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Geology and Wine in Missouri: Spatial Analysis of Terroir Using a Geographic Information System and Remote Sensing

Kathryn Nora Barnard
Missouri State University

GEOLOGY AND WINE IN MISSOURI: SPATIAL ANALYSIS OF TERROIR USING A GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

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Master of Science, Geospatial Sciences in Geography and Geology

By

Kathryn Nora Barnard

May 2009

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ABSTRACT

The concept of *terroir*, based on the French word meaning 'sense of place,' suggests that flavor and quality of wine is associated with certain physical characteristics of the earth as well as viticulture and viniculture practices. The physical characteristics of *terroir* include soil, geology, topography, and climate. Designated American Viticultural Areas (AVAs) are discrete appellations in the United States that have well-established and historic viticultural practices, but the relationship between *terroir* and AVA appellations is complex. Wineries are a growing industry in the United States and the use of a GIS and remote sensing has proved useful in many other studies on *terroir* and in consulting vineyard owners on management practices. This study examines the relationships between *terroir* and viticultural areas in Missouri. USDA National Agriculture Imagery Program (NAIP) aerial photographs and soil maps, USGS digital elevation models, and Missouri Division of Geology and Land Survey geologic maps are used to develop a Missouri vineyard geodatabases for four study areas. These data are used to create suitability maps for viticulture regions, describe the physical characteristics of vineyards in these four Missouri wine regions, and finally describe the *terroir* of each region and propose a new AVA appellation be created in the Ste. Genevieve wine-region of Missouri.

KEYWORDS: Missouri, American Viticultural Area (AVA), terroir, viticulture, land suitability, geographic information systems (GIS), wine

This abstract is approved as to form and content

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Dr. Kevin R. Evans
Chairperson, Advisory Committee
Missouri State University

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Approved:

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Kevin R. Evans, Ph.D.

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Jun Luo, Ph.D.

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Xin Miao, Ph.D.

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Frank Einhellig, Graduate College Dean

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CHAPTER 1 – INTRODUCTION

Purpose

Geographic Information Systems (GISs) have many possible applications including answering questions about location, patterns, trends, conditions and implications assessing real-life situations (Heywood, 2006) like real estate, forestry, city planning, and animal habitat assessment (Heaton and Merenlender, 2000). GIS used as a tool in viticulture is a relatively new methodology and has mostly only been applied in the largest wine-producing states, such as California (Watkins et al., 1997 and Swinchatt et al., 2006), Oregon (Jones et al., 2004), and Washington, and the Canadian provinces of British Columbia (Bowen et al., 2005) and Ontario (Reynolds et al., 2007). GIS and remote sensing have been used in the United States to map vineyard expansion (Brooks and Merenlender, 2000; Merenlender, 2000), create suitability maps (Watkins et al., 1997; Jones et al., 2004), assess vine vigor (Dobrowski et al., 2002; Dobrowski et al., 2003; Zarco-Tejada et al., 2005), map water uptake in vines (Johnson et al., 2006), and in many studies that assess geographic distribution of chemicals and trace elements in wines and sensory characteristics (Fischer et al., 1999; Douglas et al., 2001; Sabon et al., 2002; Kontkanen et al., 2005; Schlosser et al., 2005; Pereira et al., 2005; Greenough et al., 2005; Eggers et al., 2006; Andrés-De Prado et al., 2007; West et al., 2007; and Vilanova et al., 2007).

Many scientists have addressed the concept of *terroir* (pronounced tare-wahr) and the concept that climate, geology, soils, and wine are intimately connected and affect the flavor and quality of the wine. Some have started to address this same topic using map overlay techniques, a GIS, or remote sensing as a querying and mapping tool in some way (Seguin, 1986; Pomeral, 1989; Wilson, 1998; Fischer et al., 1999; Haynes, 1999; Haynes, 2000; Meinert and Busacca, 2000; Douglas, 2001; Barham, 2002; Meinert and Busacca, 2002; Sabon et al., 2002; Busacca and Meinert, 2003; Jones et al., 2004; Joyce, 2004; Kontkanen et al., 2005; Meinert and Curtin, 2005; Schlosser et al., 2005; Gillerman et al., 2006; Swinchatt et al., 2006; Andrés-de Prado et al., 2007; and Reynolds et al., 2007; Vilanova et al., 2007). Many of these studies use climate, regional and micro-climate, to also establish suitable vineyard locations, noting that the micro-climate of a vineyard is mostly controlled by the topography and vineyard canopy management (Meinert and Busacca 2000). According to a prior study, a statistically significant relationship between vineyards and the soils on which they are grown can be established (Watkins, 1999). Using a GIS, vineyard characteristics can be used to create suitability maps (Jones et al., 2004). This is the basis for using a GIS to further describe the *terroirs* of Missouri and create suitability maps to enhance the wine industry in these regions.

The purpose of this study is to collect and assess data that will contribute to *terroir* studies as a whole and to describe how geology, soils, topography, and wine are related in Missouri. In addition, the purpose is to provide a definition of the concept of *terroir*, an explanation of American Viticultural Areas (AVAs), and a discussion of the methods that can be used to analyze *terroirs* across the world. The common physical characteristics that occur between vineyards contribute to the description of the *terroir.* A rigorous assessment of these characteristics to establish the existence of *terroir* in a region is best done using a GIS and remote sensing (Watkins, 1997; Jones et al., 2004). Combining physical factors like elevation, slope, aspect, geology, and soil of vineyards in a region provide greater insight into the best grape-growing areas in the state (Wilson, 1998; Dami et al., 2005).

According to Jones et al. (2004) t*erroir* can be broken down into three basic components that are 1) physical aspects of the region, 2) viticulture or grape-growing practices, and 3) viniculture or wine making practices. In general, the physical aspects of the region include soil, geology, topography, and climate. The regions in this study all occur within 200 miles of one another and climate data was not available, therefore climate is not addressed specifically at this time. Since no single physical characteristic of the region can be used to explain the flavor or quality of a bottle of wine, a quantitative assessment of the current vineyards and their physical characteristics is necessary in order to find statistically significant variables that can be used to create suitability maps. The existence of *terroir* in Missouri is related to the measurable physical characteristics of the land and therefore is a quantifiable study that can be performed using a GIS and remote sensing.

Designation of American Viticulture Areas (AVAs)

An AVA is an area designated by the US department of Treasury - Alcohol and Tobacco Tax and Trade Bureau (TTB) that has a history of wine making and applied for the label (2007). The geographic provenance of the grapes used to produce a wine is ensured by the label and the wine must meet certain federal and state requirements. An AVA does not guarantee the quality of any wine but guarantees from where a substantial portion of the grapes originated. An AVA is one type of appellation and a vintage labeled with the AVA origin must have used 85% of the grapes from inside the AVA boundary (see US Code of Federal Regulations 27 CFR).

An AVA can range in size and concentration of vineyards within its boundaries. AVAs may cover up to 3 states and, if this appellation is to be on the vintage, 100% of the grapes must be grown in the labeled states. A bottle can be labeled from a state appellation, different than a designated AVA, if at least 75% of the grapes are grown within the state. The boundaries of an AVA usually follow rivers, township and County lines, mountain ranges and valleys, or even power lines and roads (TTB, 2007). Most AVA boundaries were not drawn with consideration of soil and geology and many are now being separated into sub-appellations because, when taken into account, these physical parameters are connected to the characteristics of certain grape varieties (Haynes, 2000).

Collecting data and assessing the spatial relationships between the wineries provides evidence to continue to work on the concept of *terroir* in Missouri. In Missouri, seven wine regions are designated and the wineries of Missouri are separated into each wine region by Ruess and Kleinschmidt (2009) (Figure 1). The wine regions are named after the AVAs that are found within them with the additional central, western, and southeast regions, where wineries are increasing in density. Wine region descriptions can be found online at the official Missouri wine website. The official AVAs of Missouri are named the Augusta, Hermann, Ozark Highlands, and Ozark Mountain (which includes some of Arkansas and Oklahoma within its boundary) (Figure 2). Some of the wine regions are named after the official AVAs of Missouri but these regions and official AVAs should not be considered equivalent.

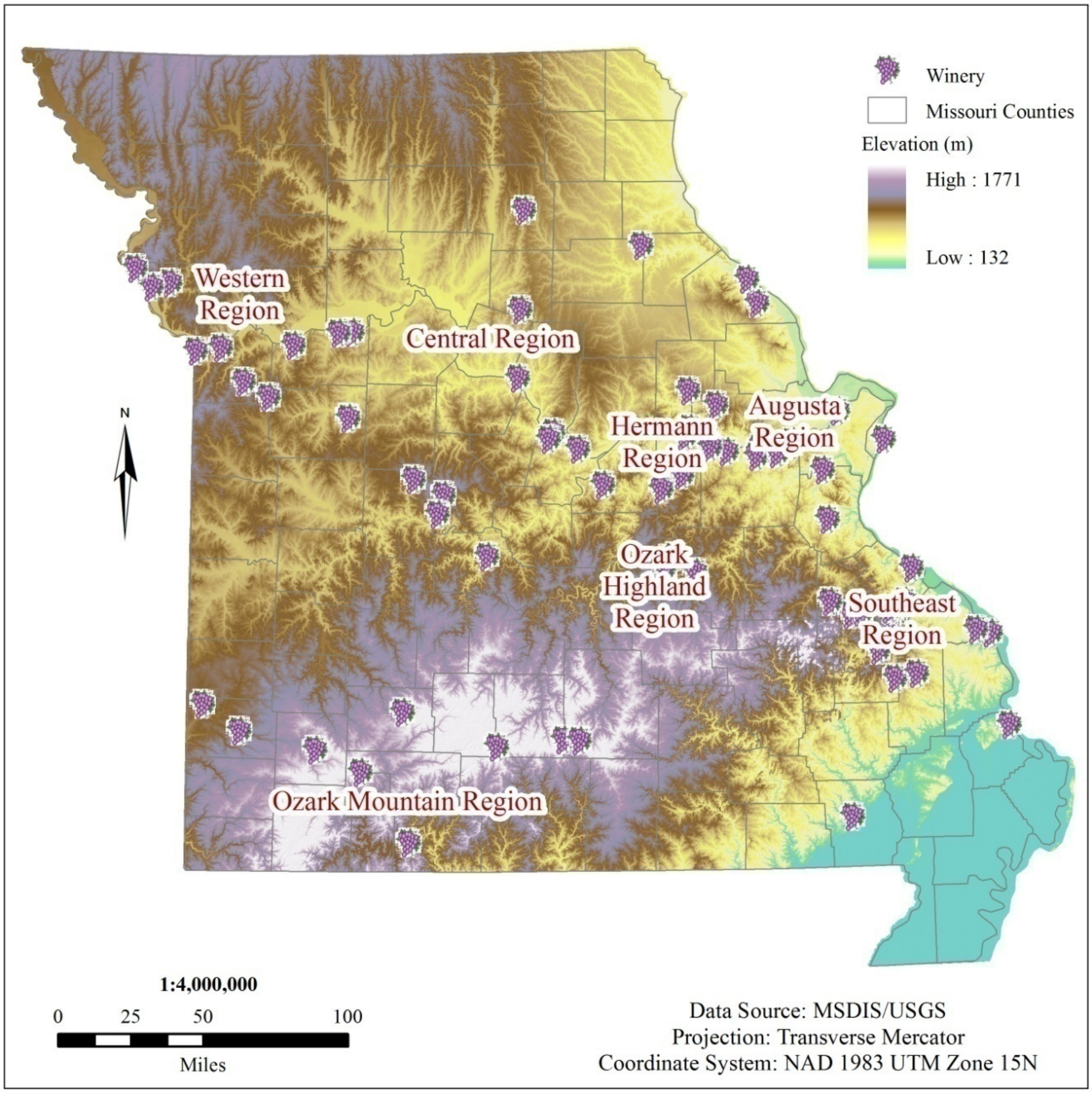


Figure 1. Missouri wine regions relative to elevation shown in graduating colors with the lowest elevations in green and the highest elevations in white. Wineries are shown as grape clusters (wine regions from Ruess and Kleinschmidt, 2009).

