic features as points, lines and polygons. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.

**Weighted Overlay:** A technique for combining multiple rasters by applying a common measurement scale of values to each raster, weighting each according to its importance, and adding them together to create an integrated analysis.

**WLC:** *Acronym for Weighed Linear Combination* - Weighted linear combination is the most often used technique for tackling spatial multiattribute decision making. It is a multiattribute procedure based on the concept of a weighted average. The decision maker directly assigns weights of relative importance to each attribute.

**USGS:** *Acronym for United States Geological Survey* - a scientific agency of the Unites States government that studies the landscape, natural resources, and natural hazards of the U.S.

**US FWS:** *Acronym for United States Fish and Wildlife Service* - federal government agency within the United States Department of the Interior dedicated to the management of fish, wildlife, and habitats.

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APPENDIX

**Questionnaire 1:**

**Mark Zahn - Land Planning: BrightSource Energy**

1. In order of importance - what geographic elements are absolutely NEEDED for utility-scale solar development? (i.e. transmission lines, % grade/slope, Insolation Values, etc)

    a. Insolation values
    b. Proximity to robust electrical transmission (230 kV or 115 kV upgradable to 230 kV)
    c. Proximity to natural gas pipeline
    d. Sloping of less than 5%
    e. Availability of water (even if project is dry cooled, need approx. 25 ac.ft. per year for each 100 MW of plant capacity)

2. In order of importance - what geographic criteria are DESIRED for utility-scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictions)

    a. See 1a. through 1e. above
    b. Site size of at least 1,000 contiguous acres in a rational geometric shape
    c. Absence of conflicting surface uses (mining, oil or gas production)
    d. Absence of conflict with FAA flight paths, DOD flight training or operational routes (Potential civilian and military aviation conflicts may be present with respect to project towers that may exceed 500 feet in height)
    e. Absence of environmentally-restricted designations that would prevent or limit use of the site

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility-scale solar development say 500 acres in size? For example a site that has cleared any political or environmental oppositions and is ready for construction. Please Estimate or explain.

    Lack of mapping software tools typically would add several weeks to several months to the site vetting process, as traditional site vetting involves an extremely labor-intensive and inefficient sorting and culling of siting areas and characteristics. Also, traditional methods of condensing this information into a visually useful form are likewise inefficient and time consuming.

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

   The competition for solar site has been intense, so the ability to quickly and efficiently vet sites and characteristics is absolutely critical to beating the competition. BrightSource's use of PPC's research and mapping capabilities has been essential to our efforts and success. Also, PPC's ability to identify and map the presence of competitors that have existing rights to desirable sites gives us the ability to evaluate opportunities to structure joint ventures with such parties.

5. What has been your biggest frustration when trying to site potential lands?

   The relatively low amount of sufficiently large private tracts with the right characteristics has been our biggest challenge. Also, finding existing electric transmission capacity for these tracts has been extremely frustrating, given the congested nature of the power grid, and its lack of flexibility to move large amounts of renewable energy to regions outside the desert southwest.

6. What would you change about current geographical siting techniques to make the overall process better?

   Current techniques have provided a quantum leap in terms of finding suitable sites that meet the criteria set out in 1. and 2., above. The next leap would be to combine current capabilities with a way to determine available transmission capacity and flexibility to deliver power to regional and national markets.

7. What type of utility-scale solar technology does your company use? What is the least amount of acreage needed? What is the most?

   BrightSource Energy employs a solar thermal technology that utilizes power towers. The boilers contained in these towers generate steam that is run through conventional Rankine cycle steam turbines to generate power. We need at least 8 acres for every Megawatt of plant capacity. Our minimum acreage is 1000 acres (for a 130 MW unit). WE have not maximum other than the limits imposed by the transmission system. We are targeting sites as large as 10,000 acres (for at least three 250 MW units).

8. How much electricity can be produced from this technology?

   Our base units are in 130 MW and 250 MW producing capacities.

**Questionnaire 2:**

**Dave Perkins - Vice President of Land Development: Meridian Energy**

1. In order of importance - what geographic criteria are absolutely NEEDED for utility-scale solar development? (i.e. transmission lines, % grade/slope, Insolation Values, etc)

   a. Aerial Imagery
   b. Land Grid
   c. Land parcels with ownership data
   d. Topography
   e. Insolation values
   f. FEMA Flood Plain Data
   g. Location of and information about existing electrical infrastructure
      a. Existing and planned power plants (thermal, wind, solar, biomass)
      b. Electric substations (existing and planned, by owner / operator)
         - high voltage (especially 115 kV and 230 kV)
         - sub-transmission (69 kV)
         - Distribution sub`s (if someone had this layer they could be very wealthy)
      - Electric Lines (existing and planned by owner / operator)
         - high voltage (1150kV and 230 kV), and
         - sub-transmission (69 kV)
         - Distribution lines
   h. Natural gas pipelines (for solar thermal or knuckleheads (like me) who want to do gas-fired firming)
   i. Land Conservation Units (such as Williamson Act Lands in CA)
   j. Environmentally sensitive areas
   k. Federal Lands (including surface management agency)
      a. Status of current Solar site applications (they are actually ROW applications) by state
      b. Ditto for wind applications (there may be synergy between a wind farm and a solar farm)
   l. State Lands (by management agency… DWR, CalTrans, etc.)

m. Transportation Infrastructure (roads and railroads – the equipment has to be delivered)
n. Soil Data
o. Hydro Geology
p. State Level groundwater data (some states have designated groundwater basins, some of which are open or closed, managed / restricted by the state, not managed / restricted, etc.)

