SITE SUITABILITY ANALYSIS FOR LOCATING A VINEYARD IN THE DRIFTLESS AREA OF WISCONSIN

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Geography 578

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Introduction

Wisconsin is known for its agricultural history, and in recent decades that has grown to include a fairly robust vineyard and wine industry. Although the wine industry in Wisconsin dates to the early 1840s, pre-dating statehood, Wisconsin is still primarily a beer-making state. The goal of this project is to help expand the wine industry while also following guidelines set forth by the 'local food' movement. The Driftless Area of Wisconsin is the state's primary region of wine production -the "state's biggest wineries...and another half dozen smaller enterprises" produce over 90 percent of Wisconsin's wines. (Monaghan 2008: 94). The Driftless Area is also home to Wisconsin's only two American Viticultural Areas, the Lake Wisconsin AVA and the Upper Mississippi Valley AVA.

Specifically, the capstone statement for this project is to: "Identify and map potential sites for a vineyard in the Driftless Area of Wisconsin. Assess land suitability using environmental criteria derived from the optimal growing conditions of the Marechal Foch grape cultivar. Evaluate market access and economic factors to locate sites to enhance the local wine industry in Wisconsin."

Suitability analysis of a variety of factors will allow us to select the land that best meets the growing criteria. Existing literature on the Marechal Foch's preferred growing conditions and GIS technology were used to calculate a weighted suitability map of the locations with the best combination of characteristics. This allows the identification of land in the Driftless Area suitable for increased viticultural activity. Expanding the vineyard industry in Wisconsin can provide important new economic opportunities to the region.

Conceptualization

The analysis can be divided into two key concepts central to the geographic problem, environmental and economic suitability. These concepts need to be defined and broken down into measurable variables to address the problem and implement the spatial analysis in a GIS. A flowchart illustrating the process of conceptualizing these variables is found in Appendix I.

Environmental Suitability

Soils

The effect of soil type and chemistry on grape production is uncertain, as conflicting opinions and evidence is widespread throughout the viticultural literature. However, favorable soil characteristics can certainly be identified in order to aid in the selection of the vineyard site. It is widely recognized that deep, well drained soils are integral to successful vine growth as they provide warmer soils with a lower water table that can accommodate the deep penetration of the vine's root system (Jackson and Schuster 1981: 59-61). Soil composition is ideally large-grained to provide for good drainage and aeration (MGGA 1993: 5). Relatively infertile soils are also typically preferred, as high fertility soils can cause overly vigorous vine growth and problems in disease control (Jackson and Schuster 1981: 59; Cox 1985: 38). Based on these soil preferences, the analysis places a constraint on soil texture in order to confine sites to those with suitable soils. Sandy loams was adopted as the soil texture with the highest suitability, as they are most consistent with the soil characteristics detailed above, and were explicitly mentioned by multiple viticultural resources as a favorable soil texture (McEachern 2011; MGGA 1993: 5). However, many soil textures fit the criteria to varying degrees and thus have varying suitabilities. Other soil textures present in the area are ranked based on their relative suitability derived from the texture's inherent properties relating to the soil characteristics listed above.

Climate

Like any agricultural crop, climate is a major constraint on where grapes can be grown. Although the varietal was chosen with particular consideration for the cool Wisconsin climate, the Driftless region does provide some climatic variability which needs to be considered. The USDA Hardiness Zones provide convenient geographic areas rated by the extreme winter temperatures which are used to identify areas capable of supporting a particular plant species. The Minnesota Grape Growers Association (2011) lists the Marechal Foch as hardy to -25° F, indicating the coldest zone which the vine is expected to survive is USDA Hardiness Zone 4b. As this variable attempts to assess the requisite, rather than ideal, conditions for plant life, Hardiness Zones are used only as a minimum constraint which an area must meet to be suitable, rather than as a criterion of continuous suitability.

The length of the growing season is another important selection characteristic which can be measured by the time between the last spring frost and first fall frost. A mean frost-free period of at least 165 consecutive days is used as an additional constraint on site suitability, this period is recommended as a general requirement for early ripening varietals such as the Marechal Foch (Kurtural 2005: 3; Sheavly 2003: 45). Growing degree days (GDDs) provide an indication of the total heat accumulation over the growing season, an important factor in plant growth and maturity. For this analysis, the parameters set by Amerine and Winkler in their widely cited 1944 paper "Composition and quality of musts and wines of California grapes" were used. Specifically, a 50° F threshold and growing season from April 1 to October 31 was used to measure the accumulation of degrees over the temperature threshold under which grapes cannot grow. A minimum of 2000 growing degree days is required for cold hardy grapes, while 2500 is considered preferable (MGGA 1993: 4; Sheavly 2003: 45). Thus, a floor was set at 2000 GDDs and any values exceeding this minimum were ranked according to the relative suitability.

Topography

Topography plays a particularly influential role for viticulture in northern latitudes, as it can provide marked climate-altering effects. Ultra-local climatic zones, or mesoclimates, are highly affected by a given site's elevation, slope, and aspect, so each of these characteristics were included as input layers in this analysis. Gently sloping land is necessary for adequate water and air drainage. In order for cool air to flow downhill, which is advantageous for keeping the vines warmer in cold weather, the land must have a slope of about two percent (Cox 1985: 36; Plocher and Parke 2001: 47). However, the return on this climate-mitigating feature diminishes due to increasing erosion, as well as increasing labor and hazards associated with pruning and harvesting (Kurtural 2005: 4) as the slope increases. A ceiling of fifteen percent is generally agreed upon throughout the viticultural literature (for example, Cox 1985: 63; Kurtural 2005: 4), and therefore defines the upper bound of the range of suitable slopes for this analysis (i.e. two to fifteen percent).

The relative elevation, or landscape position, of the site is similarly important for temperature mitigation. Optimal sites are elevated above their surroundings, thus avoiding the damaging frost pockets created by valleys or other low-lying areas (MGGA 1993: 4; Plocher and Parke 2001: 47). As absolute elevation is inconsequential for the purposes of the analysis, elevation data was used only to discriminate between valley floors and other areas. No distinction was made between ridge tops and middle elevations, as both are suitable for vineyard placement in terms of their position in the landscape.

Aspect has the capability to greatly affect the crop potential by controlling, to a large extent, the amount of sunlight a location receives. As grapes prefer full sun, a southern aspect should be favored in the northern hemisphere as it maximizes light interception (Jackson and Schuster 1987: 66; MGGA 1993: 4). The amount of sunlight also influences the heat balance, particularly in the cooler months where a south-facing slope receives 22.5 percent more solar radiation compared to a flat site (Plocher and Parke 2001: 45). For this analysis, aspect was used as an input layer in which north, northeast, and northwest slopes are not tolerated and preference is given to south-facing slopes, and to a lesser degree, southwest and southeast slopes.

Economic Suitability

In addition to the environmental factors required to successfully grow the Marechal Foch grape varietal, locating sites with beneficial economic characteristics will help to ensure commercial success of the vineyard. Variables included in the economic analysis were proximity to roads and proximity to urban areas. Through an examination of extant vineyards in the Driftless Region, it was determined that many vineyards appear to be located near prominent roads. It stands to reason that proximity to transportation networks benefits the vineyard both by decreasing shipping times and cost, and by providing convenient public access to the vineyard for tastings, tours, and retail operations. However, given the highly developed transportation network in Wisconsin and the high ownership of personal vehicles, no location in the region is thought to be so isolated as to render the site completely unsuitable for a vineyard. Thus, distance from roads was treated only as a ranked variable so that it did not exclude any areas from consideration. Due to the observed relationship between extant vineyards and roads, the distance between each vineyard and the closest Interstate or State Trunk Highway is used to establish criteria for desirable proximity measures. Using the mean distance of 2.5 miles and the standard deviation of 4.8 miles, sites were classified into regions of similar distance and ranked accordingly.

The second economic variable, proximity to urban areas, was chosen to prioritize suitable growing areas that are within a certain distance of population centers which could serve as their customer base. Nevertheless, in the same line of reasoning given for establishing accessibility rankings for transportation, no site will be assumed to be prohibitively far from a sufficient market. Using guidelines generally accepted by the local food movement, a distance of one hundred miles is used as a buffer distance around metropolitan areas (Sustainable Table 2011). The U.S. Census Bureau describes metropolitan areas as having "at least one urbanized area of 50,000 or more inhabitants," and thus provided the definition of a metropolitan area for this particular constraint (2011).

Implementation

Overview of Methodology

All data was obtained either as tabular or spatial data and converted to raster layers. A spatial resolution of thirty meters was the finest resolution available for the data obtained directly as raster layers and was thus used for the analysis. Data was obtained either at the county or state-level and needed to be standardized to the extent of the study area. Although the borders of the Driftless Area do not conform to political boundaries, county boundaries provided a convenient and relatively close approximation. All data layers were clipped to the study area, which was defined by all counties falling completely or partially within the Driftless Area of Wisconsin. All projected using Transverse Mercator based on the NAD 1983 HARN datum with adjusted parameters to reduce distortion around the study area (Wisconsin TM).

In defining the variables to be used in the analysis, general patterns emerged regarding their relationship to the geographic problem at hand. As previously alluded to, some variables provided only a minimum condition which must be met in order to facilitate vine growth. A Boolean classification scheme fit the data distribution for these variables, as the minimum condition effectively separated the data into two clusters: unsuitable and suitable values. Thus, a Boolean map was created for each, in which the cells deemed unsuitable were reassigned a value of zero and those that were at least minimally suitable were given a value of one. The Boolean maps were then combined in order to eliminate any area which failed to meet the minimum condition of any such variable [Appendix C:1].

Areas identified as at least minimally suitable were then grouped into discrete classes based on their relative suitability for vineyard placement. Three classes were devised for each variable, thereby characterizing any given cell as highly suitable (3), moderately suitable (2), or minimally suitable (1) in terms of the particular criteria. While any number of ranks could have been chosen, the decision to split the data into three classes was based on implications from the literature and the level of precision required for the analysis. Throughout the literature, explicitly defined conditions characteristic of the best vineyard sites were commonly found, as well as conditions that should be avoided. Considering slope as an example, the viticultural literature clearly identified a 2 percent slope as being adequate for proper drainage and over 15 percent as excessively labor-intensive and hazardous for machinery. However, there was very little information indicating which slopes should be given preference between the two extremes.

Without adequate information on how to further partition the range, a three-rank system was regarded as the best option, as low, medium, and high suitability areas were easily derived from the literature. A finer scale would have suggested a deceivingly high level of accuracy and familiarly, and was also unnecessary for the purposes of the analysis.

After creating a ranked map for each variable having a continuous range of suitability, a weighted linear combination was performed to obtain a weighted rank sum map. The weights were assigned using a pairwise comparison in which each pair of variables was compared to determine their relative importance [Appendix D:1]. This method was chosen to ease the weighting process as it limits the focus to two criteria at time. After devising a matrix containing the relative ranks, weights for each criterion were generated within the GIS [Appendix D:2]. After multiplying each grid by its corresponding weight, the layers were added together to produce a weighted rank sum map [Appendix C:2]. The Boolean suitability map and ranked suitability map were lastly combined to create the final suitability map [Appendix C:3]. A complete overview of the implementation process is found in

<u>Environmental Suitability</u>

Soils

A GIS layer obtained from the Natural Resource Conservation Service (NRCS) provided data on the soil textures for Wisconsin. The data was reclassified into a Boolean map according to the available literature regarding soil texture suitability. Soils with a texture classified as clay, silt clay, silty clay loam, or silt were assigned a value of zero, while all other soil textures were given a value of one. The suitable soils were then ranked using a quasi-fuzzy scoring system, assigning scores to soil textures based on their comparative relation to the ideal soil texture, sandy loam. Sandy loams were considered highly suitable and assigned a score of 3. The second "tier" of soils was assigned 2 points, and the third "tier" was assigned 1 point [Appendix C:4]. Tiered ranks were determined based on an evaluation of the common soil texture pyramid [Appendix C:5].

Climate

Hardiness Zones

There were difficulties involved in acquiring, evaluating, or formatting several of the necessary data layers for this evaluation. Although the USDA provides a Hardiness Zone map including Wisconsin, the map is at a continent-level scale which was not scale appropriate for this study. Consideration was given to interpolating a more appropriate map using available climate data for Wisconsin, but it was determined that the various other climate factors would most likely be sufficient to eliminate areas that were not climatically suitable so the variable was dropped. Further research is necessary to confirm whether or not these assumptions are accurate.

Frost-Free Days

A GIS layer obtained from the Natural Resource Conservation Service (NRCS) provided data on the average length of the frost-free season calculated from 1971-2000 for the state of Wisconsin. The data was reclassified into a Boolean map to reflect its suitability for the grape varietal, which was defined above as a minimum of 165 days [Appendix C:6]. A large area in the center of the study region had a No Data value in the original dataset. The decision was made to classify this area as suitable, so as not to exclude it due solely to a lack of data. However, the No Data area was quite large, thus introducing some uncertainty into the layer and ultimately the final map.

Growing Degree Days

Growing degree data was obtained from the Midwest Regional Climate Center's Applied Climate System (MACS). Data from 68 weather stations was imported into the GIS as point data using the geographic coordinates provided by MACS and interpolated to produce a continuous surface [Appendix C:7]. A tension spline using nine neighbors and a weight of five was used for the interpolation. The tension spline was chosen due to the widespread acceptance and use observed in the literature review for the interpolation of low temporal resolution climatological data (for example, Sluiter 2009: 12; Irmak 2010: 1761). The tension spline is an exact interpolator, thereby ensuring that the interpolated surface passes through each labeled data point. They are generally regarded as the most appropriate interpolation method for modeling smooth surfaces, such as growing degree days, due to the smoothing algorithm, which the user has some control over in the weighting parameter (Childs 2004: 34). The weight was determined by trial and error, in which an interpolated surface was created using a training set and validated with a test set consisting of a small number of points within the study area. The points contained in the test set were randomly selected and removed from the training set. The interpolation surface using a weight of five performed the best and generated values for the study area which best reflected the probable actual values.

After producing the interpolated surface, the growing degree days layer was reclassified to reflect the relative suitabilities as determined by the literature review. A Boolean map was created using a threshold of 2000 GDDs to discriminate between the unsuitable and suitable areas. The suitable areas were then reclassified to produce a ranked map. As the literature review indicated a minimum of 2000 but a preference for at least 2500 GDDs, an equal interval class break was used to split the values into the three ranks such that areas with 2000-2250 were given a value of 1, 2250-2500 a value of 2, and over 2500 a value of 3 [Appendix C:8].

Topography

Slope

A digital elevation model (DEM) was obtained from the USGS Seamless Server and used to derive percent slope for the study area. A Boolean map was created using a range of two to fifteen percent as indicated in the conceptualization portion of the paper. The viticultural literature was nearly universal in their praise of gently sloping land. The guidelines provided by the Department of Revenue's Agricultural Land Productive Values were adopted to determine the rankings, as they give indications of which grades constitute gentle, moderate, and steep slopes for land valuation purposes (Carnahan 2008: 3). A ranking of 3 was given to gentle slopes (2-5 percent), a ranking of 2 to moderate slopes (5-10%), and a ranking of 1 to steep slopes (10-15%) [Appendix C:12].

Elevation

Low-lying areas were deemed unsuitable for vineyard placement due to their tendency to produce unfavorable microclimatic conditions. In order to determine landscape positioning in the GIS, a special extension was used which discriminated between valleys, ridge tops, and intermediate elevations. A Boolean map was created in which valleys were given a value of 0 and all other areas were given a value of 1 [Appendix C:13]. In reality, the suitability of non-valley areas doubtlessly vary substantially in terms of their landscape position, but were treated the same in this analysis due to inadequate information. While this approach greatly simplified the terrain found in the Driftless Area, it provided a baseline with which to eliminate unsuitable areas.