As of 2009, there are 79 wineries located in Missouri and many of these are found within the delineated AVA boundaries drawn based on the directions given by the TTB (2007) (Appendix A) (Figure 2). The importance of the AVA appellation boundaries is based on the history of wine-making in that region. The Augusta AVA was the first AVA in the United States to be created, and certain prestige and history is attached to having an

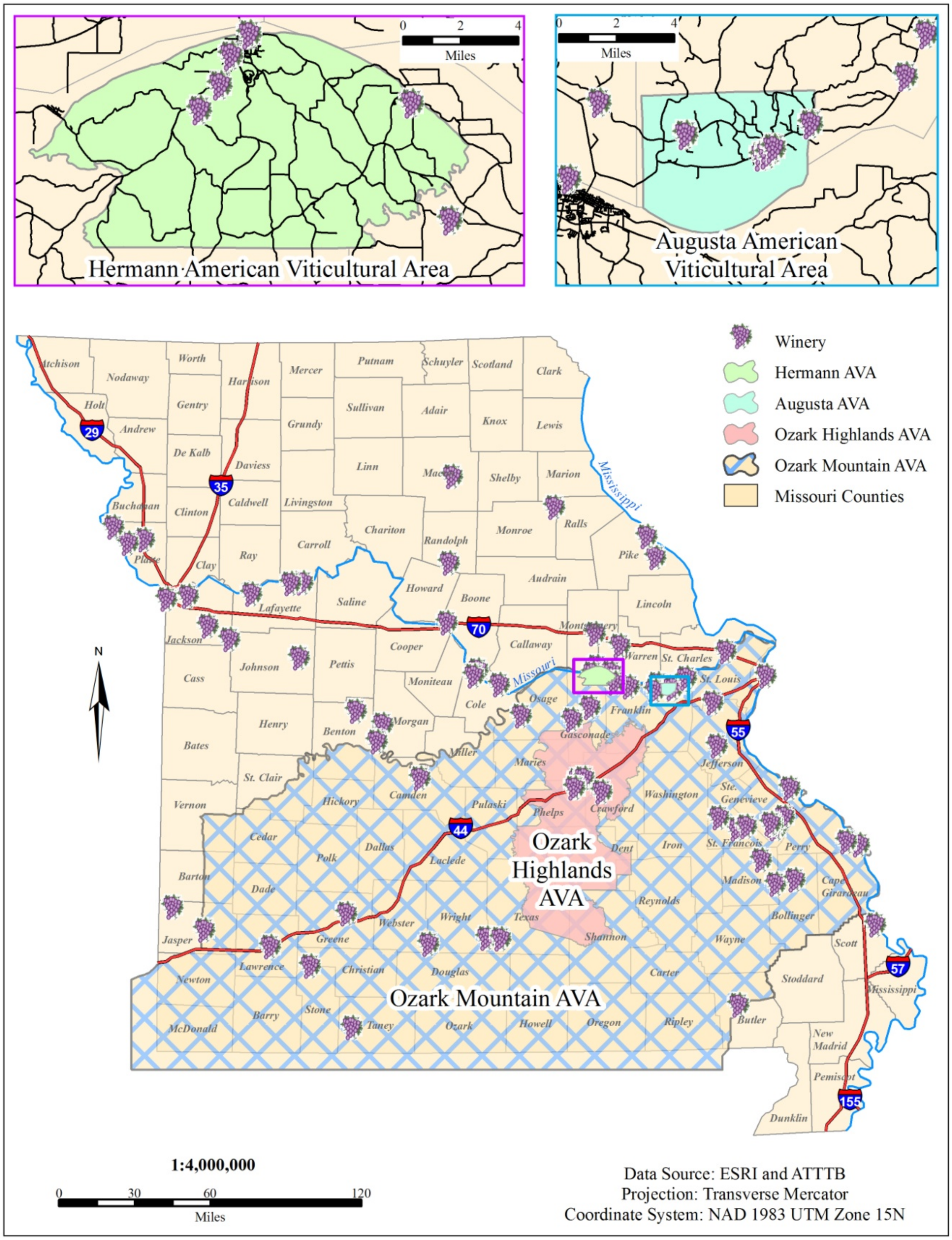


Figure 2. Map of the official American Viticultural Areas (AVAs) of Missouri as described by the publication of the Alcohol and Tobacco Tax and Trade Bureau (2007). Insets are of the smaller Hermann and Augusta AVAs.

AVA appellation on the label of a bottle of wine. Based on the distribution and spatial trends of Missouri winery locations, new wine regions are delineated and the justification for creating a new AVA is established. Also, based on the spatial relationships found between wineries, and from the spatial analysis of the physical parameters of *terroir* for vineyards, evidence for re-drawing the AVA boundaries in Missouri is recognized. The impact of AVAs on the economy and tourism in Missouri is significant and this research provides the evidence needed to justify Missouri AVAs as popular destinations for wine lovers (Barham, 2002; Ditter, 2005).

Definition of *terroir*

The interest in the connection between geology and wine was recently sparked by James E. Wilson with his 1998 book *Terroir: The Role of Geology, Climate, and Culture in the Making of French Wines*. In this book, Wilson explains the historic and cultural aspects of French winemaking and how quality wines have a connection with certain soils and the bedrock geology that lies underneath the vineyards that are used to make them. According to the leading French dictionary, *Le Petit Robert* (Robert, 2008), the French word *terroir* has many definitions, all of which can be molded together to help one understand a *terroirs'* relationship to wine. *Terroir* has its roots in the word territory, which refers to land that is used for diverse activities by the rural community. This territory possesses certain homogeneous physical properties (soil, geology, drainage, etc.) which are suitable for certain agricultural products (Robert, 2008).

Specifically, the nature of the soil is thought to be communicated through the character of certain products, most notably with wine (Robert, 2008). Wine, according to its *terroir*, will have a particular taste that is associated with the soil where the vineyard is located (Robert, 2008). Because of this, *terroir* refers to a certain region, province, or countryside that has a cultural tradition of producing wine (or another agricultural product like cheese or meat) that has certain characteristics that reflect the place of origin (Robert, 2008). Many publications use various methodologies to analyze chemical compounds in wines and in the vineyard soils in order to compare the wine with its *terroir.* Other studies use organized sensory tests to compare the flavor of wines to their *terroirs* (Fischer et al., 1999; Douglas et al., 2001; Sabon et al., 2002; Kontkanen et al., 2005; Schlosser et al., 2005; Pereira et al., 2005; Greenough et al., 2005; Eggers et al., 2006; Andrés-De Prado et al., 2007; West et al., 2007; and Vilanova et al., 2007).

Charles Pomeral's translated version of *The Wines and Winelands of France* (1989) explains *terroir* based on the French system of wine regulation that comes from the idea of Baron LeRoy de Boiseumarié who wanted to protect the quality of certain wine regions and the distinctive characteristics of the wine produced there. In 1905 the government of France began to control the production of certain agricultural products within those boundaries. In 1937, the failure to make a management plan and enforce these laws inspired the creation of the *Institut National des Appellations d'Origine des Vins et Eaux-de-Vie – INAO* (National Institute of the Labels of Origin of Wines and Brandies) who established the guidelines for the *appellation d'origine contrôllée - AOC* (Appellation of Controlled Origin) and other wine quality standards in France. These guidelines were created by committees of wine experts, including geologists and other scientists, to control the quality of wines coming from Bordeaux, Burgundy, Champagne, and Rhône (Pomeral, 1989).

The *INAO* distinguishes between two types of wine; *vins ordinaire* (ordinary wine) and quality wines. *Vins ordinaire* can be separated into *vin de table* (table wine) and *vins de pays* (country wine). Table wines are the lowest category and are made from a combination of wines from many different regions, or even countries. These wines do not have origin labels while country wine will indicate a geographic origin in one of three levels, either regional, departmental, or locally zoned areas. Country wine (*vins de pays*) undergoes the same control as *appellation d'origine* but alcohol levels can be lower as a result of higher vineyard yields (MacNeil, 2001 and Pomeral, 1989). The European Union distinguishes the *Vin de Qualité Produits dans des Régions Determinées – VQPRD* (Quality Wine Produced in Determined Regions). In France, the quality wines are separated into *appellation d'origine contrôlée* and *vin délimité de qualité supérieure - VDQS* (MacNeil, 2001). These levels are very strict and are systematically regulated and controlled to guarantee quality wine to the consumer. When buying quality wine the *VQPRD* is found on European wines in general and the *VDQS* and *AOC* is only used in France for French wine and is more restrictive than the European label (Pomeral, 1989).

According to Pomeral (1989) the geological and pedological (soil genesis, morphology, and classification) nature of an area determines the delineation of an *appellation* and the *terroir* for that specific wine. The close relationship that exists between the bedrock geology, soil texture and structure, stoniness, depth and chemical composition and the quality of wine is noted in the *INAO* and used to determine quality wine regions (Pomeral, 1989). This labeling system for French wines is the most stringent in the world and its success implies that similar practices in designating AVA appellation boundaries in the United States should be followed (Barham, 2002). From this, the description of current AVAs, the justification of their boundaries, and creation of new AVAs should be based, at least partly, on the geology, soil, and topography of the vineyards in that region.

Terroir in France, according to Seguin (1986), can be described and delineated based on soil alone. His quick method of characterizing separate *terroirs* uses the physical, chemical, and physiochemical analysis of the soil and subsoil. His studies concluded that the only soil parameter that is generally associated with quality wine is calcium carbonate (Seguin, 1986). Nitrogen-rich land usually produces poor quality wines and can increase vine-root sensitivity to rot. Deep, fertile soils grow large vines but the fruit quality will be poor (Dami, 2005). High quality wines can be produced from soils that are stony, with very little clay, or from soils that are clayey and have very little pebbles (Seguin, 1986). Because of the human influences on soil, which include fertilization, irrigation, and mechanical manipulations (i.e. plowing), the best soils can vary greatly. It is well understood that the best soils are well-drained, well-aerated, and contain no restrictive layers, like a caliché, hardpan, or fragipan (Dami, 2005). These soils are described as having good internal drainage and structure. The best soils are also deep allowing for the roots to penetrate and reach the available water and nutrients (Seguin, 1986; Dami, 2005).

The best *terroirs* are characterized by having a high degree of macroporosity (Seguin, 1986) causing rainfall to percolate successfully and leave air in some pore spaces so that the roots of the vines do not suffocate and die. The vines require some clay in the soil mixed with organic matter, sand, and silt so that the roots can easily penetrate it. This clay content helps make the soil more resistant to erosion (Seguin, 1986). The soil structure (sand, silt, clay ratio) is important and ultimately controls internal drainage. More sand in the soil results in quicker drainage and the need for deeper soil thickness. Therefore, the areas with quality *terroirs* in France according to Seguin (1986) typically can be described as having the best soil structure, porosity, and permeability to allow for root development and regulation of water supply to the vine. These physical properties of the soil will ultimately limit the effects of climatic destruction from either heavy rainfall or drought by allowing for the vines to neither be suffocated by too much water nor dry out from the lack of it (Seguin, 1986).

Previous *terroir* studies

Studies that are based on the concept of *terroir* were done in the Umpqua Valley of Oregon (Jones et al., 2004), the Okanagan and Similkameen Valleys of British Columbia (Bowen, 2005), the Red Mountain Appellation (Meinert and Busacca, 2002), the Walla Walla Valley Appellation in Washington (Meinert and Busacca, 2000), and in the Coastal Region of South Africa (Bargmann, 2003). These studies have attempted to find correlations between wine and the physical aspects of the land on which it was produced. All aforementioned studies refer to the areas where grapes of a certain quality are grown as *terroir.* In these papers, it is understood that geologic bedrock is the parent material for the soil, controlling composition and texture, and ultimate control for the topography of a region (Haynes, 2000). Washington, Oregon, Idaho, and California are very prolific in wine production, and studies in these states have stressed the importance of many factors that influence the distinct *terroir*s that are found there.