2. In order of importance - what geographic criteria are DESIRED for utility-scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictions)

   a. Solar radiation values
   b. Proximity to appropriate substation (in terms of voltage as well as ownership of the substation – PG&E, SCE, etc.) or a t-line of appropriate voltage with available capacity that could provide access to the desired point of delivery.
   c. The status of the transmission interconnection queue for a given point of delivery (i.e. could we obtain an interconnection agreement at a given point of delivery for a given amount of energy). This information may not be a currently available spatial data element at present but is certainly an important consideration in siting. The information is actually available on-line in tabular form and could be compiled and depicted geographically by someone with a Masters in GIS.
   d. Parcel size and character - previously cultivated or not (runs to land use / environmental approvals)
   e. Topography
   f. Drainage
   g. Flood zone status
   h. A given site's perceived potential to create significant environmental impact$ due to the presence of listed or endangered animal and plant species (as determined by the use of environmental / biological spatial data, if available)
   i. No known environmental restrictions
   j. No conservation related land use restrictions (such as Williamson Act land in CA)
   k. Local land use data such as General Plan and existing zoning overlays help developers evaluate general areas to focus attention (or not) and are important in terms of evaluating the perceived ability of a project to obtain the necessary land entitlements.

l. Location of Federal lands vis-à-vis the various project components (i.e. want to avoid Federal lands so as not to trigger NEPA / EIS, etc.) This runs to $chedule and cost impact$ and thus, project viability.

m. Soil types to determine footings / piles (runs to cost as well at type of technology we could employ)

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility-scale solar development say 500 acres in size? For example a site that has cleared any political or environmental oppositions and is ready for construction. Please estimate or explain.

   A long time. Lots of airplane and windshield time (a big carbon footprint). Much leg work, phone calls swabbing lots of people – measured in months.

   Perhaps we should discuss this question because I think that a project site that has already cleared political and / or environmental opposition and is ready for construction, by definition, would be an already permitted site (to be acquired from another developer perhaps) – which is another angle – Project Acquisition due diligence. That could involve the use of all the spatial data discussed above.

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

   There are always going to be both competition and opposition. There is not much one can do about competition except design the most efficient, <u>least cost</u> project you can so you can get "selected" by the utility / offtaker and let the chips fall where they may. If you are talking about competition for a given piece of land, it usually comes down to <u>most cost</u>… money (and when they say it's not the money, it's the money).

   In terms of opposition, all one can do is listen to and accept (to the extent feasible) input from all of the various stakeholders, including project opponents and proponents; as well as work together to resolve or mitigate such concerns (to the extent feasible or possible) by modifying the overall design of the project, within the confines of all of the various components / criteria listed above (which can be tricky to accomplish).

5. What has been your biggest frustration when trying to site potential lands?

   The large amount of Federal lands (and related Federal bureaucracy) in the Solar

Southwest; the politicization of solar energy in CA and the undue influence of special interests like the unions, farm bureaus, etc.

6. What would you change about current geographical siting techniques to make the overall process better?

   More, and more reliable data (that no one else has but me).

7. What type of utility-scale solar technology does your company use? What is the least amount of acreage needed? What is the most?

   Meridian Energy USA, Inc. is focused on Photovoltaic (PV) solar technology.

   The back-of-the-envelope calculation is 1 MW = 8 acres, depending upon location. That ratio works for the Central Valley in CA in general, and would be a bit conservative for the eastern desert region and Antelope Valley where there is more solar radiation. Go to NREL's website for lots of information, including GIS links.
   http://www.nrel.gov/about/
   http://www.nrel.gov/analysis/
   http://www.nrel.gov/science_technology/

   20 MW = 160 acres, more or less.

   Utilities are typically contracting for PV projects in the range of 3-250 MW. Meridian is focused on the 20 MW – 150 MW range.

8. How much electricity can be produced from this technology?

   I suggest you research this at the NREL site

**Questionnaire 3:**

**Samantha Smith – Project Manager of Development: FRV, Inc.**

1. In order of importance - what geographic criteria are absolutely NEEDED for utility-scale solar development? (i.e. transmission lines, % grade/slope, Insolation Values, etc)

    a. High Insolation
    b. Transmission Capacity
    c. Close proximity to point of interconnection (short gentie)
    d. Available easements for gentie
    e. Located outside of a mineral rich area

2. In order of importance - what geographic criteria are DESIRED for utility-scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictionns)

    a. No biological/environmental constraints (CESA, ESA, 404, etc.)
    b. Outside of flood zones
    c. Low discretionary permitting risk (CEQA/NEPA)
    d. > 2% slope
    e. Located in an area without subsistence

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility-scale solar development say 500 acres in size? For example a site that has cleared any political or environmental oppositions and is ready for construction. Please Estimate or explain.