Aspect

The DEM was also used to derive aspect values for the study area. Aspects were represented as degrees from 0-360 and were reclassified to create a Boolean map of suitable and unsuitable areas. Aspects between 292.5-360 and 0-67.5 (north, northwest, and northeast aspects, respectively) were given a value of 0 and all others a value of 1 in the Boolean suitability analysis [Appendix C:14]. As south aspects are the most preferential, the highest ranking (3) was given to aspects between 157.5-202.5 degrees, while southeast and southwest aspects (112.5-157.5 degrees, 202.5-247.5 degrees) were given a rank of 2, and western and eastern aspects (247.5-292.5 degrees, 67.5-112.5 degrees) were given a ranking of 1 [Appendix C: 15].

Economic Factors

Distance to Urban Areas

It was originally conceived that the distance to urban areas of 50,000 or more people would serve as a proxy for market access. Population data was obtained from the U.S. Census Bureau and imported into the GIS as a point layer. A buffer of 100 miles was applied to the city points and it was observed that all areas in the study region are within 100 miles of at least one of the cities. Thus, as it did not contribute any additional information to the analysis, it was dropped as a variable.

Distance to Roads

For this analysis, access to transportation was simply conceptualized as the distance from a state or interstate highway, without consideration for either local or county roads or restrictions of road access. These roads were extracted from a roads layer obtained from Wisconsin Department of Natural Resources (DNR). Distance to roads was evaluated as a ranked variable in which a Euclidean distance function was used to obtain a continuous surface of distance values. The grid was reclassified into classes based on the observed distance of extant vineyards to major roads. Those areas within 2.5 miles a road (the mean distance) received a ranking of 3, areas within 2.6-7.3 miles (the mean plus one standard deviation) received a 2, and any areas over 7.3 miles away received a ranking of 1 [Appendix C:16].

Results and Discussion

In an unclassified version of the final suitability map, several sizable patches with high suitability rankings are scattered throughout the region while large contiguous areas of unsuitable land are found primarily along the boundaries of the study area [Appendix C:3]. Most areas of high suitability in the ranked map also appear on the final map, with the exceptions of some areas in the north, south, and southeast that were eliminated from the Boolean overlay. This evaluation shows the areas that are suitable or not suitable, but it does not indicate which characteristic influenced the rating of an area or which constraint caused an area to be removed from consideration. Knowing which characteristics influenced the overall ranking of an area can be extremely beneficial in evaluating the output of the project.

This is particularly the case considering the level of uncertainty associated with several of the data layers. Uncertainty beyond that owing to the need to use representations and proxies in the GIS influenced a few layers most significantly. The frost-free days layer had large areas of No Data which were included in the analysis but may not be suitable. The assumption that areas falling into unsuitable hardiness zones would be eliminated by other climatic variables was not grounded in research, and thus may be unfounded.

Perhaps greatest level of uncertainty stems from the process of deriving the growing degrees days data layer. The interpolation used to derive the GDD layer introduced uncertainty in and of itself, but the nature of the original dataset presented several larger issues. . While a large quantity of tabular data was available through MACS, it could not be accessed as average values so a large amount of manual data manipulation was required. Data was complied for all 365 Wisconsin weather stations in the MACS system, as well as for 213 stations in eastern Minnesota, northeastern Iowa, and northern Illinois, over a thirty year period (1980-2010).

Missing data became a significant limitation in the calculation of the averages, as the majority of weather stations were missing anywhere between one day and several months worth of climate data. Lacking an efficient method to determine the amount of missing data points, any season which came flagged from MACS as 'missing one or more days in the accumulated period' was eliminated. The elimination of these incomplete seasons resulted in a drastically reduced number of data points. Thus, while it was intended to produce thirty year averages for each station, the actual number of seasons used to calculated the average varied between two and thirty years. While it surely introduced uncertainty into the analysis, it was the most complete data accessible given the time and funding limitations.

The final map was also classified into nine equal-interval classes allowing for the areas of high suitability to be better visualized [Appendix C:17]. The equal-interval classification scheme also theoretically splits each of the three classes used in the analysis into three more classes, created a pseudo-fuzzy membership classification. While cells did not take on all possible values, this scheme still makes it possible to distinguish which cells in each of the high, moderate, and low suitability classes are near the class breaks. While at the regional scale, it appears that no cells are more than moderately suitable, an inset map illustrates that this is a consequence of scale and display rather than of the actual range of suitability values [Appendix C:18]. Due to the continuous nature of the variables, using fuzzy membership function to rank the variables during the analysis could provide more objective results, as abrupt cut-off is not often realistic, particularly for environmental phenomenon.

The topography of the region is apparent in both the classified and the unclassified final maps. This reflects how dramatic the shift in topography can be in this region as well as the importance of topographic features in the overall weighting and evaluation scheme. Although the weighting scheme was heavily grounded in the literature, it is inherently subjective. Weights could be adjusted to assess whether certain areas remain highly suitable under different schemes and which are sensitive to the weighting. Ideal areas would have high suitability for all criteria and thus not fluctuate due to differences in weighting.

The weighting scheme as well as the number of variables was much weaker for economic variables compared to the environmental variables. Research into the various environmental requirements for growing grapes has been done extensively, but there has been little to no evaluation of the various economic factors that go into the placement and management of a successful vineyard. Also, a variety of factors that could influence the economic restrictions of establishing a vineyard were not considered for this initial study. Issues such as current land use, land availability, zoning restrictions, taxes/licensing costs, and infrastructure development were not considered. These factors may greatly influence the site selection process by increasing the costs of establishing the location and/or by restricting the land use itself. Before a site is purchased for development, these types of issues would need to be looked into carefully.

While these factors weren't included for various different reasons, including data availability, cost, and added complexity, many of them were also inappropriate for an analysis at this scale. Knowledge of local regulations and ground truthing would be required to incorporate some of the more complicated socioeconomic and political variables, which would be both time and capital intensive. Because of the strong influence of environmental conditions on vineyard site suitability, an initial regional analysis such as this is advantageous to locate smaller areas of high suitability. These smaller areas can then be more closely examined in terms of the viability for vineyard establishment as opposed to the entire study area.

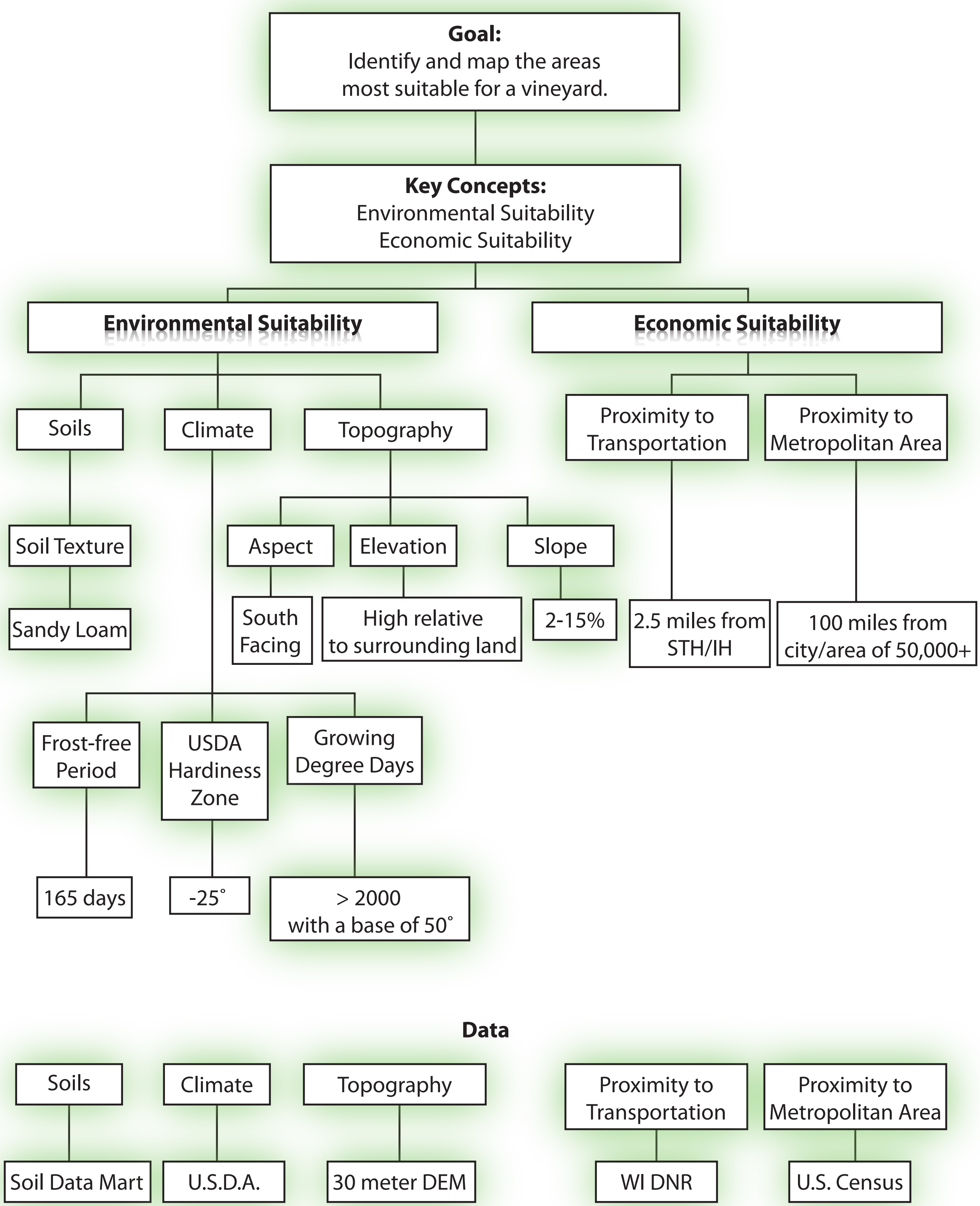
Conclusion

The use of Geographic Information Systems software allowed for the large area that is covered by the Driftless Region to be quickly evaluated based on the identified criteria. Several areas appear to have high concentrations of high-suitability pixels when reviewed using these criteria. These high-suitability areas would be appropriate locations to focus efforts when deciding on a site for a new vineyard in this region of Wisconsin. However, the scale of this regional study makes it difficult to choose an exact location for a vineyard based solely on this evaluation. Further detailed studies, either through GIS or field studies, are necessary in order to select an exact location for vineyard sites.

APPENDIX A

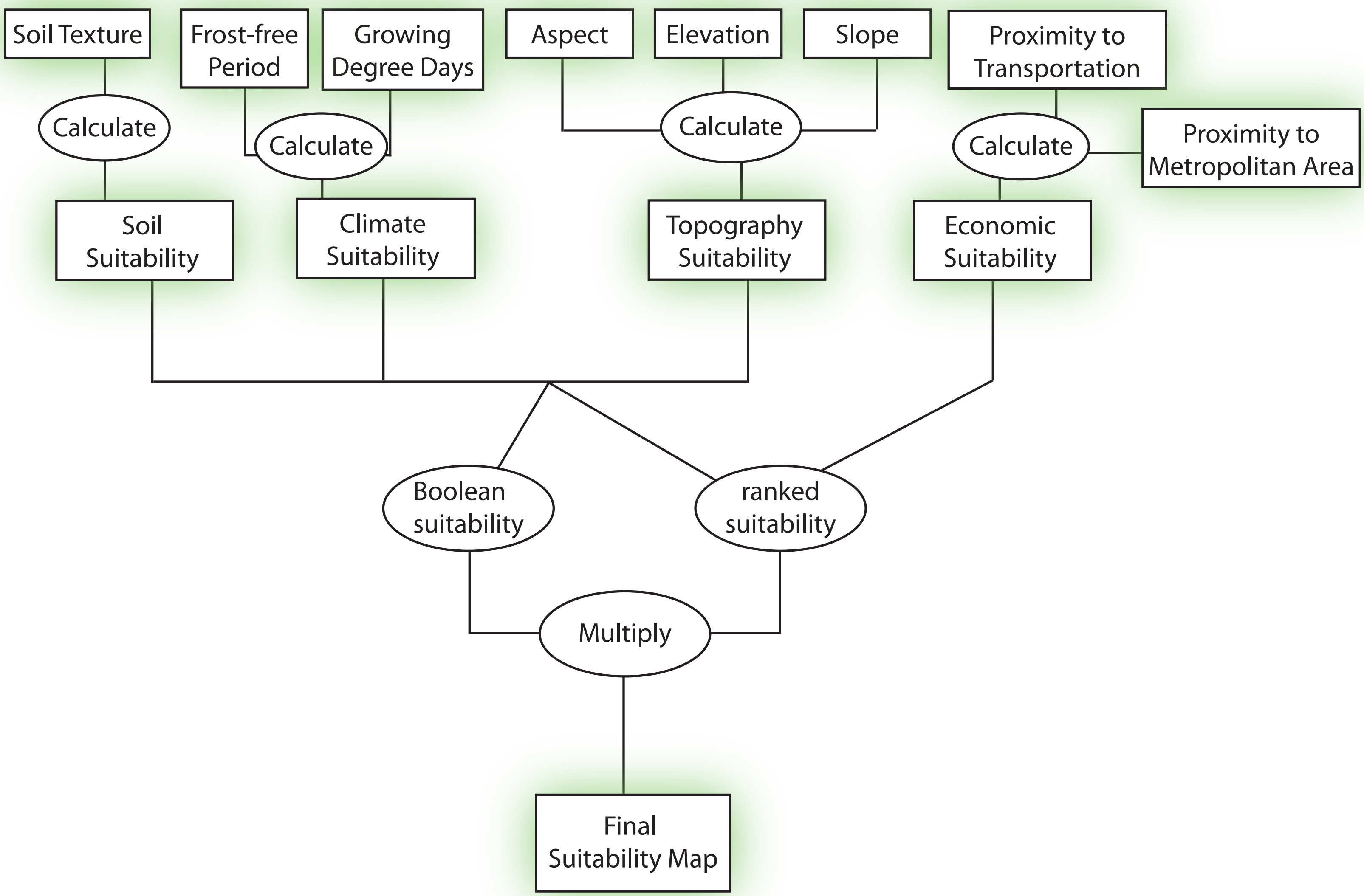
CONCEPTUALIZATION DIAGRAM

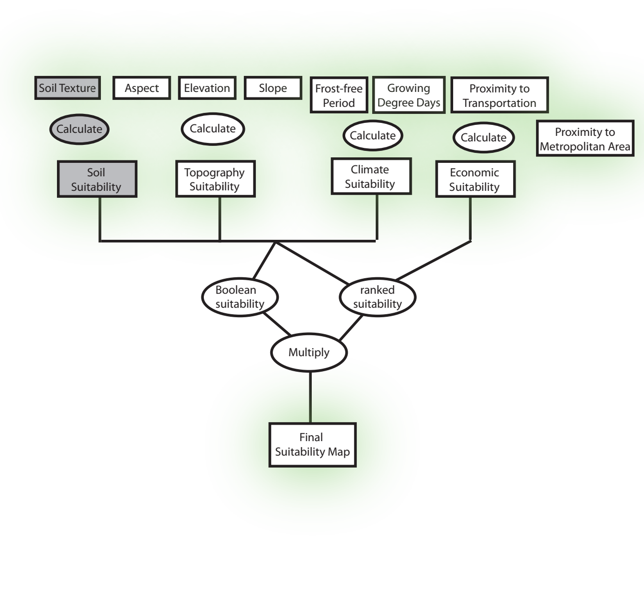
Identification of Potential Vineyard Locations in Wisconsin