In 1999, Simon J. Haynes wrote the first in the series Geology and Wine, published in Geoscience Canada. Haynes (1999) defines the factors that affect *terroir* into five groups. These groups are meteorological, physiographic, pedologic, geologic and viticultural factors. In short these factors are climate, topography, soils, geology, and wine-making techniques affect the quality and taste of wine. These factors form complex interrelationships that are included in concept of *terroir* (Haynes, 1999). In the New World, it is very common to address one or two of these factors at a time, with the geology, and topography usually ignored (Haynes, 1999). Haynes (2000) focused his research in the Niagara Peninsula in Ontario, Canada and proposed that the Designated Viticultural Areas (DVAs) appellations (similar to AVA in the U.S. but designated by climate only) should be subdivided based on significant differences in geology, landform physiography, soils types, and groundwater flow.

According to Haynes (1999) the *terroir* that contributes to quality wine from a specific area includes factors of physical geology, petrology, and hydrogeology. To be more specific these factors are elevation, types of landform, azimuth to the sun, slope aspect, gradient, mineralogy, texture, porosity, and geochemistry, surface water and groundwater flow rate, direction and chemistry. In the new world most of these factors, other than soil texture and a history of grape-growing practice, are ignored and not considered when creating a DVA in Canada (Haynes, 2000) or an American Viticultural Area (AVA) in the United States. It seems only appropriate that geoscientists become more involved with viticulture and that GIS be used to organize, query, and find relationships between these many factors that might be used to describe terroir in the United States and delineate the boundaries for AVAs.

Haynes (2000) stated that the existing viticulture areas in the Niagara Peninsula should be broken up into to smaller sub-appellations. He based this on the significant geological differences within the current viticultural areas that undeniably contribute to variations in physiography, soil, and groundwater flow. His use of the word *terroir* refers to these sub-appellations that produce wines of certain taste that can be directly connected to specific vineyards. The designation of smaller *terroir*s within a large viticultural area based on geology follows the practice of the people who invented the term and concept of *terroir*. To overcome the problem with wines produced from grapes from many vineyards and possibly many growers, and the blending of juices before bottling, Haynes (2000) performed his research on wines that were from specific vineyard soils only, similar to the *AOC*-labeled wine. This way, certain taste and flavors could be associated to only one soil type and bedrock underlying the vines.

The purpose of Haynes' (2000) paper is to promote the use of geology for determining the boundaries of sub-appellations. *Terroir* is defined at the level of the sub-appellation in France where, in a viticulture region, differences in geology, soils, and physiography control where certain grapes are planted. *Terroir* can also be defined at the micro-level of a specific vineyard with a specific varietal which separates the AOC-labeled *grand crus* from the *vin de pays* (Haynes, 2000). In the new world the distinction at the micro-level or *terroir* cannot occur because viticulture practices are still young and only time will tell which varietals and vineyard locations produce the best wines (Haynes, 2000). Further tests and experiments will determine if wines from each sub-*appellation* truly are different and should be described with one of these specific sub-appellation *terroir*s and time will tell if the *climat* (or micro-level *terroir*) that separates the *grand crus* from the *vins de pays* will develop in each of these sub-appellations.

Wilson's 1998 book, highly acclaimed by Haynes, clearly illustrates the connection between geology, subsoil, soil, drainage, topography, and microclimate when describing *terroir*. The detailed description of geology in the French *AOC*s was made possible by overlaying an image of the *AOC* boundaries on geologic maps. Having maps that can be overlain to see the vineyard location in association to the geology, soils, topography, and climate is extremely beneficial to those who study *terroir*. Wilson (1998) noticed that The Alsace and Haut-Beaujolais regions were mostly underlain by acidic and sandy soils on granite bedrock. The majority of the other regions were on carbonate bedrock that creates alkaline soils with good soil structure and has active calcium carbonate that favors moisture retention (Wilson, 1998). He claims that grapevine roots can obtain great depths to avoid drought and that the most popular soils had no caliché, or hardpan, and a granular structure with approximately 25% sand which agrees with Seguin (1986) and Dami (2005). Clay content and abundant rock fragments or pebbles were also commonly found in the *AOC* boundaries. The sloping bedrock, created by the uplift and deformation from mountain building, helps drainage and the fractures in the bedrock contribute to an increase in water storage. Therefore, the vigor of the grape-vines is closely related, through porosity and permeability, to bedrock geology and soil type (Wilson 1998).

Meinert and Busacca (2000) emphasize that many factors, like temperature, sunshine, rainfall, soils, bedrock, and viticultural practices need to be understood in order to define the *terroir* of their research area in Washington. Gillerman (2006) studied the *terroir* of the Snake River Plain, addressing the unique combination of factors that affect which cultivars are appropriate for the area based on physiographic, geologic, pedologic, and climatic criteria. There are many contributions to precision agriculture in the wine industry with the advances in mapping programs. Watkins (1997) and Jones et al. (2004) provide precise methods to using a GIS to analyze the *terroir* in California and southwestern Oregon, respectively. By using GIS they were able to establish evidence for using *terroir* analysis to create suitability maps for new vineyards (Watkins, 1997) and this evidence was used to support using information obtained from the knowledge of local grape growers to create suitability maps in Oregon (Jones et al., 2004). The location of current vineyards was commonly in the areas with the most suitable land according to the maps created with the GIS. Watkins (1997) used soil variables and physiographic parameters to justify the study of the Zinfandel grape in Eastern California to see if vineyards were placed on land that is unique. He found that vineyard placement is significantly based on soil characteristics. Jones et al. (2004) method used climate, topography, soils, and land zoning criteria to help understand the *terroir* of the Umpqua Valley appellation.

Watkins (1997) discussed how studies in Italy and regions of France focus on matching cultivars to the environment using GIS and finding the optimal place to grow certain grape varietal and this precision may eventually be done in Missouri. Highlighting soil and topographic variables, his study hypothesized that there occurs a statistical difference between vineyard sites and non-vineyard sites. Based on six variables, slope angle, slope aspect, Storie Index (a suitability rating), soil depth, water-holding capacity, and cation exchange capacity are significantly different at a 95% confidence interval.

Effective rooting depth, natural runoff, and clay content were also significantly different at the 85% confidence interval. These results support the idea that soil and topography influence viticulture. Suitability maps can then be created using soil, geology, and topography data here in Missouri as well as other grape growing states.

Objectives

The primary hypothesis in this study is that there is a statistically significant relationship between the current vineyard locations and the geology, soil, and topography of that location in Missouri wine regions. The overall goal of this research is to establish a GIS method that can use established relationships between factors to predict the most suitable locations within or near AVAs for establishing more vineyards. This project may also lead to establishing new AVAs or wine regions within Missouri. To test this hypothesis, that the concept of *terroir* is applicable in Missouri, five main objectives are addressed and discussed.

Objective 1. Create a map of the current AVAs in Missouri based on the descriptions from the TTB (2007). Locate existing wineries and vineyards in the wine regions near the Missouri River in the Augusta and Hermann AVAs, Les Bourgeois Vineyards area, and in Ste. Genevieve and St. Francois counties. Assess the accuracy of identifying vineyards from aerial photography.

Objective 2. Attribute the fields for each vineyard with important *terroir* variables including soil, geology, elevation, slope, aspect, curvature, area, row orientation, varietal, and owner. Organize data and sources into a geodatabase that will aid in future research. Addressing objectives 1 and 2 will provide a basis for monitoring and assessing future developments in Missouri viticulture.

Objective 3. Find the range, mean and standard deviation for important *terroir* variables in each AVA and vineyard region as well as the use percentage for non numerical variables. Compare the values found for the vineyards within an AVA to the vineyards outside of the AVA. Justification for the current AVA boundaries can be determined by whether or not there is a significant difference between vineyards inside and outside the AVA. Use the major soil and bedrock types as well as the ranges of elevation, slope, aspect, and curvature to create suitability maps for each study area.

Objective 4. Use GIS to describe the spatial variation in Missouri winery locations. Trends in winery locations may be based on common physical parameters established by objective 1, or they may be based on cultural or economic factors instead. This information can be used to establish wine regions in Missouri and help develop wine tours that can increase tourism to these wineries.

Objective 5. Give detailed analysis of the soil types used in some vineyard regions of Missouri for vineyards and an explanation of the relationship between geology, soil, topography in these regions. Boundaries for sub-appellations and the specific *terroir* characteristics of each are described based on the findings from the spatial analysis of the vineyards.

CHAPTER 2 – MISSOURI VITICULTURE

Study area

There is a rich viticultural history in Missouri that started in the 1820's by Jesuit priests who made wine from local wild grapes. The earliest grape-grower in Missouri was from Sweden named Jacob Fugger, a Swedish immigrant, who in the town of Hermann in the early 1840's, planted Isabella, Cynthiana (Norton), and Catawba grape varieties (Dami, 2005). Immigrants from Germany eventually settled in Augusta and Hermann and immediately found the land near the Missouri River perfect for cultivating grapes (Durfor, 2007). Immigrants from France were early pioneers in the Ste. Genevieve area and the Italians settled Ozark Highlands (Eccher et al., 2008).

The establishment of many vineyards because of the climate and soil of Missouri, increased wine production until, in the 1880's, Missouri was the nation's leader at more than 800,000 cases annually (Eccher et al., 2008). The Norton at this time also became popular overseas and won "Best Red Wine of All Nations" at the 1873 Vienna World Exposition (Eccher et al., 2008). When France and California's *Vitis vinifera* grape crop was devastated by the Grape Phylloxera (*Daktolusphaira vitifoliae*) in the latter of the 19th century, a Missouri scientist discovered rootstock grafting as a way for *Vitis vinifera* vines to resist the Phylloxera (Dufor, 2007). It is because of Missouri's wine industry that European and California vines were saved (Eccher et al., 2008).

In 1920, when the Prohibition Act stopped commercial winemaking, some 100 wineries existed in Missouri. Vines were saved for table grape production but many were uprooted, burned, or left to go wild (Dufor, 2007; Eccher et al., 2008). When prohibition was repealed in 1933, the wine industry in Missouri took about 27 years to before there was significant production in the state again (Eccher et al., 2008). Stone Hill Winery in Hermann and Mount Pleasant Winery in Augusta were the first two wineries to reopen and even though production is not the same since pre-prohibition, there are 79 wineries in Missouri today and the industry continues to grow (Figure 1) (Dufor, 2007).

Missouri's currently delineated regions are the Augusta AVA, Hermann AVA, Ozark Highlands AVA, and the Ozark Mountain AVA (Figure 2). The first AVA to be designated in the U.S. was the Augusta AVA on June 20, 1980 (Pollack, 2007). This was rapidly followed by the creation of many other AVAs including the well-known Napa Valley AVA in 1983 (TTB, 2007). There are now 5 wineries located within the Augusta AVA and four others within 4 miles of the boundary (Figure 3). Although Missouri viticulture essentially started in Hermann, the official AVA was not designated until August 18, 1983, four years after Augusta was designated. The Hermann AVA includes 5 wineries with one just outside the boundary to the east (Figure 4). The AVA boundary description was then amended on February 27, 1987. The Ozark Mountain Ozark Highlands AVAs were created on July 2, 1986 and August 31, 1987, respectively (TTB, 2007) (Appendix A). In the United States there are 167 AVAs at the time of this publication.