    Environmental constraints can be determined in a matter of days if familiar with the area. Topography and flood zones can also be determined with minimal effort. Determining transmission capacity is difficult and time consuming. That information is generally not know until a Generator Interconnection Application is filed with CAISO and you receive your Phase 1/System Impact Study results. ISO does publish their interconnection queue, but it's taken us months to research all of the projects (projects and applicants are confidential, only the MW, line/substation, power generation, and county are published) to determine which projects are "real" where it's located, etc. Aside from GIP study results, queue analysis is our best tool.

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

   Community members and environmental groups have slowly began to embrace solar, but finding suitable sites with available transmission outside of critical habitat areas is becoming increasingly difficult. We look for sites that have little to no environmental impacts.

5. What has been your biggest frustration when trying to site potential lands?

   The CEQA process in California opens the door to multiple levels of comments and complaints about development projects. All developers continue to struggle with the special interest groups to limit unnecessary opposition while ensuring that a profitable project can be built. In this instance, the higher the cost to developer, the higher the utility rates that will be passed along to consumers.

6. What would you change about current geographical siting techniques to make the overall process better?

   Mapping technology has come along way. I'm quite please with the ability to map fatal flaws, with the exception of transmission capacity.

7. What type of utility-scale solar technology does your company use? What is the least amount of acreage needed? What is the most?

   We use photovoltaic technology in the Untied States. Acreage is dependent upon minimum project size. Our minimum commercial project size is 20 MW which typically requires a minimum of 160ac.

8. How much electricity can be produced from this technology?

   Electricity production is dependent upon project size, project location (insolation affects production), and specific panel manufacturer (panel rating and efficiency).

**Questionnaire 4:**

**Dave Krolick - Corporate Manager of Mapping and Spatial Information Technology: ECORP Consulting, Inc.**

1. In order of importance - what geographic criteria are absolutely NEEDED for utility-scale solar development? (i.e. transmission lines, % grade/slope, Insolation Values, etc)

    a. Transmission Line and Grid Tie-in Geospatial Data
    b. Medium to High resolution topo data to provide slope constraints
    c. Insolation data (particularly for concentrated solar)
    d. Biological resource assessment data
    e. Cultural resource assessment data

2. In order of importance - what geographic criteria are DESIRED for utility-scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictions)

    a. Proximity to grid tie-in
    b. Proximity to market
    c. Low to no impact to endangered species habitat
    d. Low slopes on-site
    e. Easy access to transmission corridor

3. Traditionally (when not using a form of mapping software) how long would it take from beginning to end to find a viable site for utility-scale solar development say 500 acres in size? For example a site that has cleared any political or environmental oppositions and is ready for construction. Please Estimate or explain.

    N/A

4. What competition and/or opposition has been encountered when considering potential solar lands? How has you/your company dealt with it?

    Primarily we have had to deal with endangered species issues out in the desert. We can get permits to complete solar projects, but it is difficult to find mitigation land to purchase due to the fact that the BLM owns most of the land. We deal with it by combing the assessors data for appropriate parcels in private ownership.

5. What has been your biggest frustration when trying to site potential lands?

   Lack of good topo data and good direct solar input models. GHI data is fine, but solar collectors are quite a bit more challenging.

6. What would you change about current geographical siting techniques to make the overall process better?

   It is more about a lack of good data than the technique.

7. What type of utility-scale solar technology does your company use? What is the least amount of acreage needed? What is the most?

   We consult, but we have assisted with both PV and thermal projects.

8. How much electricity can be produced from this technology?

   It depends on the amount of land you can permit and build on. It is certainly industrial scale power.

9. Please add any useful comments not mentioned in the questionnaire.

   As with most GIS/Geospatial Analysis projects, the results of the analysis can only be as good as the data that gets input into the models. It is not very difficult to do a regional assessment with available USGS national datasets, but site specific analysis is quite a bit more challenging to complete without a significant investment in on-site data.

**Questionnaire 5:**

**Lara Wood - GIS Operations Manager: PPC Land Consultants**

1. In order of importance - what geographic elements are absolutely NEEDED for utility scale solar development? (i.e. transmission lines, % grade/slope, Insolation Values, etc)

    a. Insolation Values (preferably high-resolution, greater than 30m)
    b. High resolution Digital Terrain Models, or LIDAR for areas of interest
    c. Accurate (ground-truthed) transmission line data
    d. Ownership/Stewardship data to avoid protected areas

2. In order of importance - what geographic elements are DESIRED for utility-scale solar development? (i.e proximity to sub-stations, T-lines, no environmental restrictions)

    a. Flat landscape
    b. High Insolation value
    c. Minimal environmental restrictions
    d. Proximity to infrastructure (substations, t-lines, etc.)

**Remainder of questionnaire left blank**
**No physical solar experience**