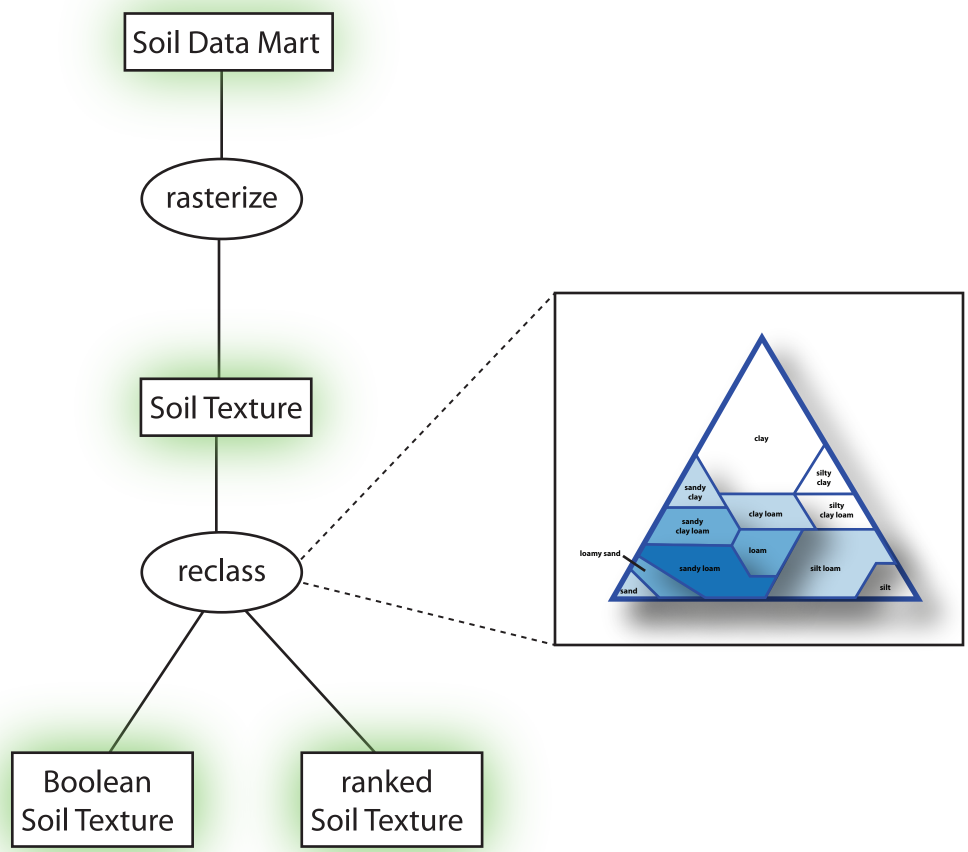


APPENDIX B

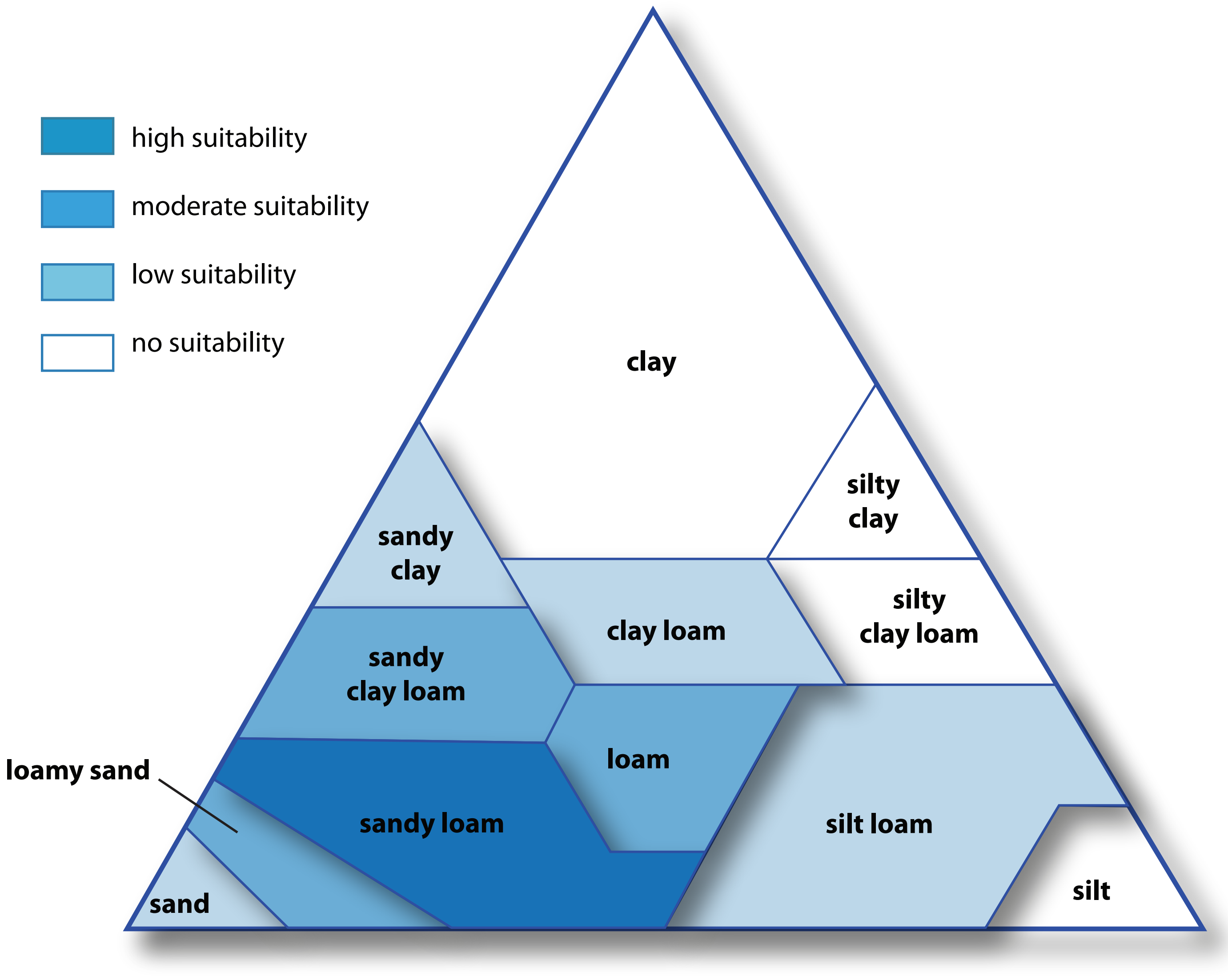
IMPLEMENTATION DIAGRAM


Soil Texture
Frost-free Period
Growing Degree Days
Aspect
Elevation
Slope
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Climate Suitability
Topography Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map

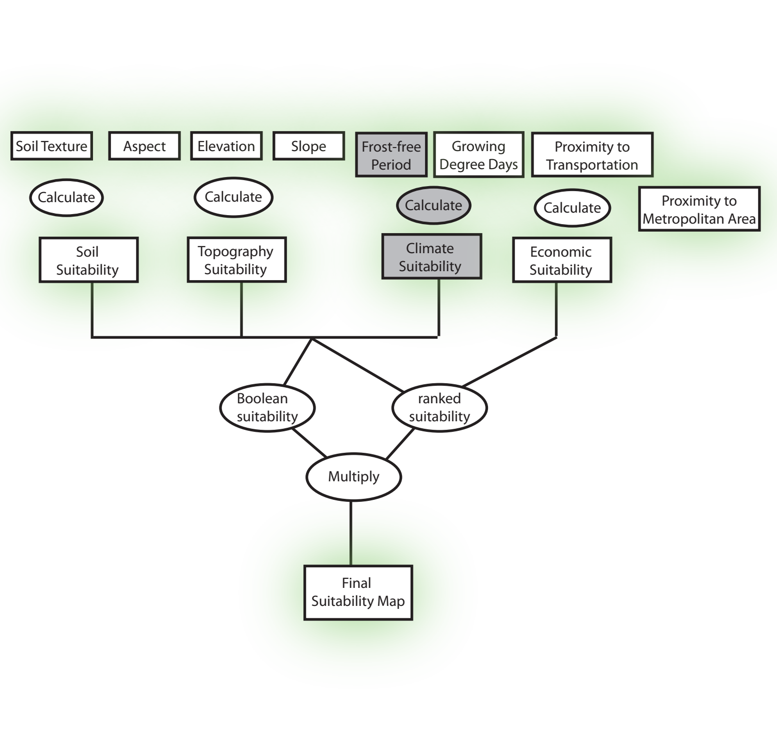

Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map

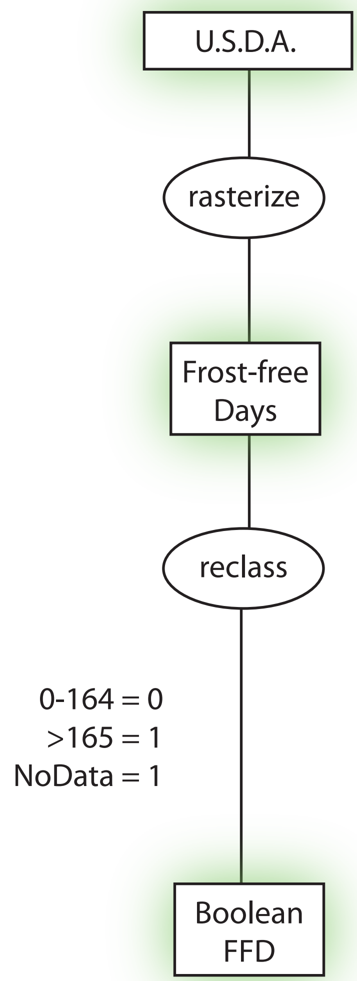

Soil Data Mart
rasterize
Soil Texture
reclass
Boolean Soil Texture
ranked Soil Texture
clay
silty clay
sandy clay
clay loam
sandy clay loam
silty clay loam
loam
loamy sand
sandy loam
silt loam
sand
silt

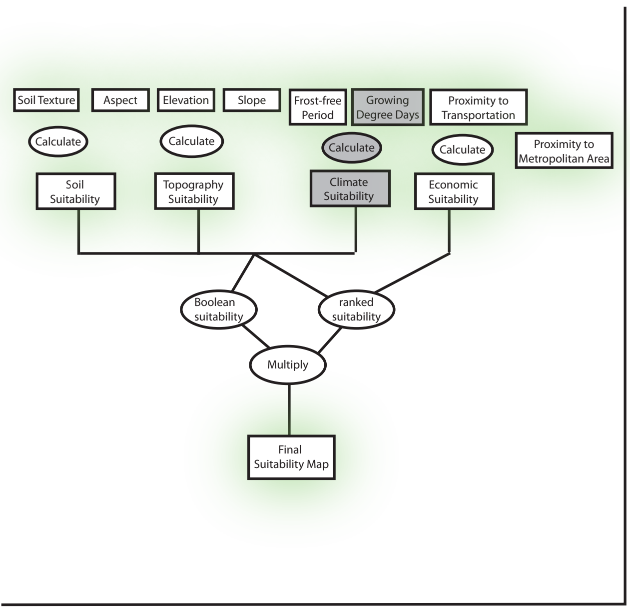
Soil Texture Rankings



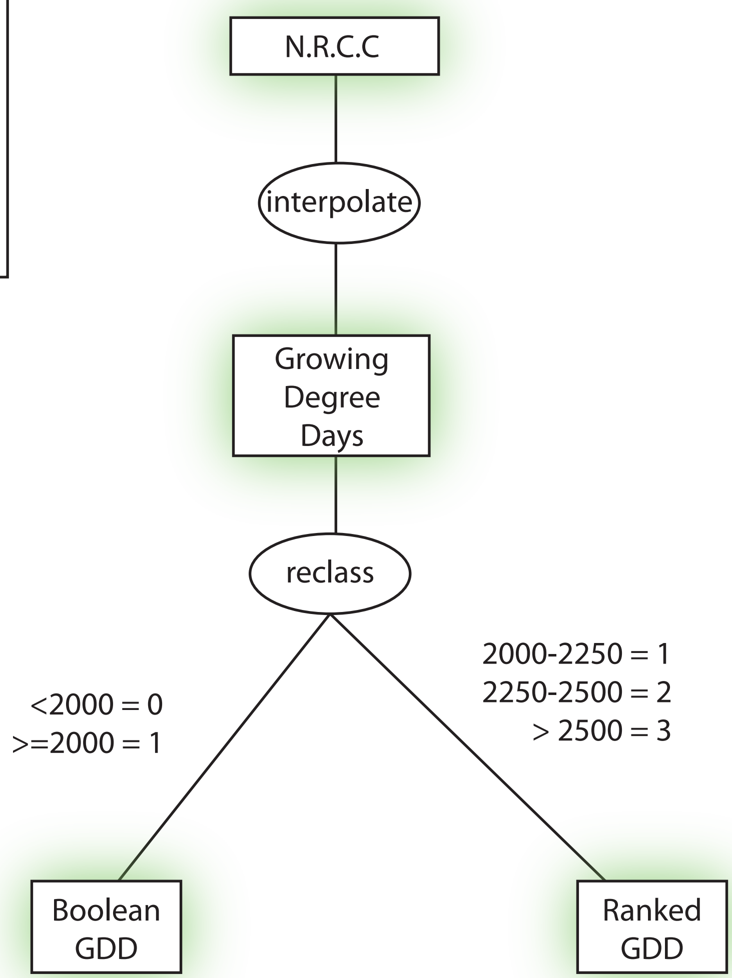
additional categories: peat
muck


Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map


U.S.D.A.
rasterize
Frost-free Days
reclass
0-164 = 0
>165 = 1
NoData = 1
Boolean FFD



Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map



N.R.C.C
interpolate
Growing Degree Days
reclass
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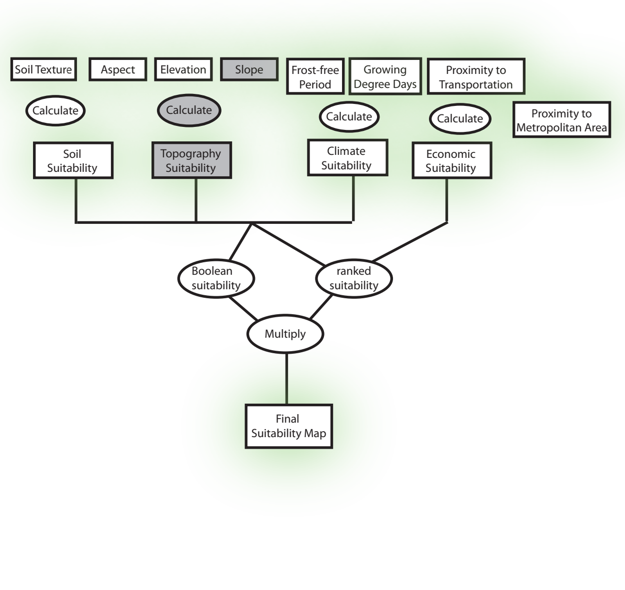
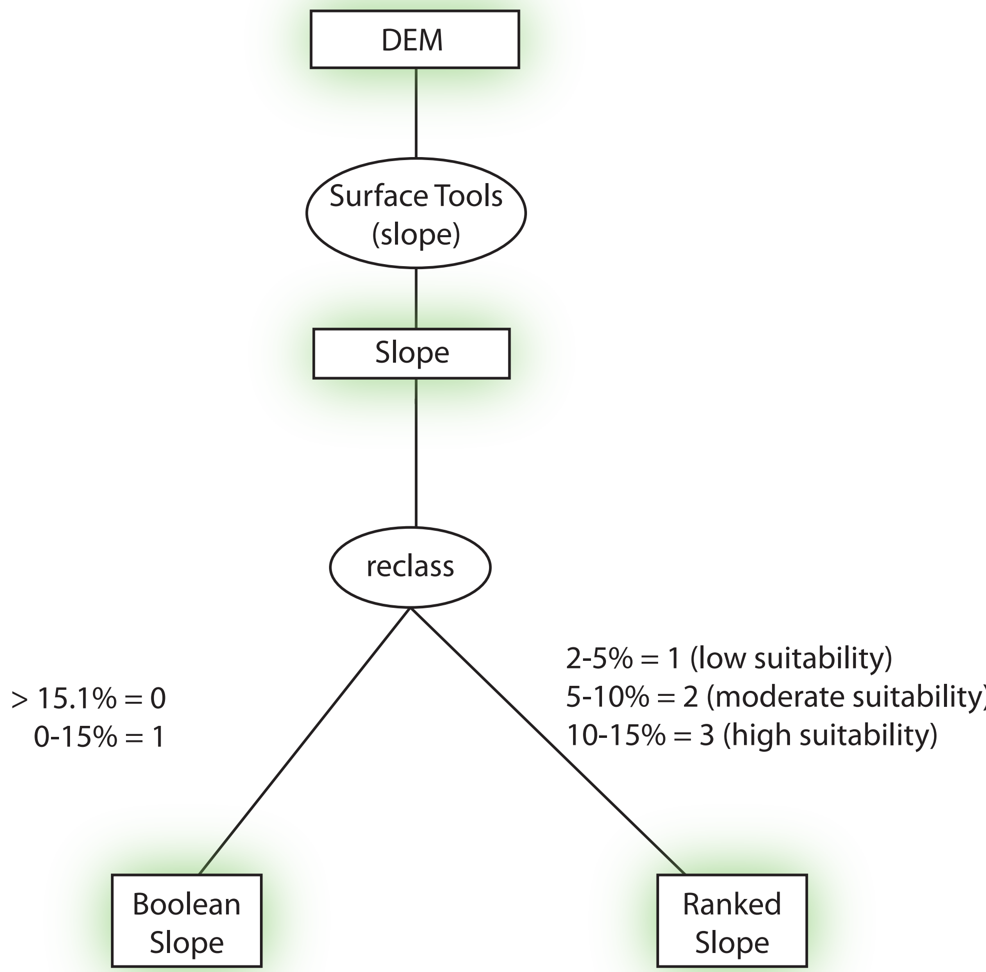
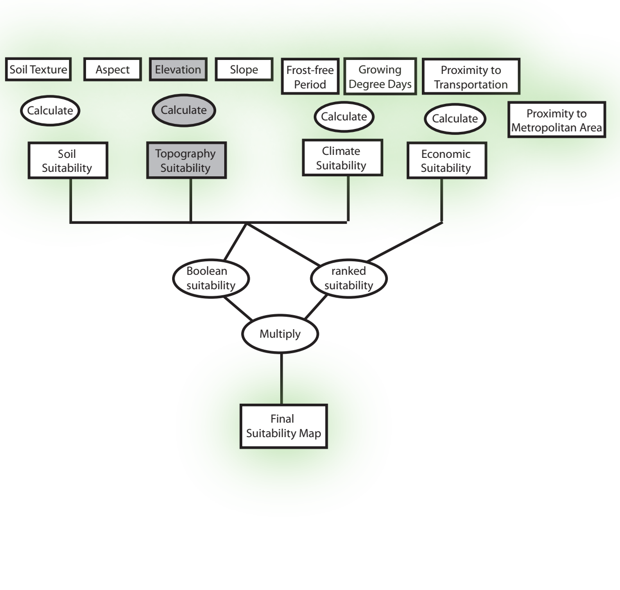
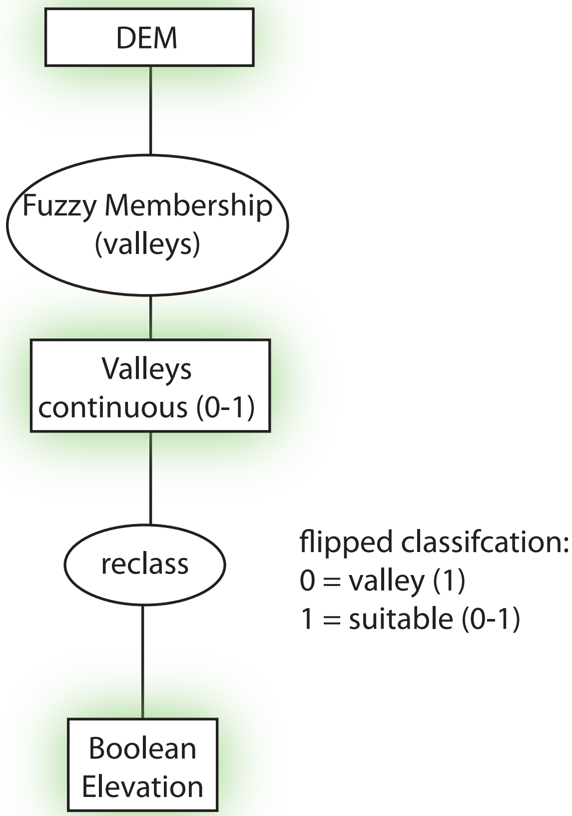
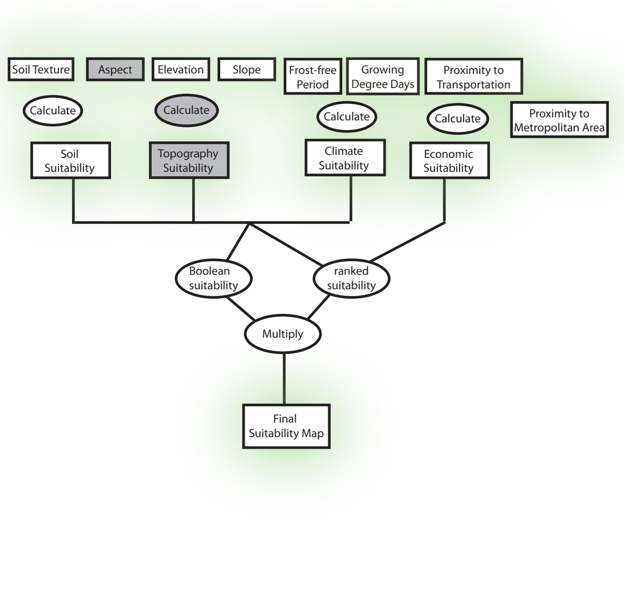
>=2000 = 1
2000-2250 = 1
2250-2500 = 2
> 2500 = 3
Boolean GDD
Ranked GDD

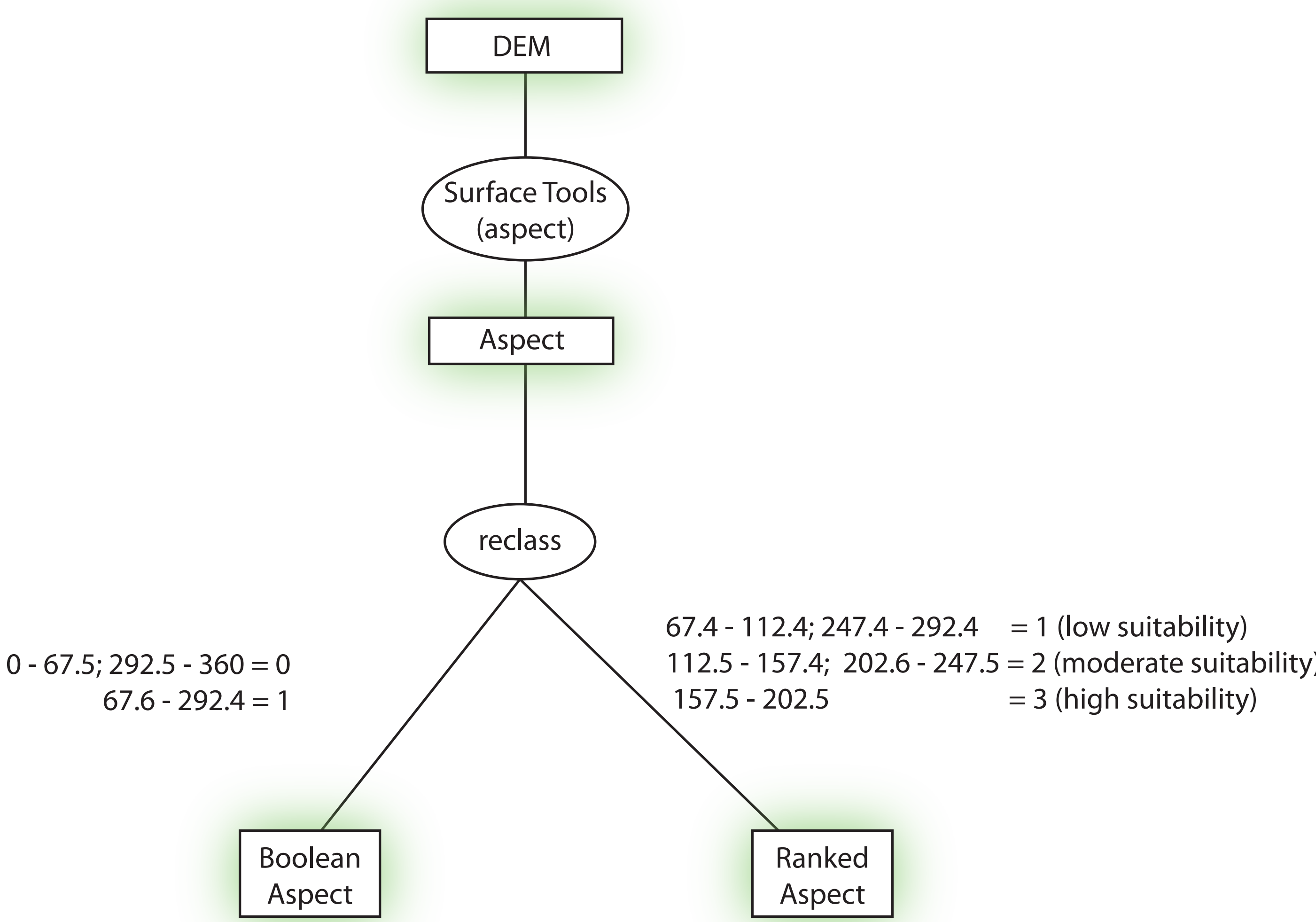

Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map

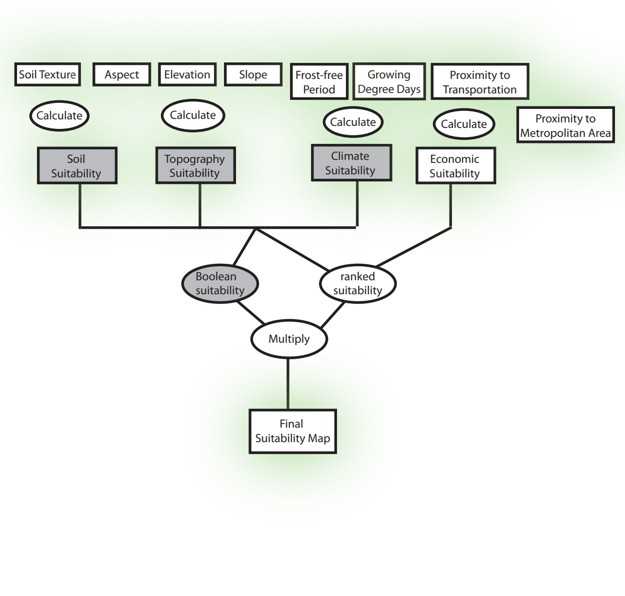

DEM
Surface Tools (slope)
Slope
reclass
> 15.1% = 0
0-15% = 1
2-5% = 1 (low suitability)
5-10% = 2 (moderate suitability)
10-15% = 3 (high suitability)
Boolean Slope
Ranked Slope


Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Proximity to Metropolitan Area
Calculate
Calculate
Calculate
Calculate
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map

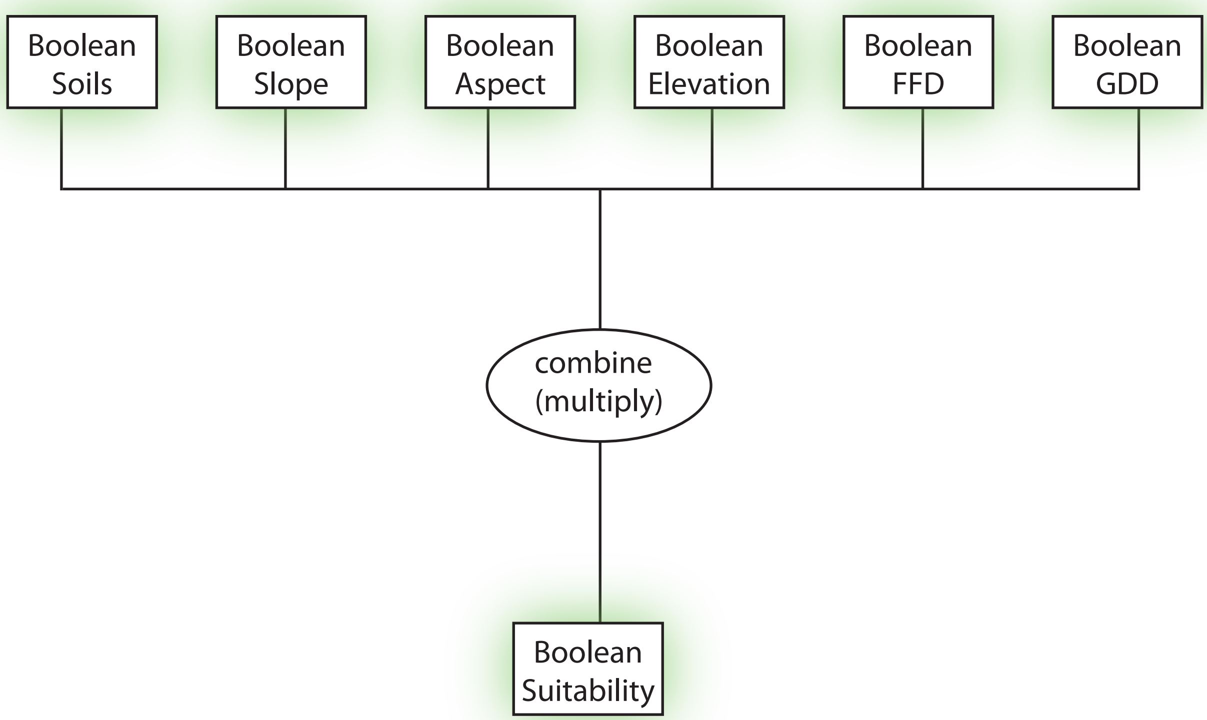

DEM
Fuzzy Membership (valleys)
Valleys continuous (0-1)
reclass
flipped classifcation:
0 = valley (1)
1 = suitable (0-1)
Boolean Elevation


Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Proximity to Metropolitan Area
Calculate
Calculate
Calculate
Calculate
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map


DEM
Surface Tools (aspect)
Aspect
reclass
0 - 67.5; 292.5 - 360 = 0
67.6 - 292.4 = 1
67.4 - 112.4; 247.4 - 292.4 = 1 (low suitability)
112.5 - 157.4; 202.6 - 247.5 = 2 (moderate suitability)
157.5 - 202.5 = 3 (high suitability)
Boolean Aspect
Ranked Aspect