The Rocheport area only consists of Les Bourgeois Winery and was included in this study because of the Association of Missouri Geologists (AMG) conference held in Columbia in the fall of 2008. The results from the *terroir* analysis of the Les Bourgeois Vineyards area were included in the AMG field trip guidebook for that conference (Barnard et al., 2008c). It was found that Les Bourgeois imports a majority of its grapes and an AVA designation would not be feasible for this area at this time. The *terroir*

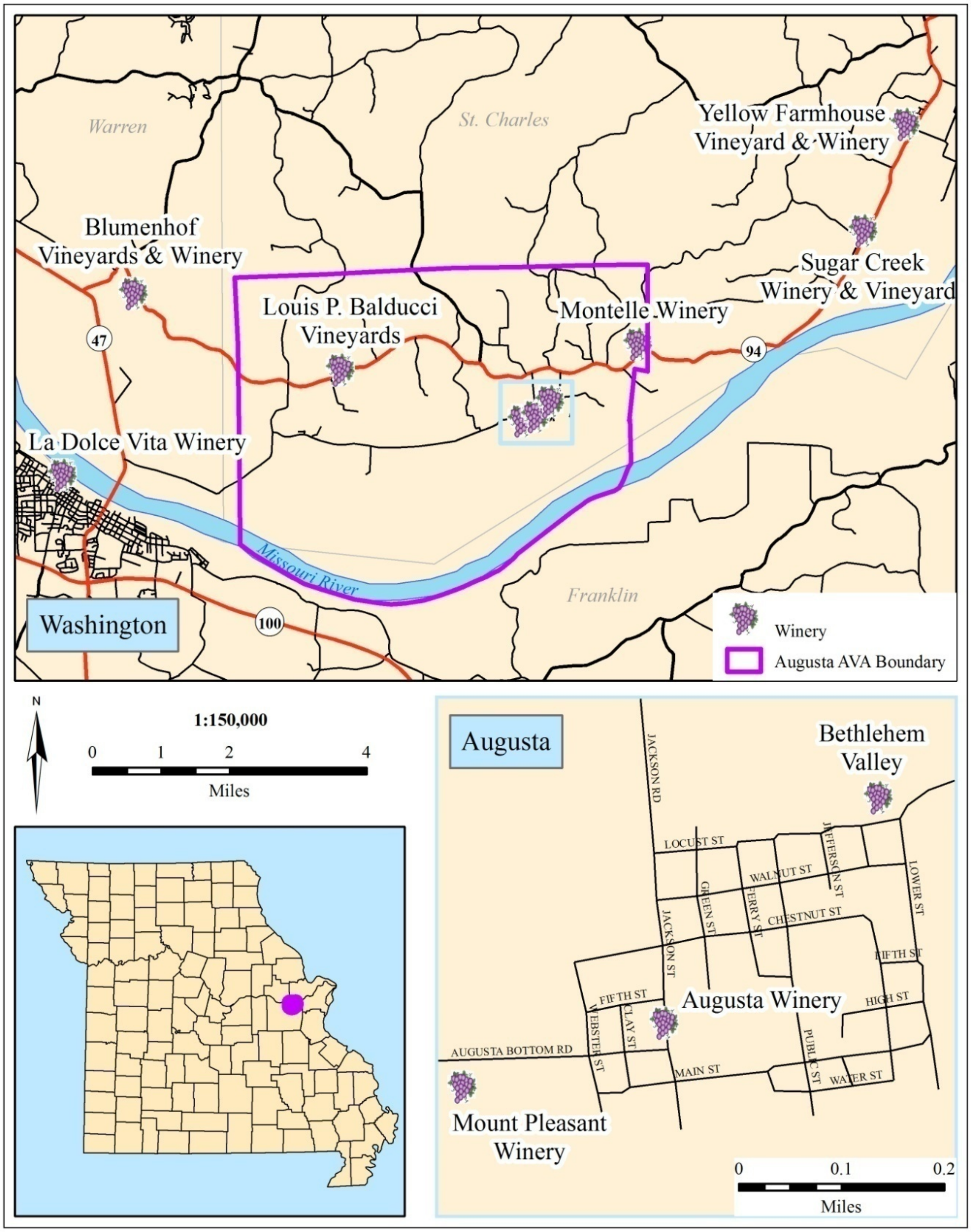


Figure 3. Augusta AVA study area showing five wineries within the AVA boundary and four others. Inset shows the town of Augusta. It should be noted that Bethlehem Valley Winery does not have its own tasting room, but wine can be purchased at the Mount Pleasant Winery.

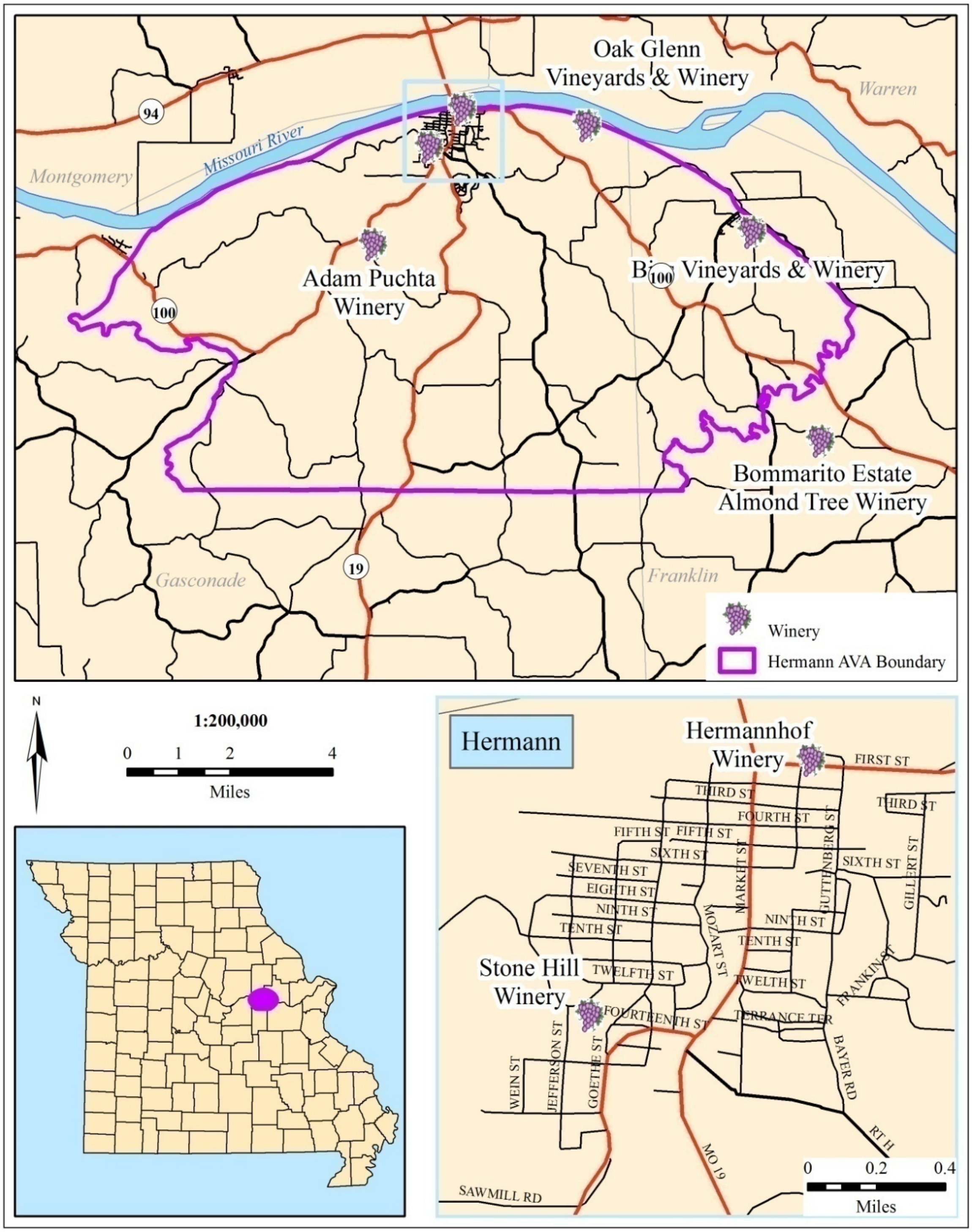


Figure 4. Hermann AVA study area showing five wineries within the AVA boundary and one other within two miles of the AVA boundary. Inset shows the town of Hermann.

description of this area will be included as well as suitability maps for the area to increase their productivity and eventually reduce their dependence on grapes from outside the state (Figure 5).

According to Dufor (2007) there are 79 wineries in operation in Missouri and the majority of these are located in one of four delineated regions. There are other wine-

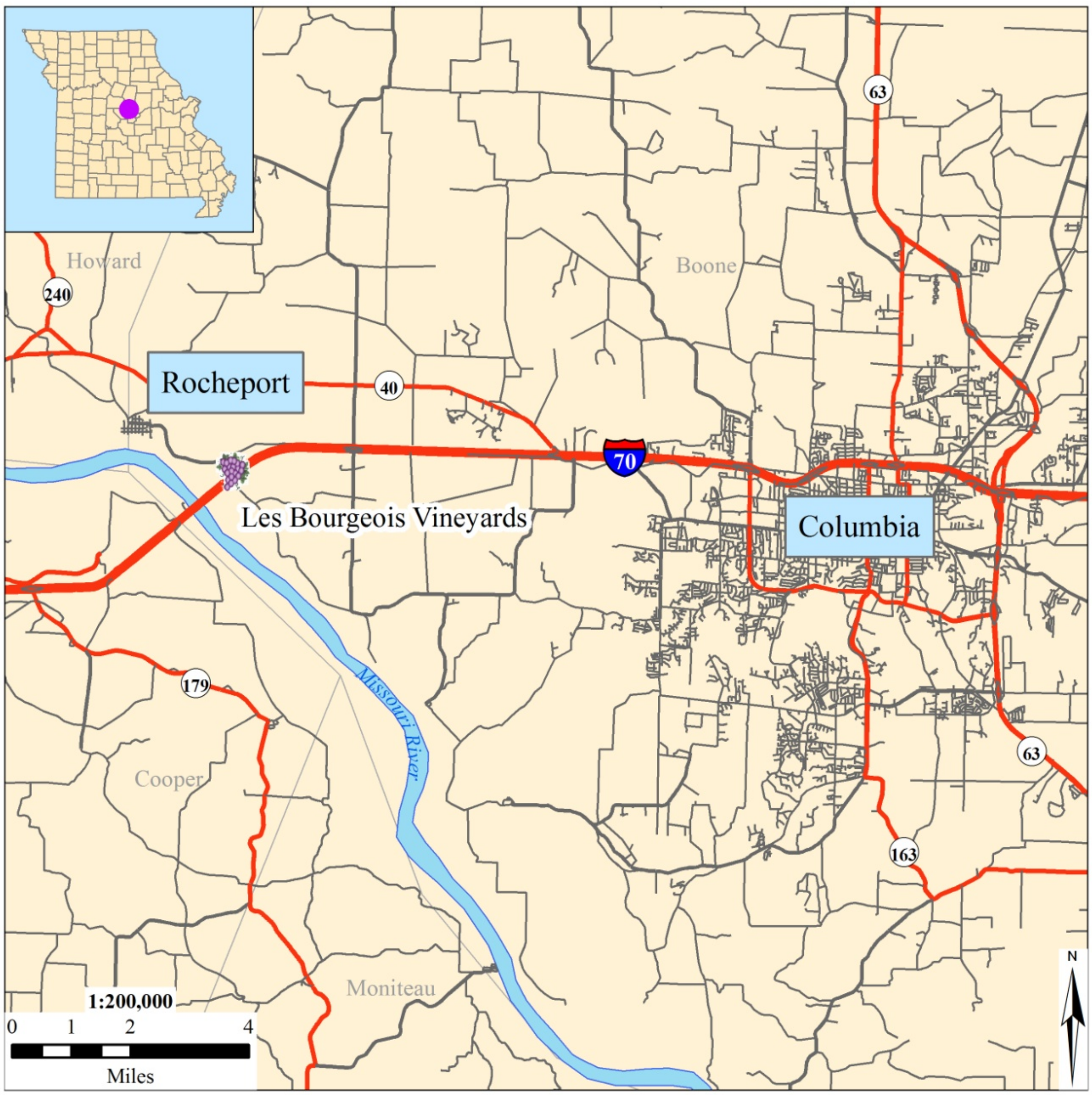


Figure 5. Les Bourgeois Vineyards area, near Columbia Missouri, in Rocheport situated along the Missouri River.

producing regions in Missouri where wineries are clustered, but an AVA is not delineated. Wineries continue to be established in certain areas where wine tourism is already prevalent. Entrepreneurs may find that understanding the *terroir* of these areas will help them start their vineyards and wineries. These areas include bluffs north of the Missouri River, including the cluster where Les Bourgeois Winery is located in Rocheport, around Kansas City and north of St. Louis. The current Ozark Mountain AVA includes parts of Oklahoma and Arkansas and there are groups of wineries in or near St. Francois and Ste. Genevieve Counties (Figure 6). The *terroir* analysis of the physical characteristics of vineyards in the St. Francois and Ste. Genevieve area was completed in order to justify delineation of a new AVA in that area and describe the area's *terroir*.