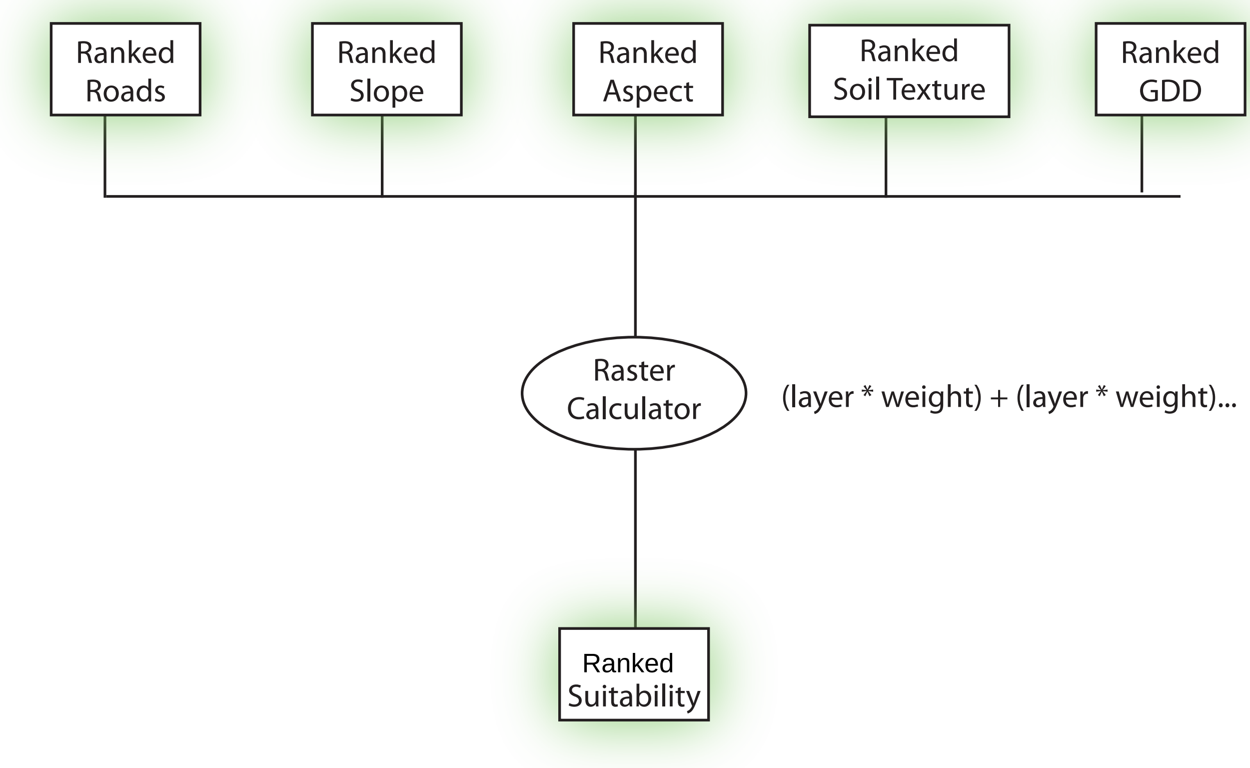


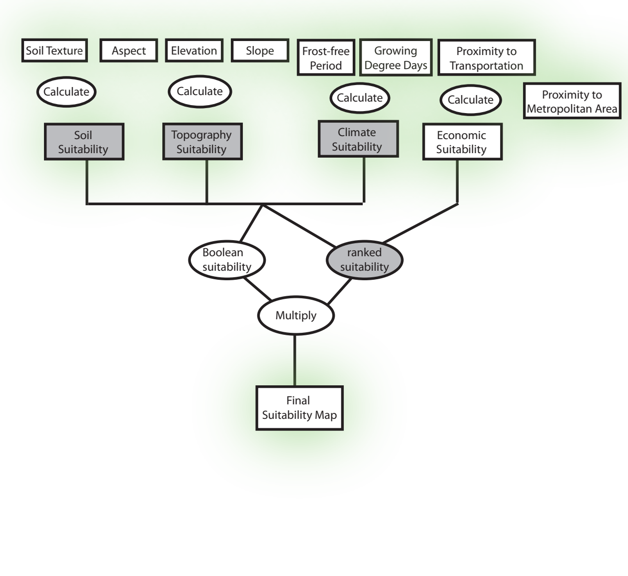
Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map

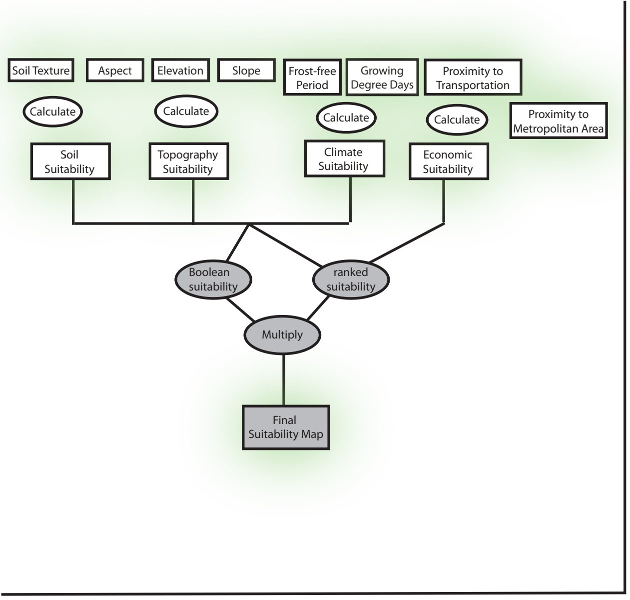


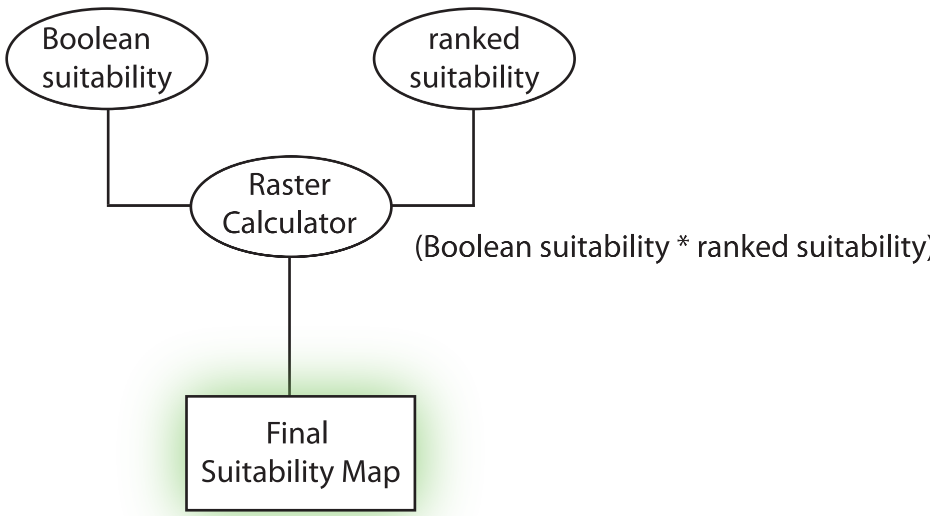
Boolean Soils
Boolean Slope
Boolean Aspect
Boolean Elevation
Boolean FFD
Boolean GDD
combine (multiply)
Boolean Suitability

Boolean Suitability






Soil Texture
Aspect
Elevation
Slope
Frost-free Period
Growing Degree Days
Proximity to Transportation
Calculate
Calculate
Calculate
Calculate
Proximity to Metropolitan Area
Soil Suitability
Topography Suitability
Climate Suitability
Economic Suitability
Boolean suitability
ranked suitability
Multiply
Final Suitability Map


Boolean suitability
ranked suitability
Raster Calculator
(Boolean suitability * ranked suitability)
Final Suitability Map

APPENDIX C

FIGURES

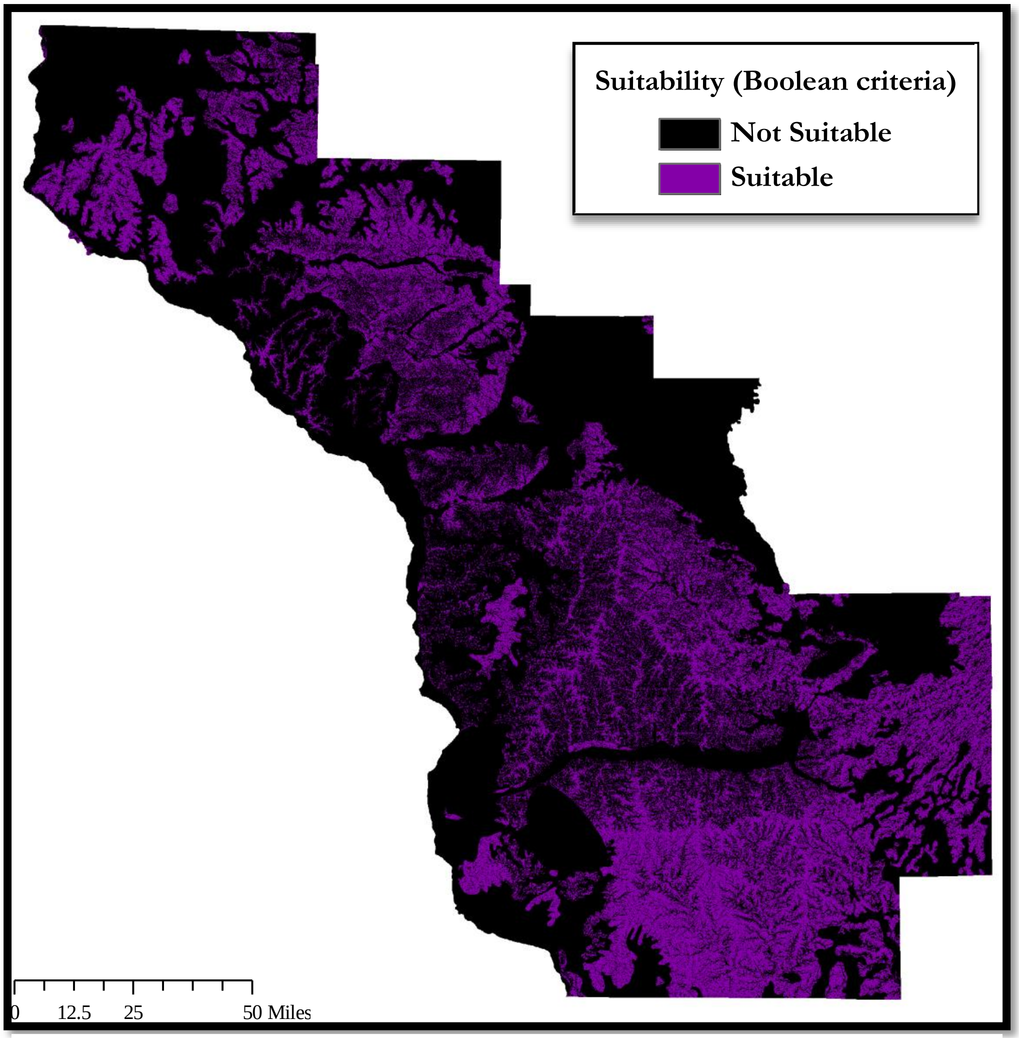

Suitability (Boolean criteria)
Not Suitable
Suitable
0
12.5
25
50 Miles

Figure 1

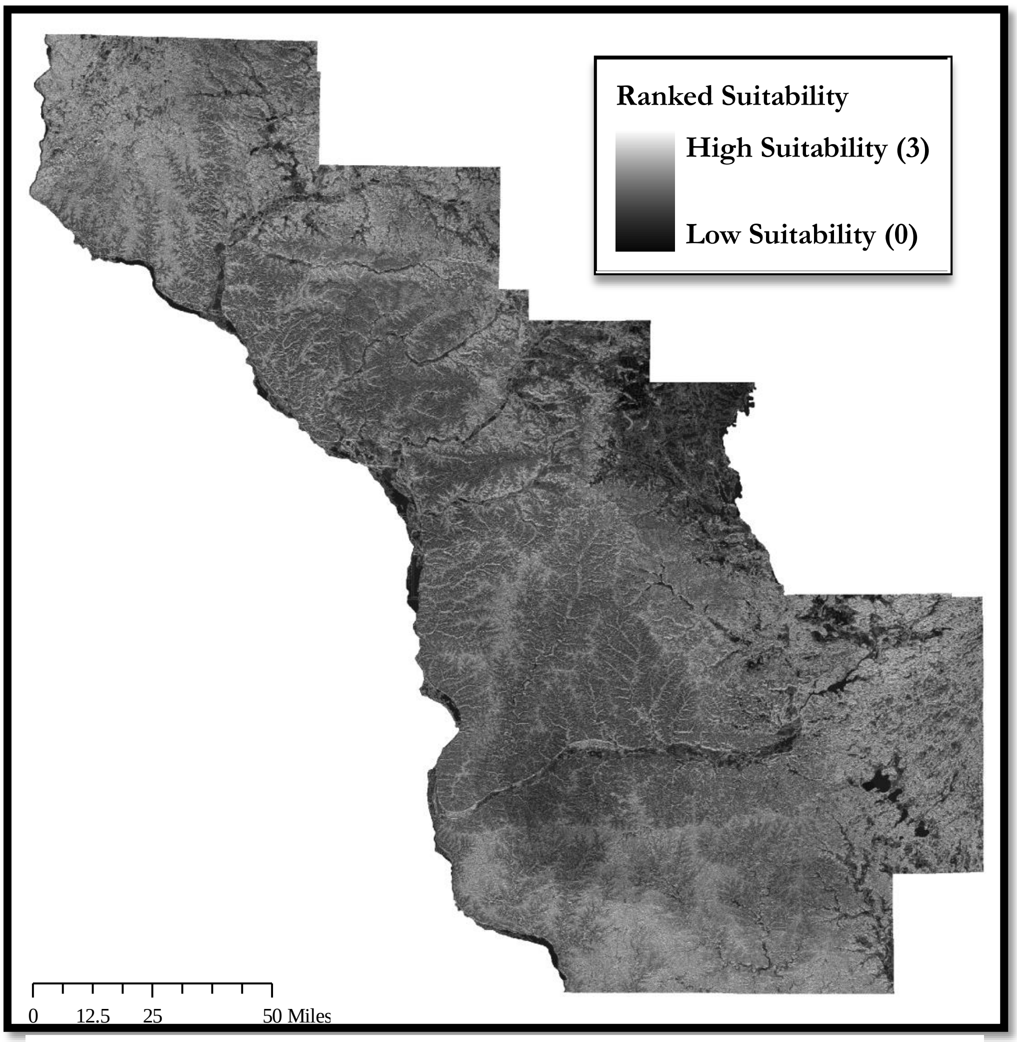
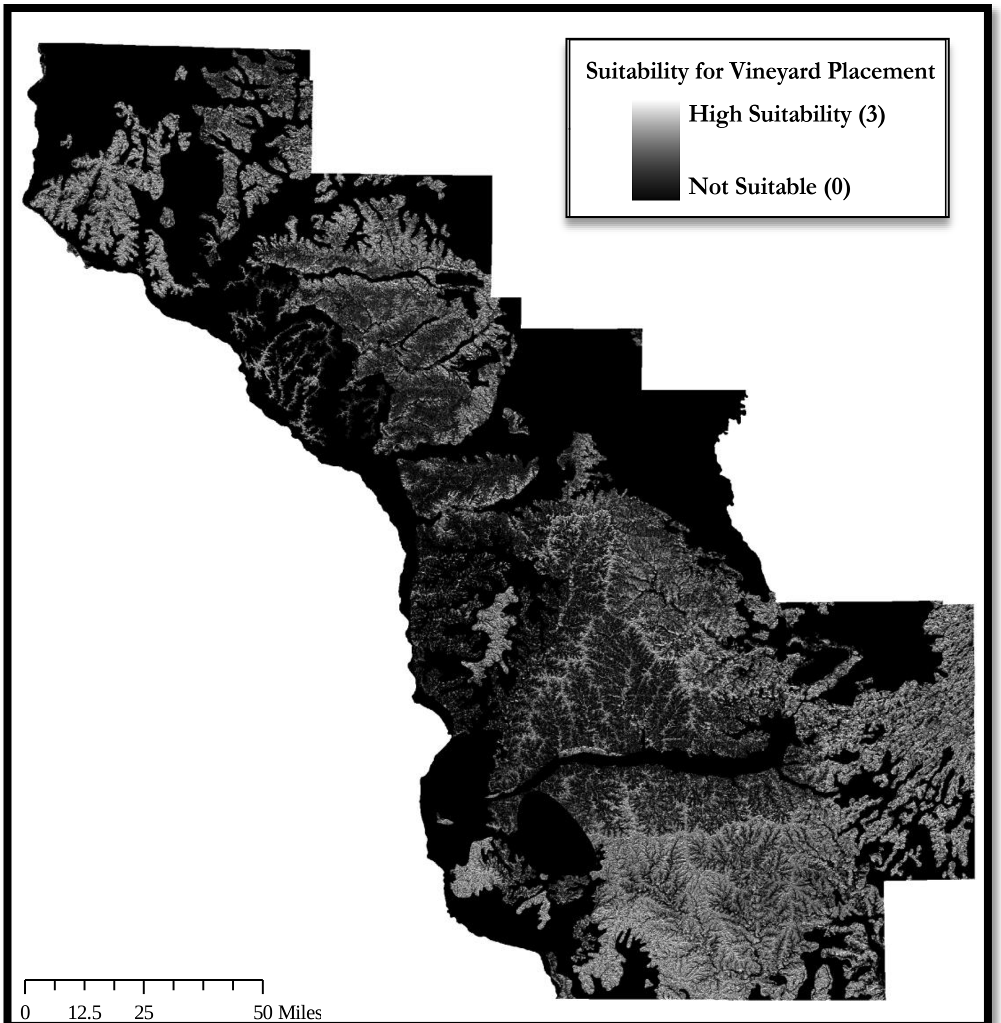
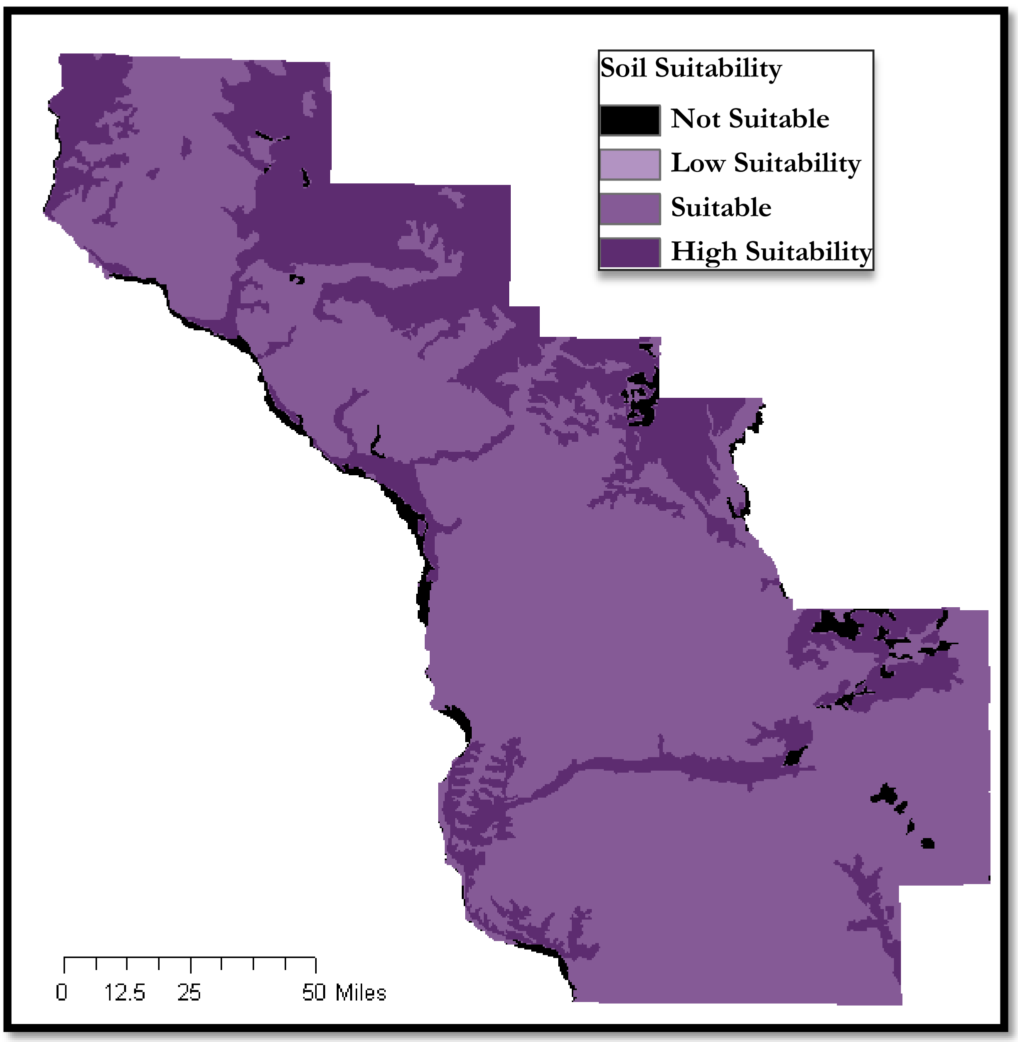

Ranked Suitability
High Suitability (3)
Low Suitability (0)
0
12.5
25
50 Miles

Figure 2



Suitability for Vineyard Placement
High Suitability (3)
Not Suitable (0)
0 12.5 25 50 Miles

Figure 3



Soil Suitability
Not Suitable
Low Suitability
Suitable
High Suitability
0
12.5
25
50 Miles

Figure 4

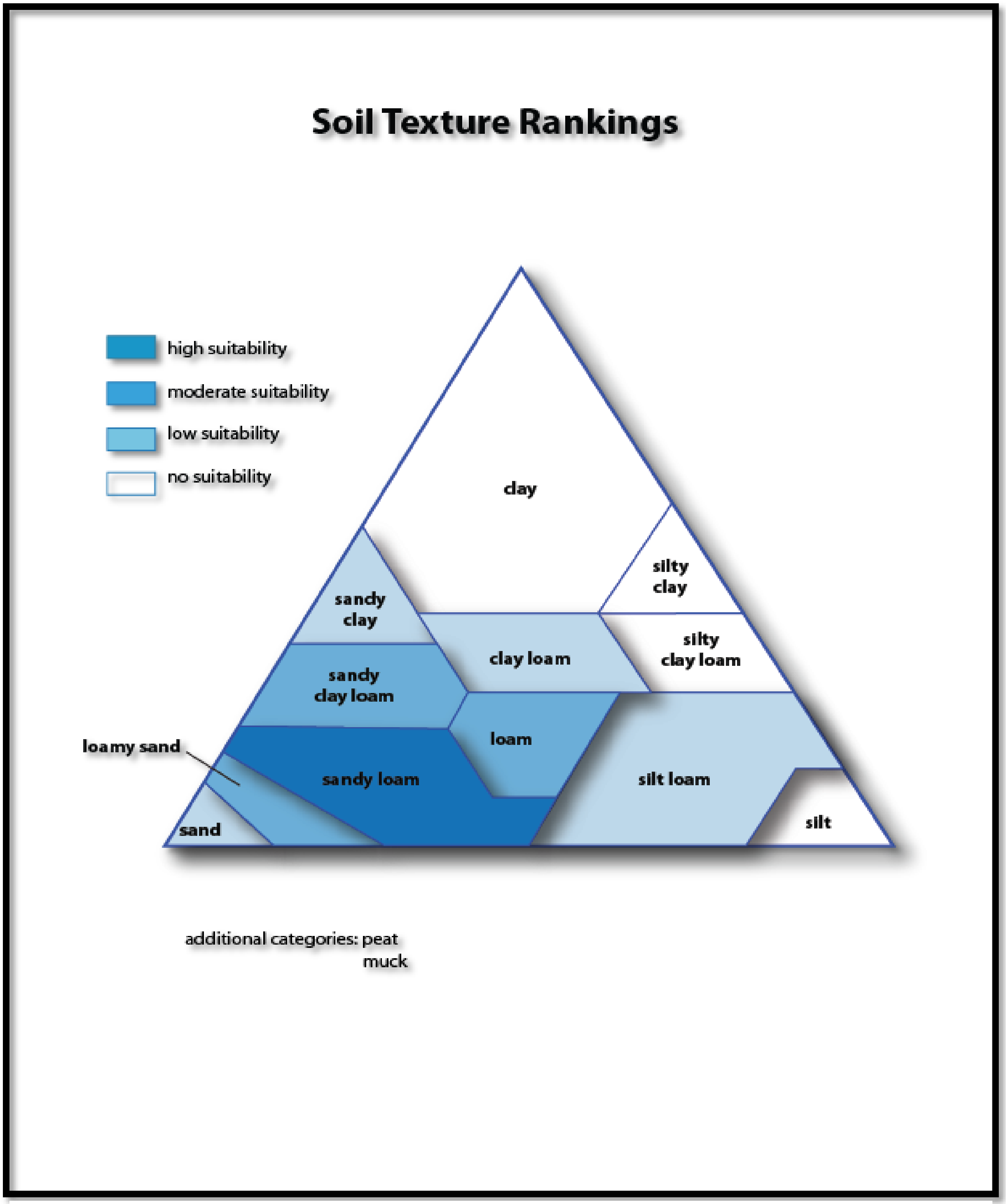

Soil Texture Rankings
high suitability
moderate suitability
low suitability
no suitability
clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
loamy sand
sandy loam
silt loam
sand
silt
additional categories: peat
muck

Figure 5

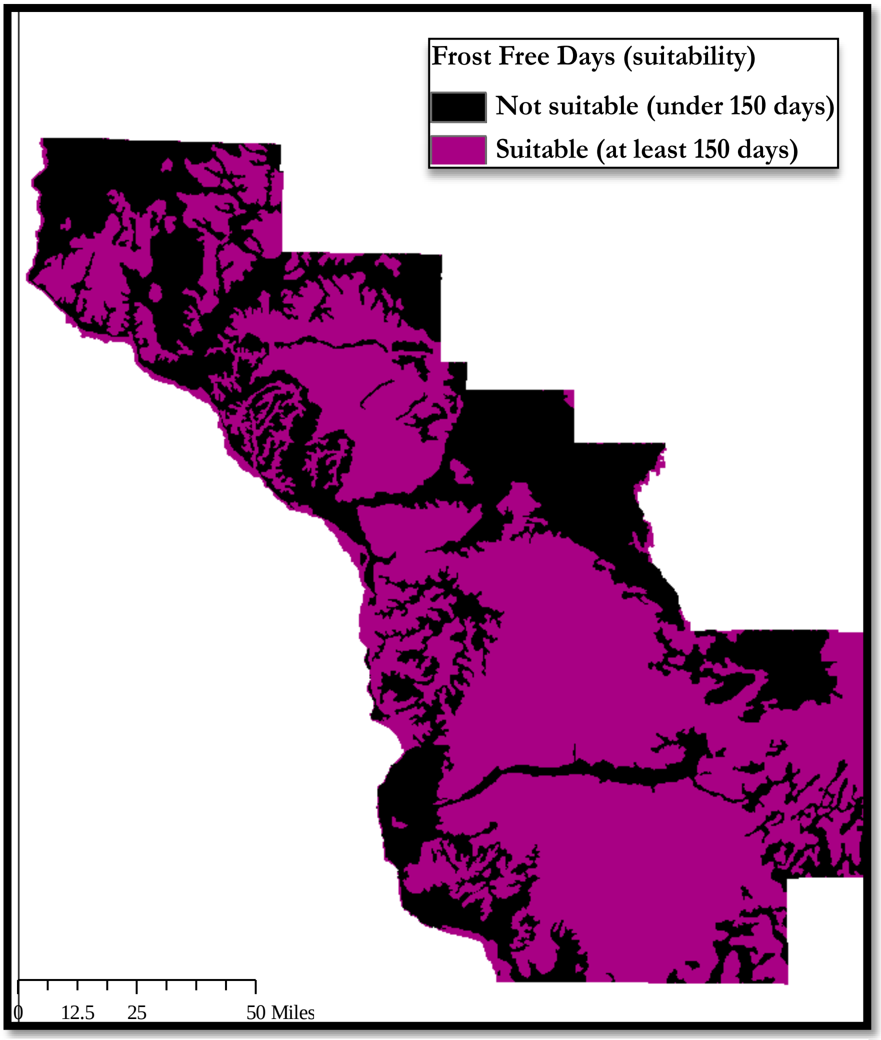

Frost Free Days (suitability)
Not suitable (under 150 days)
Suitable (at least 150 days)
0
12.5
25
50 Miles