Bedrock geology and geomorphology

The geologic history of Missouri spans almost 1.5 billion years (Figure 7). In the Precambrian, granites, rhyolites, ignimbrites, and felsites formed in what are now known as the St. Francois Mountains (Middendorf, 2003). These rocks were part of an ancient caldera system and late-stage basalt and diabase dikes are also associated with the caldera (Anderson, 1979; Middendorf, 2003). During Cambrian time, approximately 540 Ma, this area was covered by shallow seas and physical weathering of older igneous rocks provided sediment for sedimentary rocks including the Lamotte Sandstone that lies atop the Precambrian igneous rocks. As sea-level rose, the Bonneterre Formation and Elvins Group (Davis Dolomite and Derby-Doerun Formation), Potosi, and Eminence dolomites were deposited. These rock units are predominantly carbonates with minor sandstones and shales (Middendorf, 2003).

The Ordovician in Missouri continued like the Cambrian and shallow seas deposited more carbonates with some sandstones and shales. These units are separated into four series, the Ibexian, Whiterockian, Mohawkian, and Cincinnatian (Middendorf, 2003). The Ibexian Series includes stratigraphic units such as the Gasconade Dolomite, Roubidoux Sandstone, Jefferson City, Cotter, and Powell dolomites, and Smithville

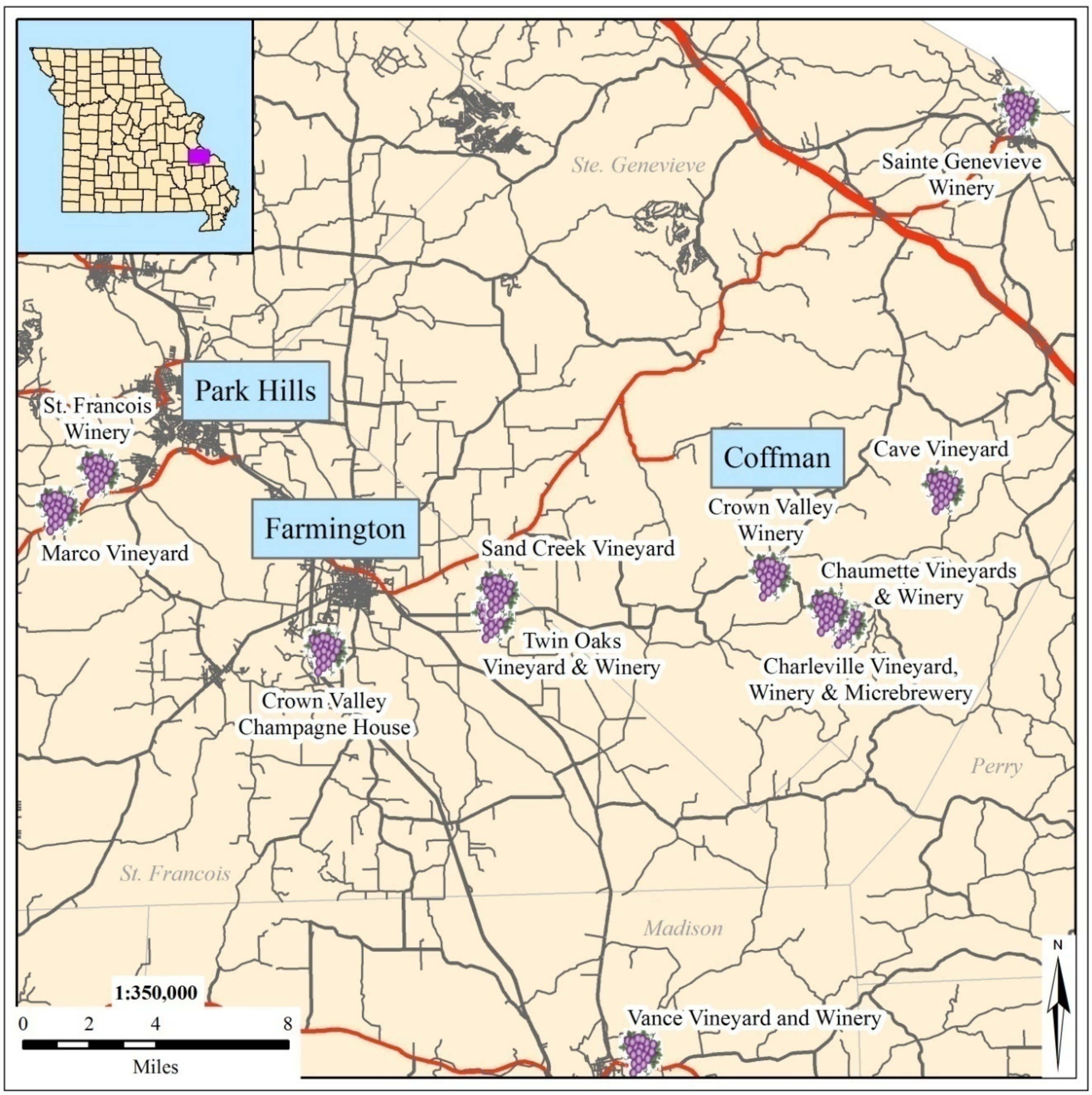


Figure 6. The wineries in St. Francois and Ste. Genevieve counties clustered near the cities of Park Hills and Farmington and rural area of Coffman in the St. Francois Mountains.

Formation. The Everton Formation and St. Peter Sandstone comprise the Whiterockian Series. Overlying the St. Peter Sandstone are upper Ordovician strata that include the Dutchtown, Joachin dolomite, Plattin, and Decorah formations that make up the Mohawkian Series. The final Cincinnatian Series includes the Kimmswick Limestone, Cape Limestone, Moquoketa Group and Leemon Limestone (Middendorf, 2003).

The Silurian period is sparsely represented in Missouri but consists of carbonates with occasional sandstones and shales similar to the Ordovician and two series are named, the Wenlochian-Ludlovian and Lanoverian (Middendorf, 2003). The Devonian is wider spread and includes the Fortune Formation, Sylamore Sandstone, and Chattanooga Shale (Middendorf, 2003). Also, during Devonian time pipe-like ultramafic igneous rocks called diatremes were emplaced in the area now called the Avon Magmatic District in southeastern Missouri (Bridges, 2008). These diatremes may be associated with the proposed Hawn Caldera.

During the Mississippian, marine carbonates and minor siliciclastics were deposited over much of Missouri and are now separated into four different series. The Kinderhookian Series includes the Bachelor, Compton, and Northview formations that are cherty limestones topped by silty shale (Anderson, 1979; Middendorf, 2003). The Osagean Series include the Pierson, Reeds Spring, and Elsey formations, and the Burlington and Keokuk limestones. The Warsaw and Salem formations and St. Louis Limestone comprise the Meramecian Series and the Carterville Formation, Hindsville Limestone, Batesville and Fayetteville formations compose the final Chesterian Series (Middendorf, 2003).

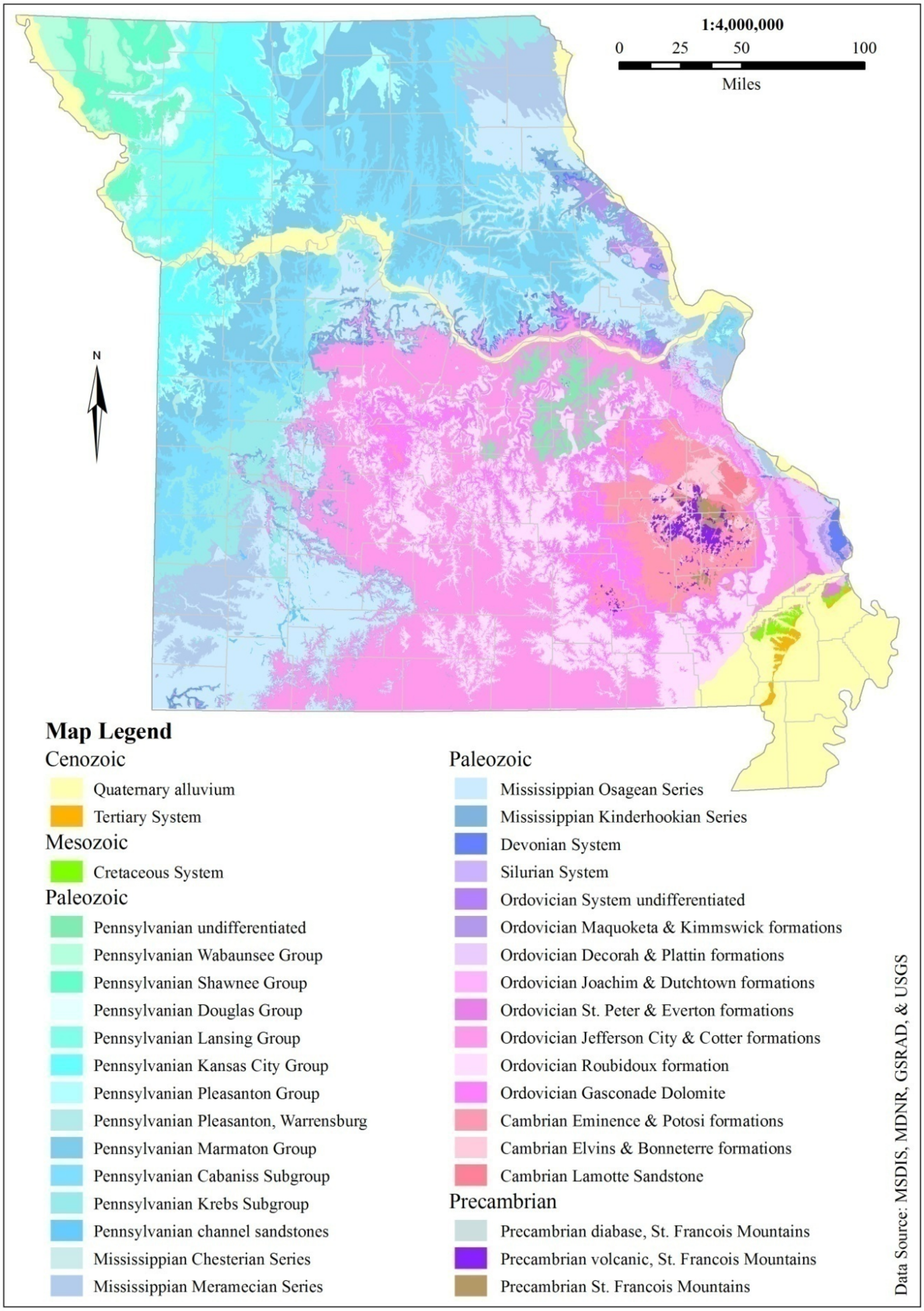


Figure 7. Geologic map of Missouri with legend (based on the Geologic Map of Missouri, Middendorf, 2003).

The Pennsylvanian System consists of many cyclothems producing five distinct successions that variously consist of shales, sandstones, clay, limestone, and coal. The Lower Series includes the Morrowan Stage and the restricted outcrop of Hale Sandstone. The Middle Series includes the Burgner and Riverton formations of the Atokan Stage, and the Cherokee group (Cabaniss and Krebs Subgroups) and Marmaton Group of the Desmoinesian Stage, which also includes the Channel Sandstones and undifferentiated units. The Upper Series includes the Missourian Stage which is made up of the Pleasanton, Kansas City, and Lansing groups. Finally, the Virgilian Stage includes the Douglas, Shawnee and Wabaunee Groups. These rock units are mostly exposed in west-central Missouri northward toward the Kansas City area. They also are the principal rocks in the shallow subsurface of northern Missouri. Permian, Triassic, and Jurassic rocks are missing in Missouri. The Cretaceous System, Gufian Series are composed of unconsolidated sand and clay and are exposed in the Bootheel area of Missouri known as Crowley's Ridge (Middendorf, 2003).

The Tertiary and Quaternary Systems include alluvial, glacial, and eolian deposits. The alluvial deposits are found in the Mississippi Embayment and are made up of Paleocene and younger clays, sand, and gravels. Along major rivers, both Quaternary alluvial and eolian deposits formed. The eolian deposits consist of windblown clays and silt known as loess (Anderson 1979; Middendorf, 2003). Loess is the parent material for many of the silt loam soil types found along the Missouri River. Till and gravels from the glaciations are found only in the northern part of Missouri with a few glacial erratics found south of the Missouri River (Middendorf, 2005). As the older bedrock, Tertiary unconsolidated deposits, and Quaternary deposits weather, residuum forms, consisting of clay and chert fragments, which becomes the parent for the soil (Minor, 1995).

The geomorphology of Missouri is largely based on the weathering characteristics of geologic units and their resistance to erosion. According to the Missouri Department of Conservation (1994), physiographic regions are "broad land groupings based on the physical features of the landscape". Physiography is geography that is created by the phenomena of the earth's surface. These phenomena include physical properties, natural features, structure, climate, and even the flora and fauna of a region. Physiographic maps of Missouri are partly based on the predominant geology and the topography that derived from eroding it over time (Figure 8).

Clearly the Mississippi Alluvial Basin is defined by the Cretaceous System, Tertiary System, and Quaternary alluvium that make up the Missouri Bootheel. The Bootheel is the northern most portion of the Mississippi Embayment. The Ozark Highlands physiographic region is defined by the Precambrian, Cambrian, Ordovician, and Mississippian Systems during the uplift that created the St. Francois Mountains. In general, the Osage Plains and Central Dissected Till Plains are located where Pennsylvanian Group bedrock predominates. The surficial sediments that overly the Pennsylvanian rocks in the northern portion of Missouri are covered by glacial deposits, (glacial till and loess) from the last Ice Age. Glacial till is a composed of unstratified drift including clay, silt, sand, gravel, and boulders (Bates and Jackson, 1984). Loess is silt-sized wind-blown sediment created by the grinding power of glaciers during the Pleistocene age. This sediment is usually homogenous, poorly stratified, porous, and

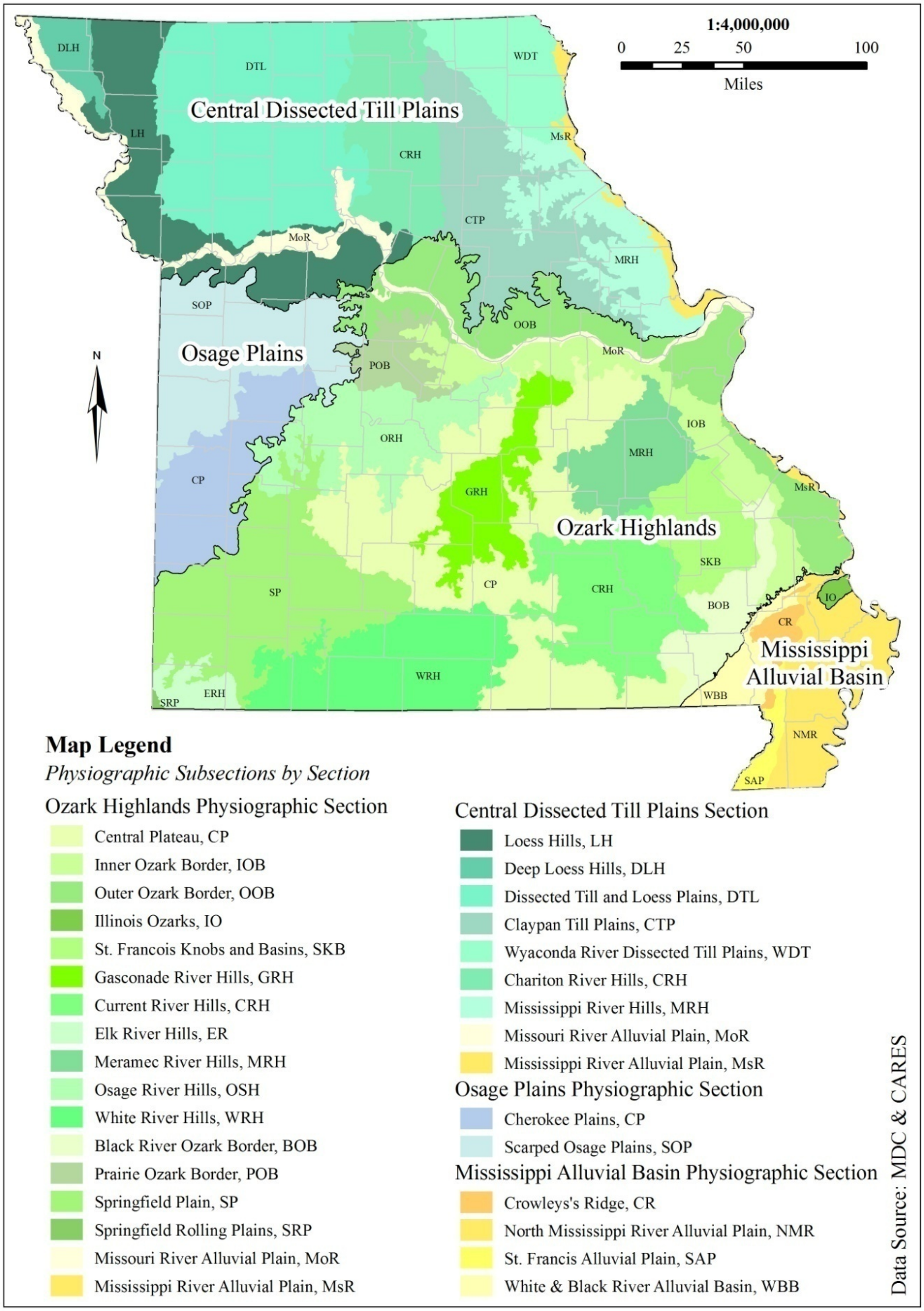


Figure 8. Physiographic map of Missouri separated into sections and subsections.

friable but can be exposed in steep vertical faces because of its rude vertical parting (Bates and Jackson, 1984).

Areas of interest to this study are located in the Outer Ozark Border and Inner Ozark Border along the Missouri River where the Hermann and Augusta AVAs and the Rocheport area are located and in the St. Francois Knobs and Basins and Black River Ozark Border where the wineries are clustered in Ste. Genevieve and St. Francois Counties (Figure 8). The Hermann AVA has Ordovician Jefferson City and Cotter dolomites, St. Peter and Everton formations, Pennsylvanian undifferentiated and Quaternary alluvium as bedrock while the Augusta AVA includes undifferentiated Ordovician System, and Pennsylvanian Cabaniss Subgroup as well. The Rocheport area includes the Mississippian Osagean and Pennsylvanian Cabaniss Subgroup bedrock units. Ste. Genevieve and St. Francois counties have many more bedrock types that include Precambrian, Cambrian, Ordovician, Silurian, Devonian, and Mississippian units. Also included in this area are 75 to 80 Devonian diatremes, ultramafic volcanic breccias pipes, that are located on the border of the two counties intruding the Ordovician Lamotte Sandstone, Elvins Group (Davis Dolomite and Derby-Doerun Formation), and Bonneterre Formation, and Eminence and Potosi dolomites (Middendorf, 2003; Bridges, 2008).

For comparison, the most notable wines made in France are grown from vines planted on an array of geological features (Seguin, 1986). The quality wines are grown on bedrock types including schists, chalk, limestone, marl, and sandstone. Most of these contain various amounts of calcium carbonate material. Other popular bedrock includes clay/shales, granite, and porphyry (Seguin, 1986). Quaternary alluvial gravels are also prominent parent materials particularly in the Bordeaux Region (Pomeral, 1989). In Oregon, the Umpqua Valley AVA is underlain by a mélange of igneous and metamorphic rock types that are part of the Klamath Mountain accreted terrane and the Coastal Range sedimentary and volcanic rocks (Jones et al., 2004). The geology is different in many wine regions across the world, and the best geology is impossible to define. It is prevalent to know the geology, and how it contributes to the available nutrients and water capacity in the soil when considering the placement of vineyards in a certain region but it usually will not have a determinant affect on the wine itself (Maltman, 2003).

Soils

The distribution of soils in Missouri has been mapped by the U.S. Department of Agriculture, Natural Resources Conservation Service (Figure 9) (Young et al., 2001). Soil types vary greatly across the state and many consider soil to be the connection between deep bedrock and the plants and animals that live on the surface. Leaching and bedrock weathering below and at the surface contribute to the mineral composition and structure of the overlying soil, which in turn controls water capacity and plant nutrient uptake (Singer, 2005). The main soil types on which vineyards are planted are described below using the official soil series descriptions. It should be noted that soil map units have variation within the unit itself and small inclusions are not described to keep the maps from becoming too complicated. There are over 500 different soil series already described in Missouri and only a few are used for viticulture in the study areas.

The principal soil type associated with viticulture in the Augusta AVA, Hermann AVA, and Rocheport area is the Menfro silt loam. This is the State soil of Missouri and is

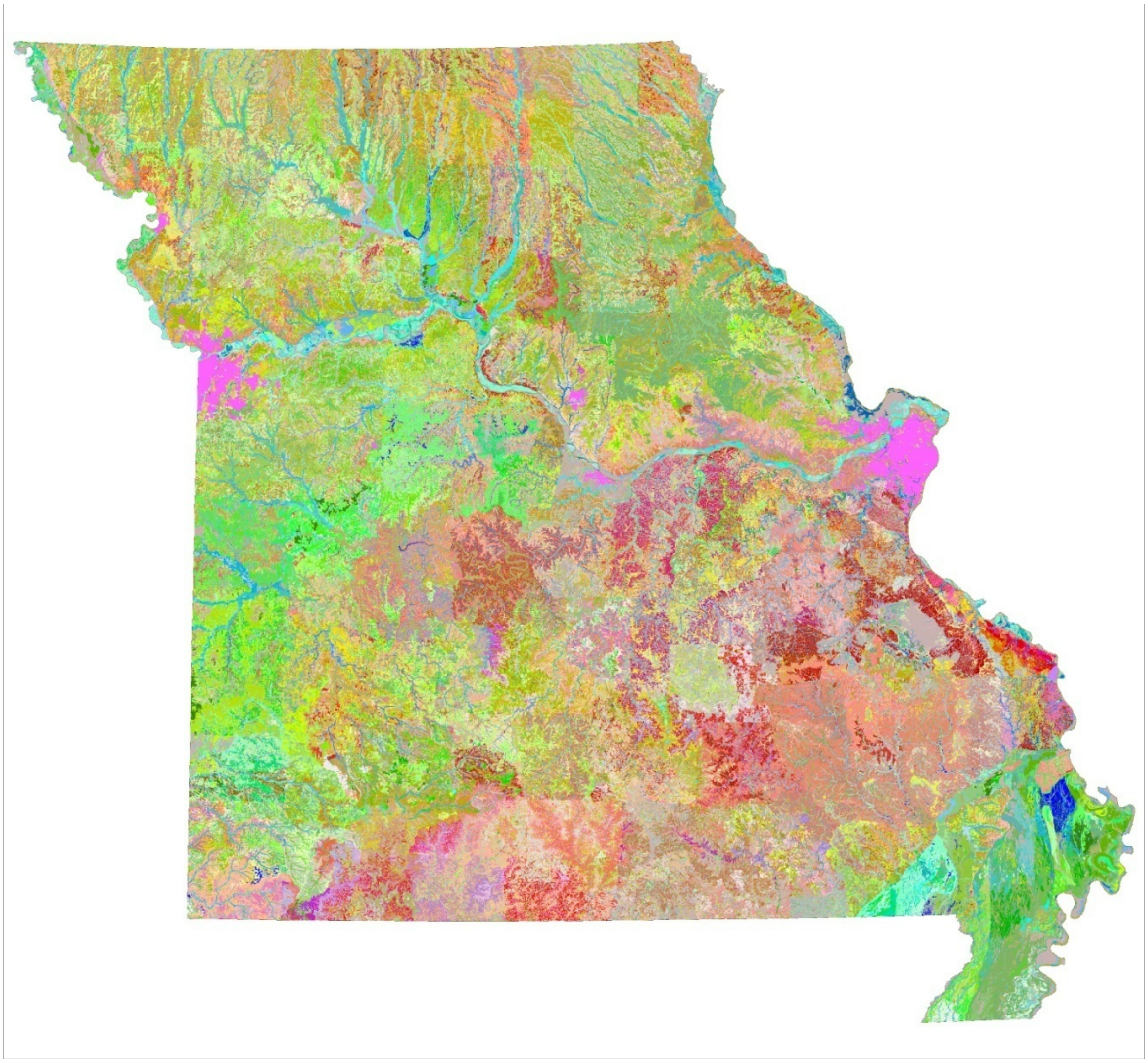


Figure 9. This soils map, created by the USDS - Natural Resources Conservation Service (NRCS) was provided by the Center for Applied Research and Environmental Systems (CARES) website. Notice the large amount of differing soil types across the state.