Figure 6

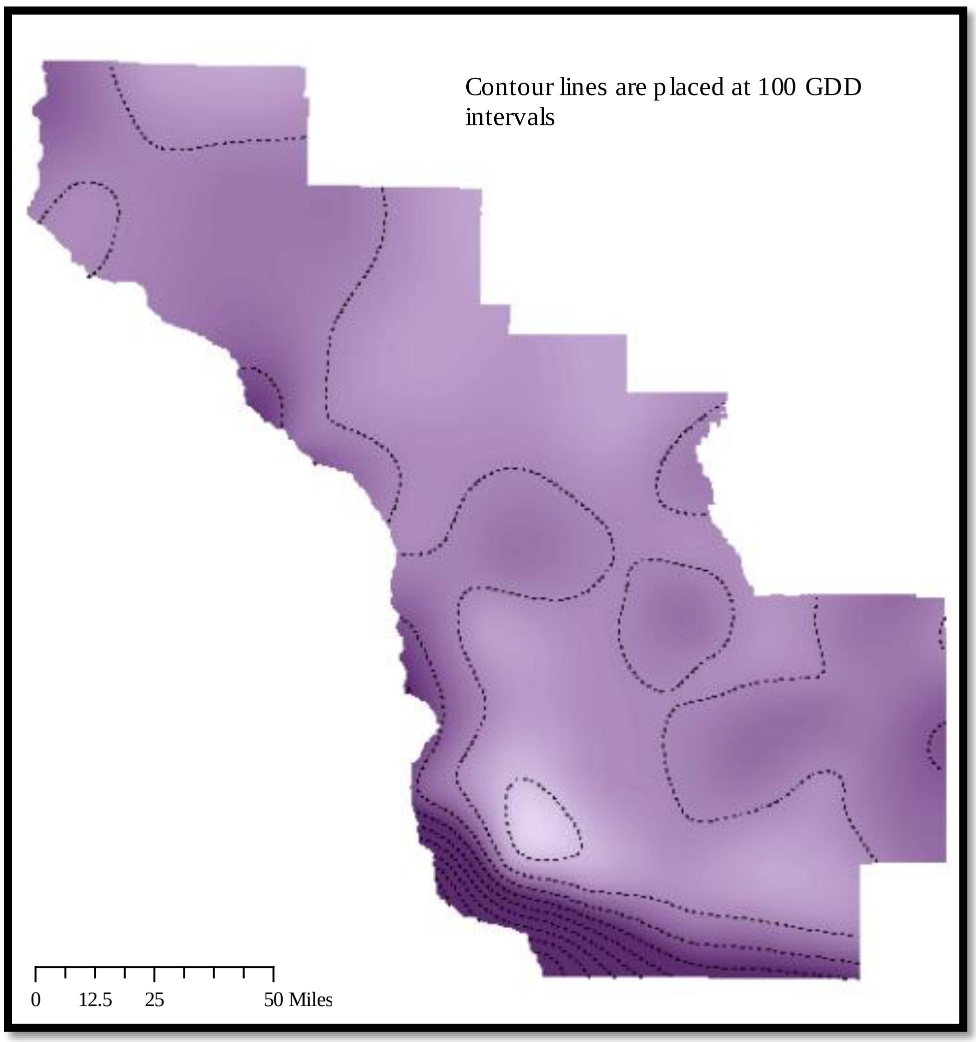

Contour lines are placed at 100 GDD intervals
0
12.5
25
50 Miles

Figure 7

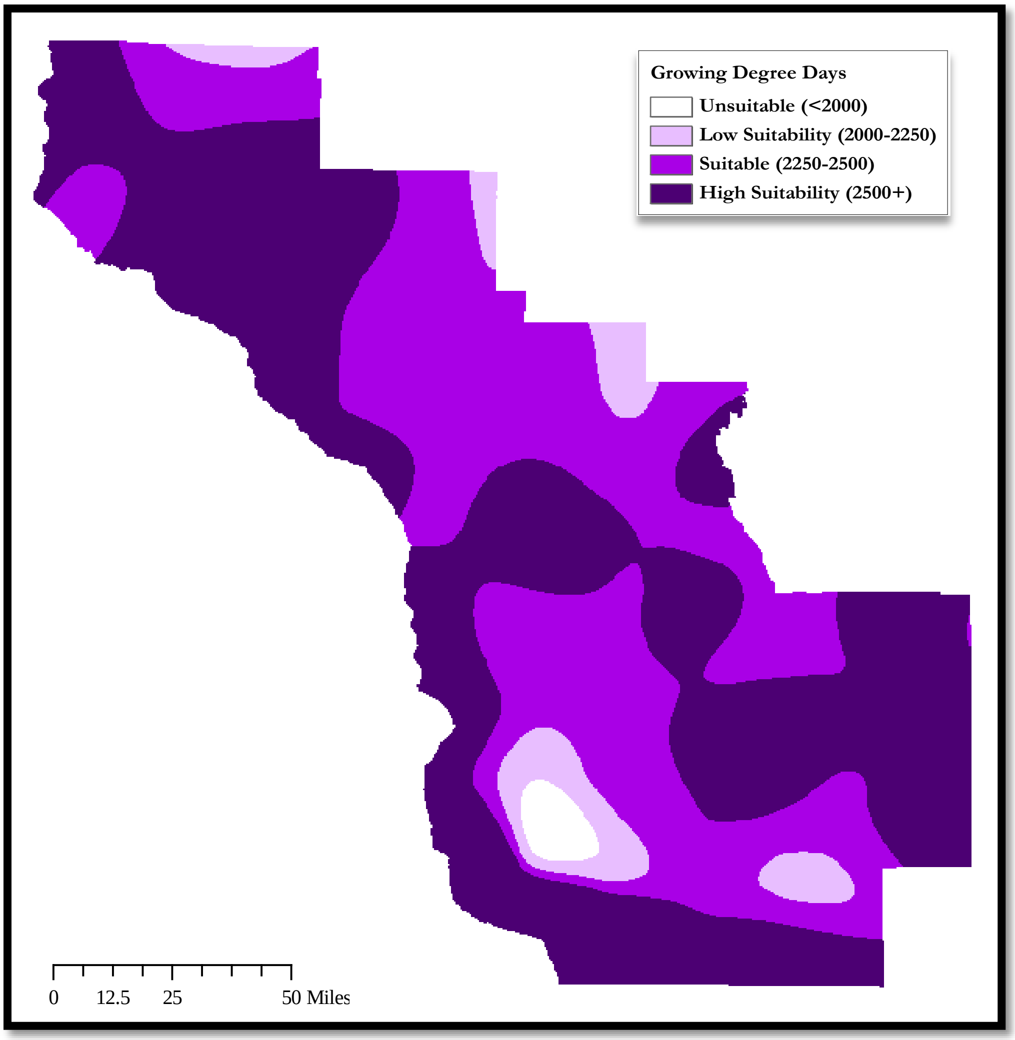

Growing Degree Days
Unsuitable (<2000)
Low Suitability (2000-2250)
Suitable (2250-2500)
High Suitability (2500+)
0
12.5
25
50 Miles

Figure 8

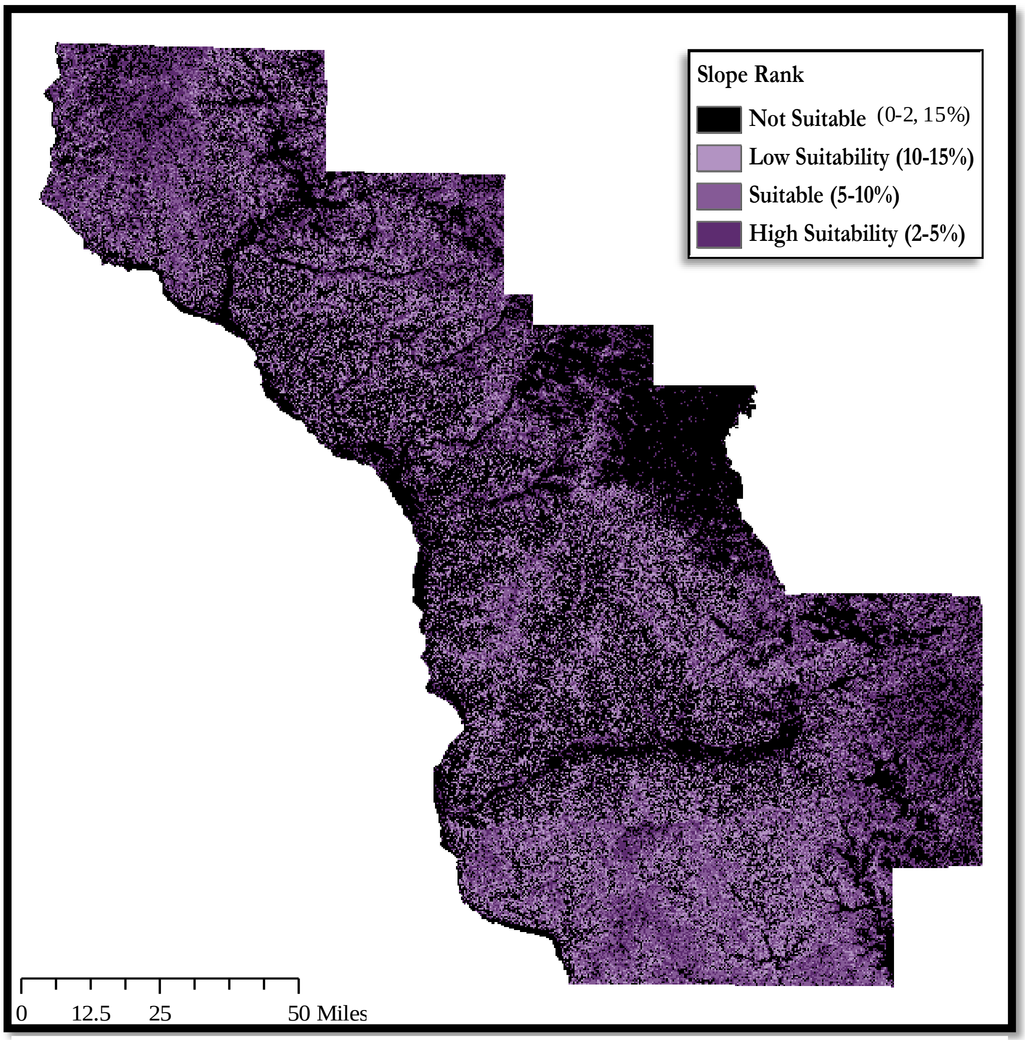

Slope Rank
Not Suitable (0-2, 15%)
Low Suitability (10-15%)
Suitable (5-10%)
High Suitability (2-5%)
0
12.5
25
50 Miles

Figure 10

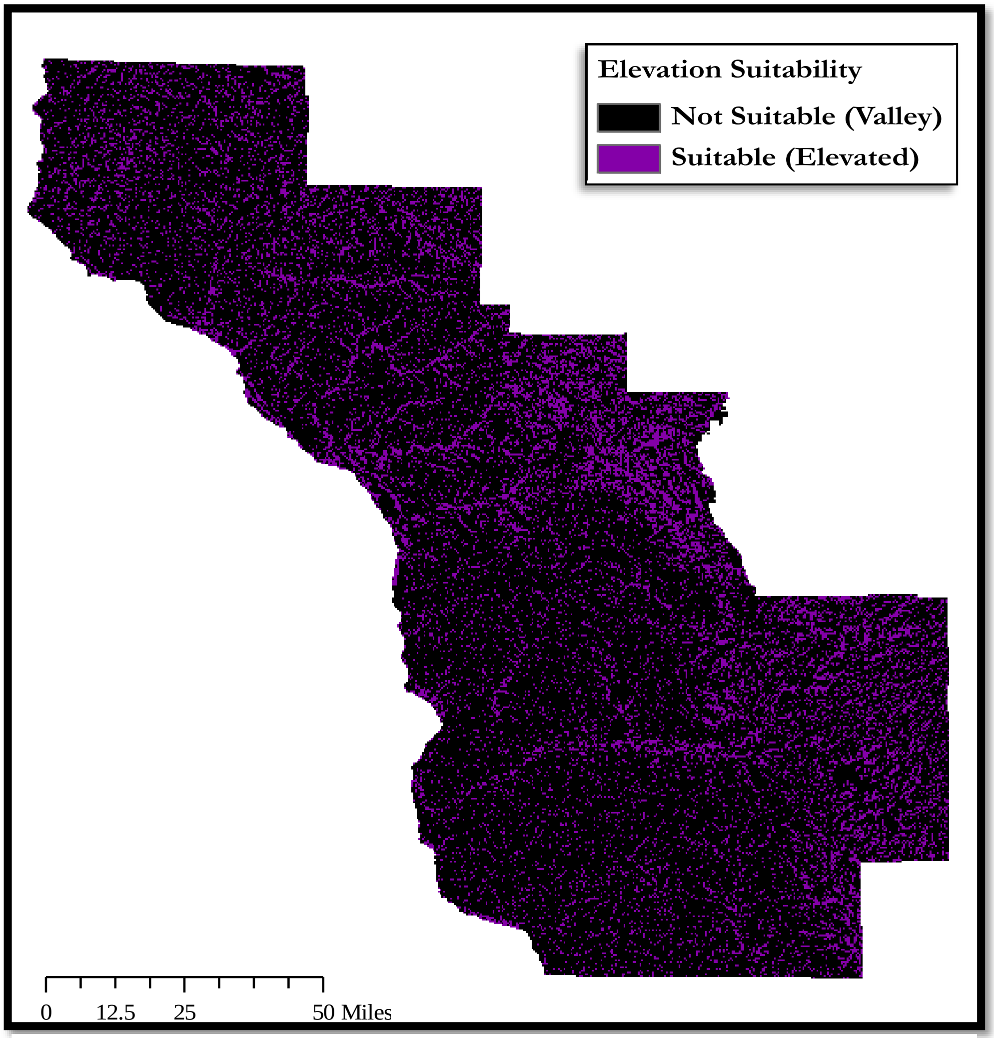

Elevation Suitability
Not Suitable (Valley)
Suitable (Elevated)
0
12.5
25
50 Miles

Figure 10

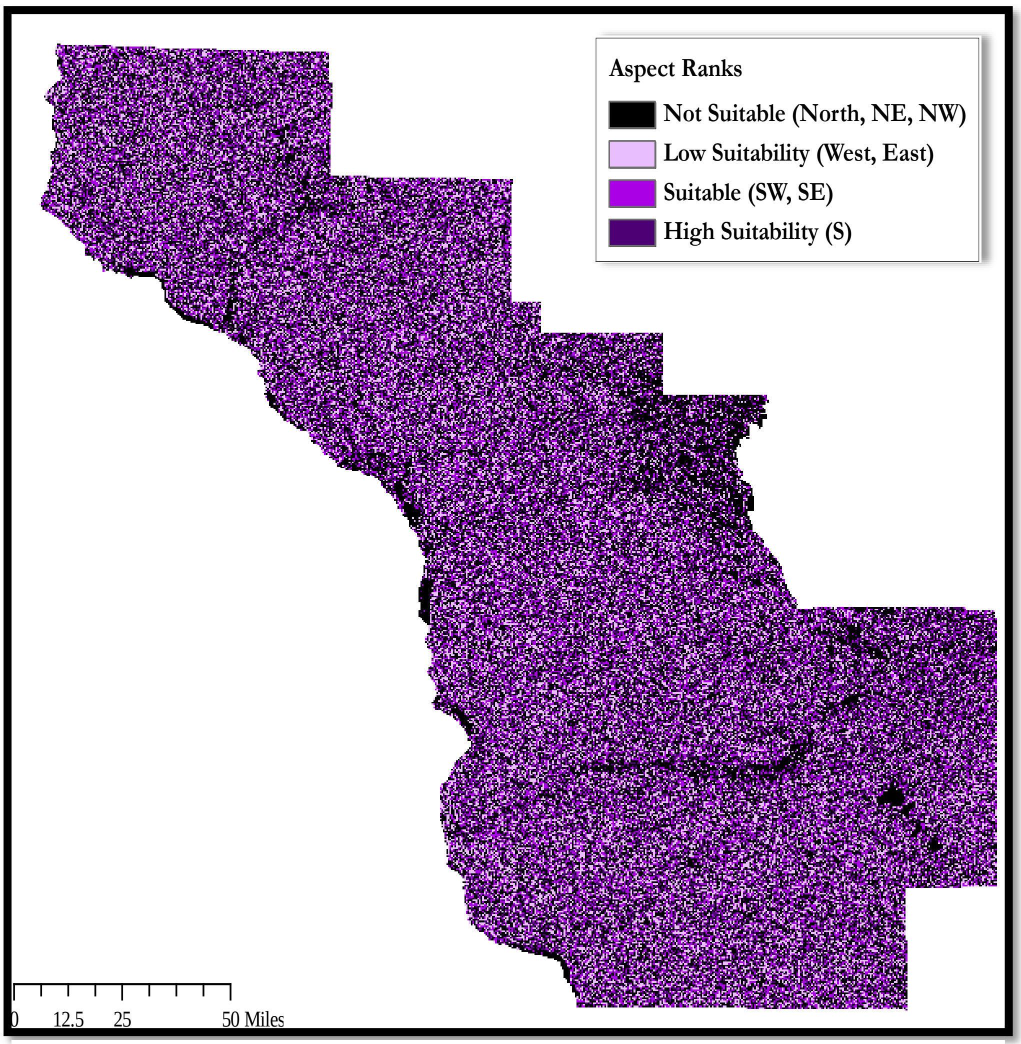

Aspect Ranks
Not Suitable (North, NE, NW)
Low Suitability (West, East)
Suitable (SW, SE)
High Suitability (S)
0
12.5
25
50 Miles

Figure 11

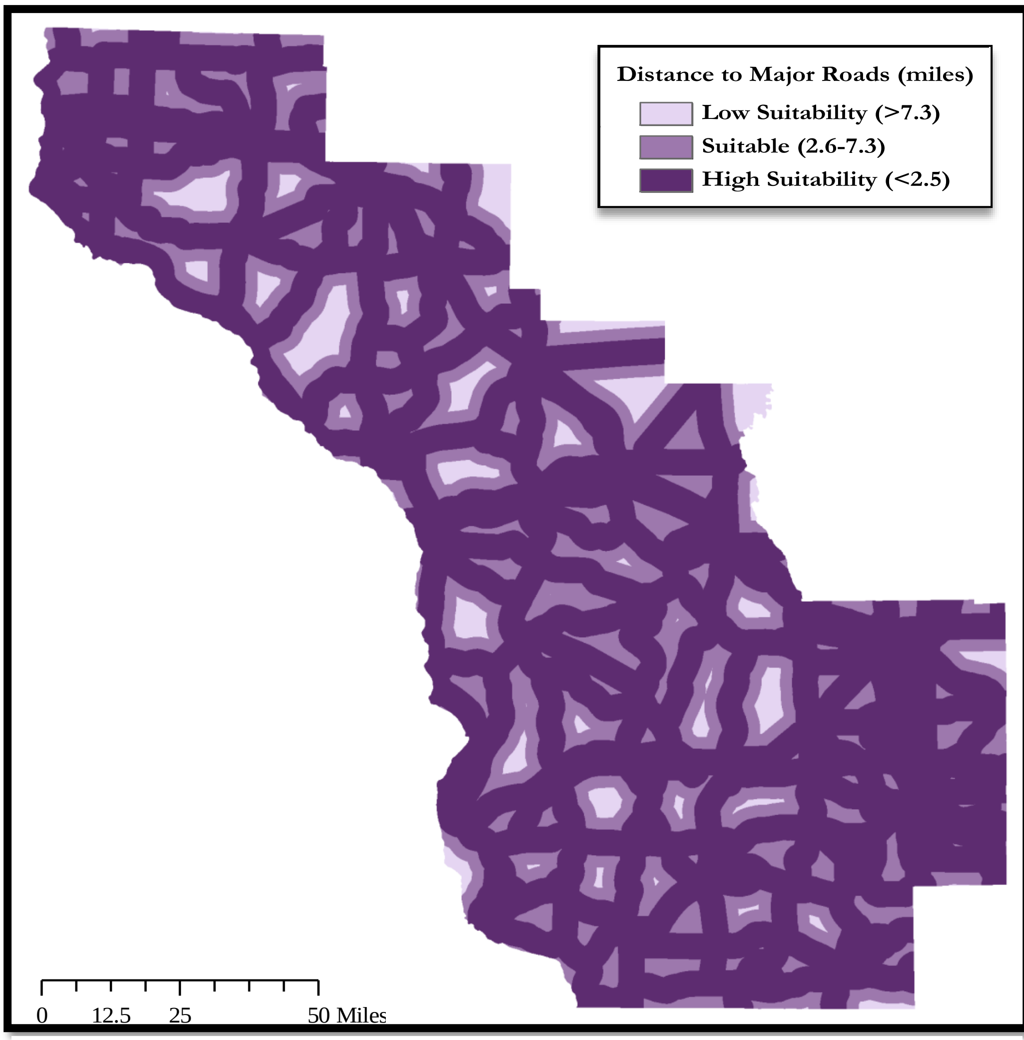

Distance to Major Roads (miles)
Low Suitability (>7.3)
Suitable (2.6-7.3)
High Suitability (<2.5)
0
12.5
25
50 Miles