used for growing corn, soybeans, small grain, and forage crops, as wells as tobacco, grapes, vegetables, and fruits. There is about 780,000 acres of Menfro soils in Missouri that formed on loess deposits in upland ridge tops, backslopes, and benches near the Missouri River and major tributaries. The type location for the Menfro Series is Boone County, Missouri, near Rocheport in section 8, township 48 N, range 14 W. The taxonomic class of the Menfro is fine-silty, mixed, superactive, mesic Typic Hapludalfs

(USDA – NRCS, 2007). Another soil type that is common for Missouri vineyards is the Winfield silt loam, which has many of the same characteristics as the Menfro silt loam, but are only moderately well drained in comparison to well drained. The taxonomic class for the Winfield is fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs (USDA – NRCS, 2007).

In the Ste. Genevieve and St Francois counties wine region, the most commonly used soils are the Caneyville silt loam and the Fourche silt loam. The Caneyville series is a moderately deep, well-drained soil that occurs on ridges and hillsides on east-facing slopes. This soil is noted to occur on limestone residuum with a depth to bedrock at 34 inches. The taxonomic class of the Caneyville is fine, mixed, active, mesic Typic Hapludalfs (USDA – NRCS, 2007). The Fourche series is very deep and moderately well-drained soils that formed in loess and have a residuum from dolomite or limestone. They are usually found on upland side slopes and ridges at an elevation around 920 feet. The taxonomic class is fine-silty, mixed, active, mesic Glossaquic Paleudalfs (USDA – NRCS, 2007).

Silt loam refers to a soil with less than 27% clay (montmorillonite and illite), between 12 and 50% sand, and 50% or more silt. The Menfro series are dark brown (10YR 3/3) in the A-horizon, have a moderate to fine granular structure, and are very friable. The eluviation horizon (E) is dark brown in color (10YR 4/3), platy or subangular blocky structure and moderately acidic. The B-horizon has many sub-layers and is up to 68 inches deep. It is dark yellowish brown to dark brown in color, moderate to strong subangular blocky texture, and slightly acidic. The C-horizon is a dark brown silt loam, has fine mottles and is friable and slightly acid as well (Minor, 1995; USDA - NRCS, 2007).

The Winfield series consists of a brown (10YR 4/3) to pale brown (10YR 6/3) moderate fine granular structure in the Ap-horizon. The E-horizon is brown in color (10YR 4/3) and has a weak medium subangular blocky structure. There are five B-horizons in the Winfield including a transition horizon (BE). These horizons have properties of translocation and gleying and range in color from dark yellowish brown (10YR 4/4) in the BE to yellowish brown (10YR 5/4 or 10YR 5/6) in the Bt-horizons to light brownish gray (10YR 6/2) and gray (10YR 6/1) in the Btg-horizons. The final C-horizon is also gleyed and a gray (10YR 6/1) silt loam, is massive and friable with some iron and manganese accumulations (USDA – NRCS, 2007).

The Caneyville series has an organic leaf litter horizon (Oi) and a dark grayish brown (10YR 4/2) silt loam, with moderate fine to medium granular structure. The E-horizon is yellowish brown (10YR 5/4) with weak medium subangular blocky structure. There are two B-horizons, both with translocated clays and are yellowish red (5YR 4/6) and strong brown (7.5YR 5/6) in color. The upper Bt-horizon has moderate fine angular blocky structure. The lower Bt-horizon has prominent mottles and a moderate fine and medium angular blocky structure with few manganese stains on the faces of peds. The bedrock is at 34 inches and is light gray limestone (USDA – NRCS, 2007).

Finally, the Fourche series, the second most used in the St. Francois and Ste. Genevieve area, consists of a brown (10YR 4/3) silt loam Ap-horizon with a moderate fine granular structure. The next horizon is the Bt-horizon with a yellowish brown (10YR 5/4 color and a weak fine and very fine subangular blocky structure and some iron and manganese accumulation. The second Bt-horizon is brown (7.5YR 5/4) silty clay loam with the same structure and accumulations but also includes concretions. There are three more Bt-horizons that range in color from yellowish red (5YR 4/6) to strong brown (7.5YR 5/6). There are accumulations and concretions and different structures including a moderate fine and medium prismatic structure parting to moderate medium subangular blocky. At 80 inches you reach the dolomite bedrock that is the R-horizon (residuum horizon). The type location for this soil is St. Francois County, Missouri, one mile north of Farmington in section 25, township 36 N, range 5 E (USDA – NRCS, 2007). The other soil types mentioned later can be found on the USDA – NRCS Official Series Descriptions website.

CHAPTER 3 - METHODS

Aerial photography interpretation

The regions of interest in this study are the Augusta and Hermann AVAs, the Rocheport area, situated along the Missouri River, and the St. Francois and Ste. Genevieve counties. To be able to compare vineyards located within and excluded by the boundary, the official boundaries for the AVAs had to be drawn and stored as a shapefile. Knowing the precise locations of the AVAs helps to accurately gather the rest of the data needed for this project. Digital Raster Graphics (DRGs) of the approved 7.5 minute and 1° x 2° quadrangles were obtained and the TTB (2007) boundary descriptions used to create the AVA boundary shapefile (Appendix A). The boundaries are based on county and township lines, railroad tracks, rivers and streams, roads, and even power lines (TTB, 2007).

Photography interpretation requires an understanding of the anthropogenic environment, biology, and geology (Paine, 2003). The precise location of vineyards is important in the full extent of this work on the terroir of Missouri (Barnard and Evans, 2008b). A preliminary step in this project is to identify vineyards in Missouri and pinpoint their precise locations in relation to the wineries. Aerial photography interpretation includes using vineyard size, shape, texture, color, pattern, orientation, and location association to identify objects. Most vineyards are 1 to 5 acres in size so images were viewed at a scale of 1:3000. The vineyards were discernable because they are green in color, usually rectangular in shape, and have a distinct row pattern creating a unique texture. This texture is more widely spaced than row crops like corn. They are similar to orchards, but an orchard trees are discrete and rows in a vineyard are continuous (Figure 10).

In order to locate the vineyards in Missouri, aerial photography provided by the National Agricultural Imagery Program (NAIP) from the United States Department of

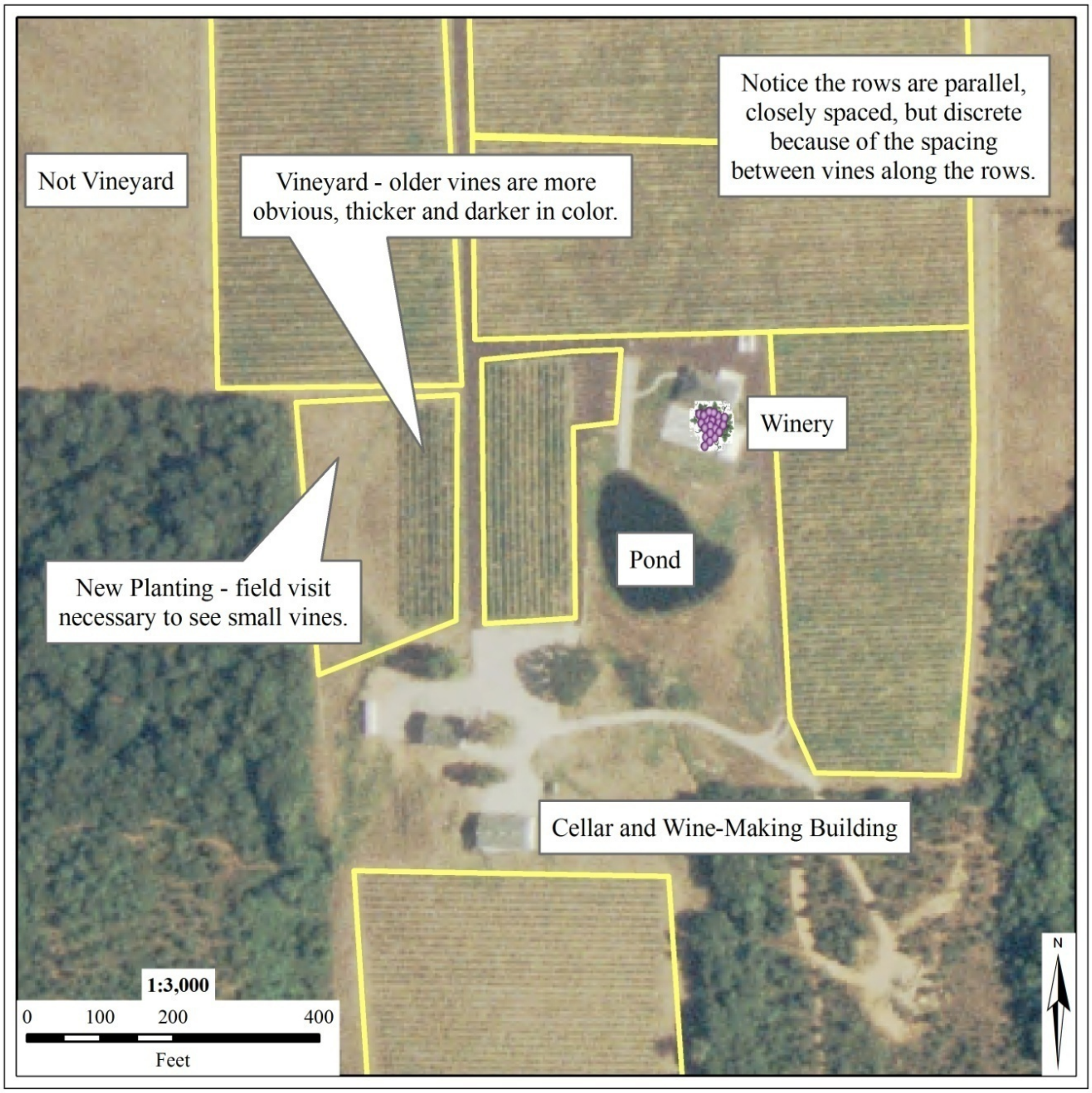


Figure 10. Aerial photography interpretation of vineyards and Twin Oaks Vineyard and Winery in Missouri. Row direction can also be determined from this photography and vineyard polygons are used to accurately calculate acreage under vine.