Figure 12

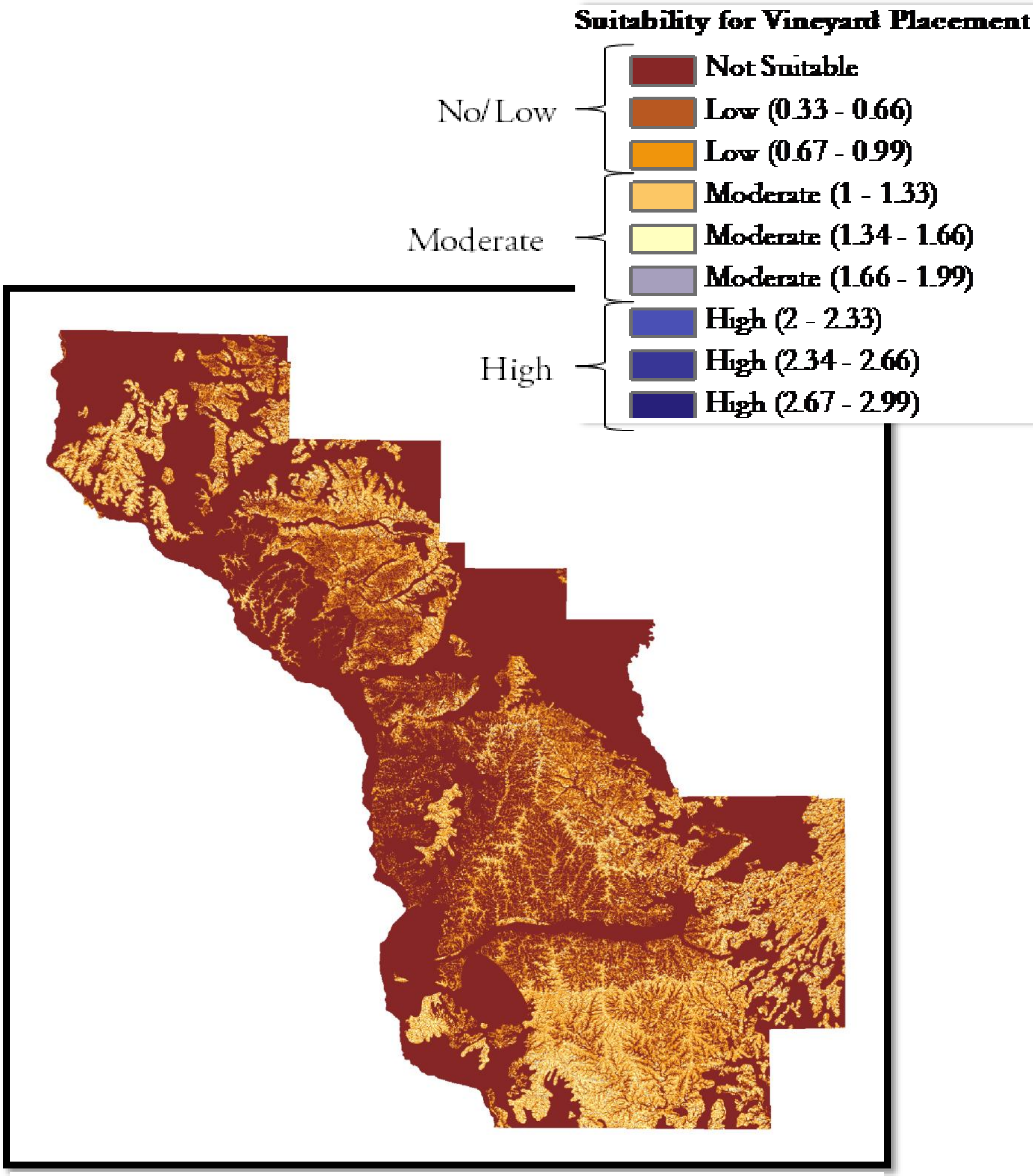

Suitability for Vineyard Placement
Not Suitable
Low (0.33 - 0.66)
Low (0.67 - 0.99)
Moderate (1 - 1.33)
Moderate (1.34 - 1.66)
Moderate (1.66 - 1.99)
High (2 - 2.33)
High (2.34 - 2.66)
High (2.67 - 2.99)
No/Low
Moderate
High

Figure 13

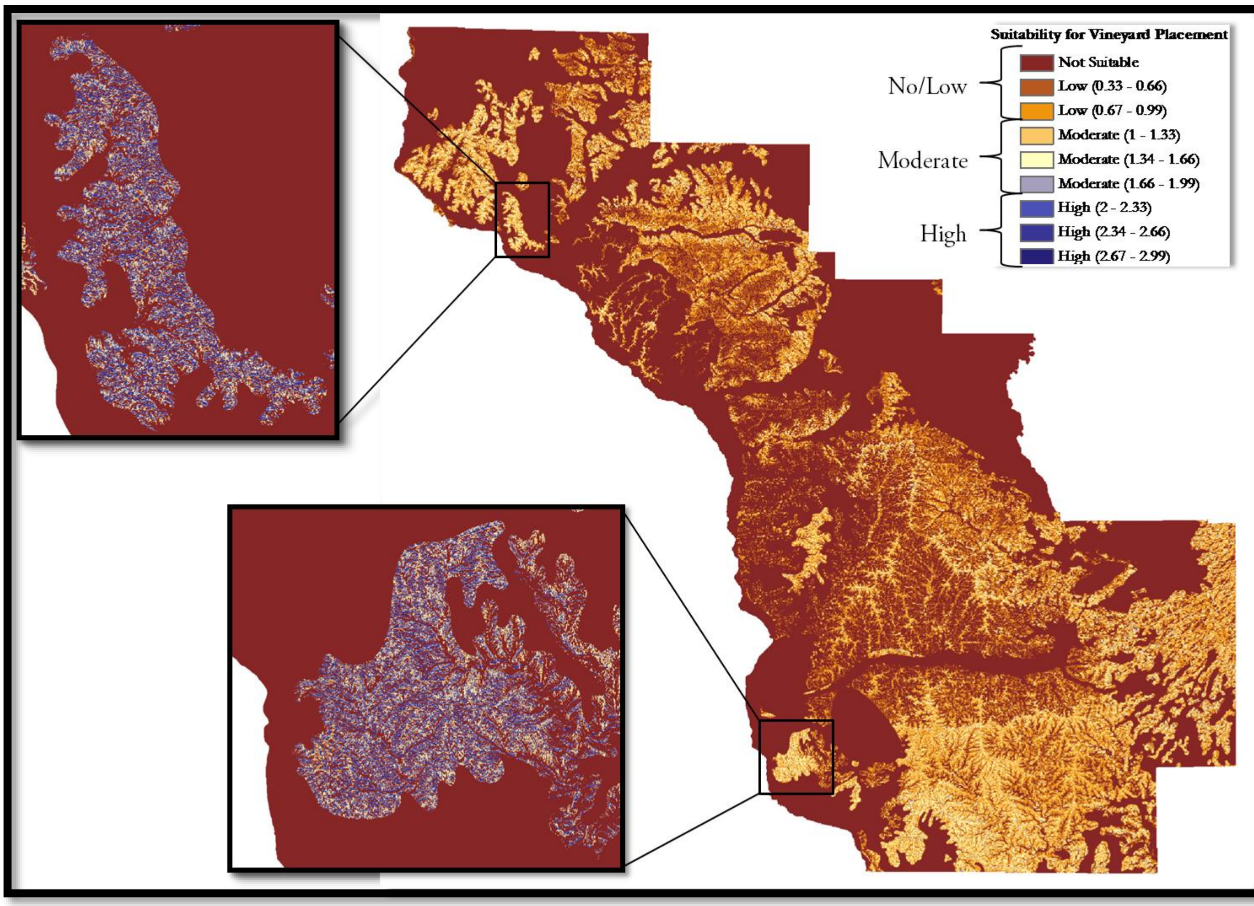

Suitability for Vineyard Placement
No/Low
Moderate
High
Not Suitable
Low (0.33 - 0.66)
Low (0.67 - 0.99)
Moderate (1 - 1.33)
Moderate (1.34 - 1.66)
Moderate (1.66 - 1.99)
High (2 - 2.33)
High (2.34 - 2.66)
High (2.67 - 2.99)

Figure 14

APPENDIX D

TABLES

Table 1.
GIS Database

Variables	Type	Unit
Slope	Boolean/Ranked	0-1; 1-3
Elevation	Ranked	0-1
Aspect	Boolean/Ranked	0-1; 1-3
Growing Degree Days	Boolean/Ranked	0-1; 1-3
Frost Free Days	Boolean	0-1
Soil Texture	Boolean/Ranked	0-1; 1-3
Distance to Roads	Ranked	1-3

Table 2.

Pairwise Comparison Table

	Aspect	Slope	Soil Texture	Growing Degree Days	Roads
Aspect	1				
Slope	1/2	1			
Soil Texture	1/7	1/6	1		
Growing Degree Days	1/5	1/3	3	1	
Roads	1/8	1/7	1/3	1/5	1

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely Less Important			Moderately Less Important	=	Moderately More Important			Extremely More Important

	Weight
Aspect	.4725
Slope	.2982
Soil Texture	.0637
GDD	.1262
Roads	.0355

APPENDIX E
METADATA

WI Average Growing Degree Days

Metadata also available as

Frequently-anticipated questions:

What does this data set describe?

Title: WI Average Growing Degree Days
Abstract:

Provides a continuous surface of the average growing degree days per growing season for the state of Wisconsin. The growing season is defined as the period

between April 1 and October 31. The GGD calculation used 50 degrees Fahrenheit as the base temperature threshold.

1. **How should this data set be cited?**

   Midwest Regional Climate Center, Unknown, WI Average Growing Degree Days.

   Online Links:

   -

2. **What geographic area does the data set cover?**

   West_Bounding_Coordinate: -93.784210
   East_Bounding_Coordinate: -86.805549
   North_Bounding_Coordinate: 46.882950
   South_Bounding_Coordinate: 41.860947

3. **What does it look like?**
4. **Does the data set describe conditions during a particular time period?**

   Beginning_Date: 1980
   Ending_Date: 2010
   Currentness_Reference: ground condition

5. **What is the general form of this data set?**

   Geospatial_Data_Presentation_Form: raster digital data

6. **How does the data set represent geographic features?**
   a. **How are geographic features stored in the data set?**

      This is a Raster data set. It contains the following raster data types:

      - Dimensions 18399 x 17741 x 1, type Grid Cell

   b. **What coordinate system is used to represent geographic features?**

      The map projection used is Transverse Mercator.

      Projection parameters:
   Scale_Factor_at_Central_Meridian: 0.999600
   Longitude_of_Central_Meridian: -90.000000
   Latitude_of_Projection_Origin: 0.000000
   False_Easting: 520000.000000
   False_Northing: -4480000.000000

Planar coordinates are encoded using row and column
Abscissae (x-coordinates) are specified to the nearest 30.000000
Ordinates (y-coordinates) are specified to the nearest 30.000000
Planar coordinates are specified in meters

The horizontal datum used is D_North_American_1983_HARN.
The ellipsoid used is Geodetic Reference System 80.
The semi-major axis of the ellipsoid used is 6378137.000000.
The flattening of the ellipsoid used is 1/298.257222.

7. **How does the data set describe geographic features?**

   Entity_and_Attribute_Overview:
   A tension spline using 9 neighbors and a weight of 5 was used to interpolate the data. The parameters were chosen based on relatively accurate prediction of values in the validation set from the surface produced on the training set. Due to the nature of interpolation itself, errors are inevitable. While the weather stations had an approximately even distribution across space, errors are more likely toward the state boundaries and in areas of high topographic variability. No formal accuracy tests were performed.

Who produced the data set?

1. **Who are the originators of the data set?** (may include formal authors, digital compilers, and editors)
   - Midwest Regional Climate Center
2. **Who also contributed to the data set?**
3. **To whom should users address questions about the data?**

   Carly Mertes
   University of Wisconsin-Madison
   GIS Certificate Program Student
   515 North Pinckney St.
   Madison, WI 53703

   cmertes@wisc.edu

Why was the data set created?

The data layer was originally developed to aid in an agricultural site suitability analysis within the Driftless Area of Wisconsin. The data is intended to give a general indication of how many accumulated growing degree days are typically observed during the growing season. The data is interpolated to cover all points in the state and should therefore not be used for applications require precise values.

How was the data set created?

1. **From what previous works were the data drawn?**
2. **How were the data generated, processed, and modified?**
3. **What similar or related data should the user be aware of?**

How reliable are the data; what problems remain in the data set?

1. **How well have the observations been checked?**

   Values were interpolated using data from 227 weather stations across Wisconsin, as well as in eastern Minnesota, Northern Illinois, and northeastern Iowa. A tension spline using 9 neighbors and a weight of 5 was used to interpolate the data. The parameters were chosen based on relatively accurate prediction of values in the validation set from the surface produced on the training set. Due to the nature of interpolation itself, errors are inevitable. While the weather stations had an approximately even distribution across space, errors are more likely toward the state boundaries and in areas of high topographic variability. No formal accuracy tests were performed.

2. **How accurate are the geographic locations?**

   Point data was imported using the latitude and longitude values of the weather stations given by the Midwest Regional Climate Center.

3. **How accurate are the heights or depths?**
4. **Where are the gaps in the data? What is missing?**
5. **How consistent are the relationships among the observations, including topology?**

How can someone get a copy of the data set?

Are there legal restrictions on access or use of the data?

Access_Constraints:

The original data was obtained from the Midwest Regional Climate Center, which is hosted by the Illinois State Water Survey. Data must be ordered or a subscription established through contacting the Midwest Regional Climate Center at <http://mcc.sws.uiuc.edu>.

Use_Constraints:

The terms of use outlined by the Illinois State Water Survey are applicable to this dataset. These terms can be viewed at: <http://www.isws.illinois.edu/data/legal.asp>

1. **Who distributes the data set?**[Distributor contact information not provided.]
2. **What's the catalog number I need to order this data set?**

   `Downloadable Data`

3. **What legal disclaimers am I supposed to read?**

   Not available for distribution

4. **How can I download or order the data?**
   - **Availability in digital form:**

     Data format: Size: 1259.360

   - **Cost to order the data:**

Who wrote the metadata?

Dates:
Last modified: 13-May-2011
Metadata author:
Carly Mertes
University of Wisconsin-Madison

carly.mertes@gmail.com

Metadata standard:
FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)
Metadata extensions used:

- <http://www.esri.com/metadata/esriprof80.html>

Generated by mp version 2.9.6 on Fri May 13 00:47:34 2011

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