Agriculture (USDA) found on the Missouri Spatial Data Information Service (MSDIS) website were used. This program is set up to acquire imagery during the agriculture growing seasons. These images show the vines with foliage so that they are easy to identify. The aerial photography used is a compressed County mosaic (CCM) made of natural color positive image tiles. Each tile is 3.75 x 3.75 minutes (latitude and longitude) with a 300 meter buffer on all four sides. The resolution of this photography is 1m. The aerial photography was used to find the vineyards for the Augusta and Hermann AVA areas, the Rocheport area, and St. Francois and Ste. Genevieve counties.

Accuracy assessment was completed using an error matrix on the vineyard location data. The total number in the matrix is the total number of vineyards that were found and analyzed in this study. The overall accuracy is calculated by adding up all the vineyards that were correctly identified and dividing by the total number of vineyards. The "user's accuracy" can also be calculated by dividing the vineyards that were correctly identified using the aerial photography by the total number of vineyards classified from the aerial photography. The "producer's accuracy" gives the omission error, where vineyards were not classified as vineyards from the aerial photography (Congalton, 1991). This is calculated by dividing the number of correctly identified vineyards by the total number of actual vineyards in the area in and around the AVA and in St. Francois and Ste. Genevieve counties (Table 1). Because there was an increase in accuracy over time, from the first study area to the last study area, the overall project accuracy was also calculated.

Table 1. Accuracy of finding vineyards in and around Missouri AVAs and St. Francois and Ste. Genevieve Counties area using aerial photography interpretation techniques at a scale of 1:3000. Rocheport identifications were 100% and a table was not created.

Hermann Accuracy Assessment				Overall Accuracy	18.68%
		Ground Truth			
		Vineyard	Not	Total Classified	User's Accuracy
Classified	Vineyard	17	35	52	32.69%
	Not Vineyard	39	0	39	
	Total Truth	56	35	91	
	Producer's Accuracy	30.36%			
Augusta Accuracy Assessment				**Overall Accuracy**	**56.79%**
		Ground Truth			
		Vineyard	Not Vineyard	Total Classified	User's Accuracy
Classified	Vineyard	79.5	53	132.5	60.00%
	Not Vineyard	7.5	0	7.5	
	Total Truth	87	53	140	
	Producer's Accuracy	91.38%			
Ste Genevieve Accuracy Assessment				**Overall Accuracy**	**100.00%**
		Ground Truth			
		Vineyard	Not	Total Classified	User's Accuracy
Classified	Vineyard	46	0	46	100.00%
	Not Vineyard	18	0	18	
	Total Truth	64	0	46	
	Producer's Accuracy	71.88%			

Table 1.Continued. Overall project accuracy of finding vineyards using aerial photography interpretation techniques at a scale of 1:3000.

Project Accuracy Assessment				Overall Accuracy	48.31%
		Ground Truth			
		Vineyard	Not	Total Classified	User's Accuracy
Classified	Vineyard	142.5	88	230.5	61.82%
	Not Vineyard	64.5	0	64.5	
	Total Truth	207	88	295	
	Producer's Accuracy	68.84%			

Raster data

The Environmental Systems Research Institute (ESRI) GIS suite of applications, Arc Map 9.3, was used to create shapefiles of the vineyards in each research area using the aerial photography. A new polygon data layer was created in order to outline the shapes of the separate vineyards. By using a GIS other attributes of the vineyards could be easily added to each polygon in the shapefile for each area. For example, the orientation of the rows and the winery that owns the vineyard was added. The area under each polygon was calculated and then the total acreage under vine for each winery and the area as a whole, including the mean, mode, median, and standard deviation of the acreage under vine for each study region was found using the statistics calculator (Barnard and Evans, 2008a).

After this step, field work was necessary to assess the accuracy of the image interpretation. Trips to the field were done during the spring and fall of 2008 and winter and spring of 2009. Field maps were created of the vineyard polygons and a road layer was added over the aerial photography. Each vineyard was located, the slope measured, and the aspect, trellising technique and grape varietal noted if the information was available (Figure 11). Some answers to questions and pertinent information were added to the vineyard shapefile from talking to the vineyard owners, vineyard managers, or employees.

Digital Elevation Models (DEMs) available on the MSDIS website and provided by United States Geological Survey (USGS) are used to retrieve the other physical attributes that pertain to the *terroir* characteristics. For each vineyard polygon the data for

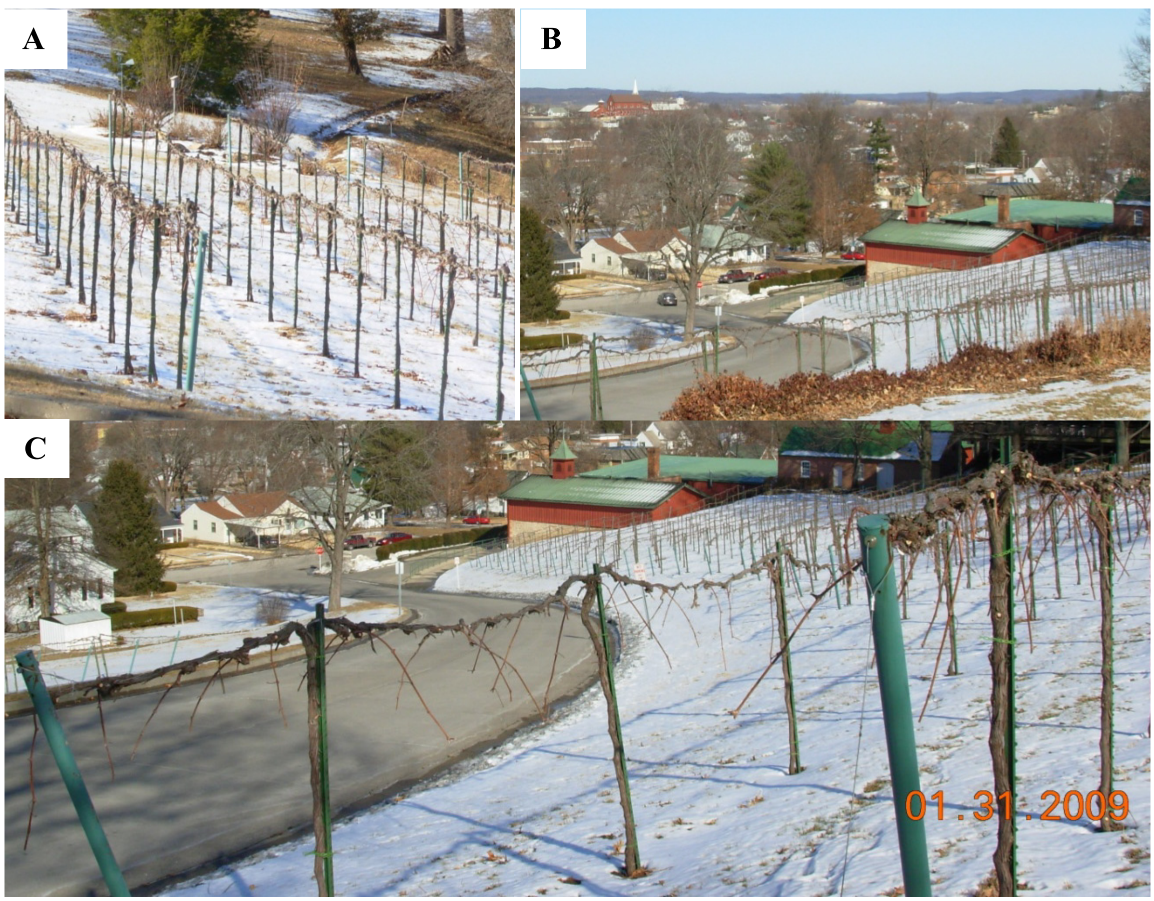


Figure 11. Field work in Hermann, MO with A) vineyard row direction is EW and aspect is north, slope equal to 11°; B) view of another vineyard across the street view from the Stone Hill Tasting Room looking northeast; C) vineyard trellis is a bilateral high-cordon with hanging canes. These vineyards are Norton/Cynthiana, the Missouri State grape.

elevation, slope, aspect, and curvature are extracted from the 10-meter DEMs. The tools used in Arc Map include the data management toolbox for clipping and mosaicking the county-sized aerial photography and the DEM images. The spatial analyst surface tools are used for creating the slope, aspect and curvature surfaces. The DEM surface is manipulated to make new slope, aspect, and curvature surfaces. Instead of elevation, each cell contains data for its slope calculated by the maximum rate of change of value compared to its neighbors. The aspect algorithm calculates the slope and, based on certain rules, the direction of slope is determined for each cell. This surface is made in both slope degree and percent rise (Appendix B).

The zonal statistics to table tool in the spatial analyst toolbox is used to extract the pertinent data and data joins are used to add all the data to the vineyard shapefile for each area. Using the zonal statistics to table tool, the vineyard shapefile was then used to extract the data from each pixel within the polygon boundary and calculate the average value for the polygon using all of the pixels. By doing this the average elevation and slope are added to the attributes of each vineyard. By using the join tool, this average is added to the vineyard shapefile (Figure 12). These final vector files, raster data sets, and information tables are then added to the geodatabase for each area to be available for future projects. The vineyard shapefile is also placed on soil and bedrock geology maps downloaded from the Center for Applied Research and Environmental Systems (CARES) map room that were converted from vector to raster format in order to extract the geology and soils data and add it to the geodatabase.

The aspect values are cyclic and a special problem occurs when averaging two directions. For example, averaging 359° and 1° yields 180° in the application, so the average of two directions close to north can appear to be due south. Therefore, the aspect values in the aspect surface were reclassified in order to obtain useful results. The reclassification, using the spatial analyst toolbox, converted the azimuthal values for northern directions (316 to 45 degrees), eastern directions (46 to 135 degrees), southern direction (136 to 225 degrees) and western directions (226 to 315 degrees) to 1, 2, 3, and 4, respectively. The zonal statistics to table tool is again used to find the majority pixel value within each vineyard. Using the join tool, this majority pixel value was added to the vineyard shapefile. This still has its problems since the majority does not indicate the only aspect used for that vineyard.

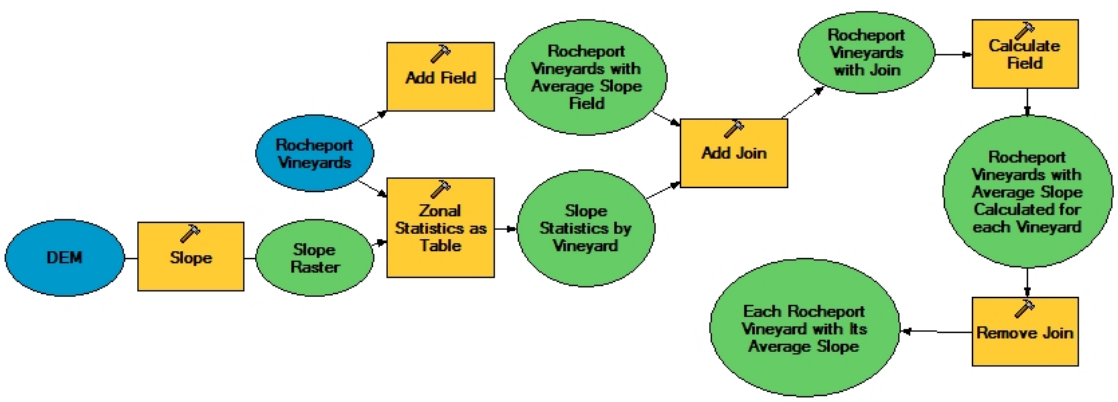


Figure12. Example model showing how each vineyard polygon receives its slope attribute from manipulating the DEM. The same procedure is used for elevation, aspect, curvature.

Curvature is calculated by taking the slope of the slope. Each cell uses a 3 x 3 window and a fourth-order polynomial to calculate the curvature of the surface at that cell. The curvature values are negative when the pixel is concave compared to its neighbors, zero when it is flat, and positive when it is convex. The values for the cells in this surface can vary from any negative to any positive number. For ease of finding the majority curvature for each vineyard, the curvature surface was also reclassified. In the reclassification, all negative values were given the value of -1, zero remained zero and, and all positive values were given the value of +1. The zonal statistics to table tool then was able to give the majority pixel value for each vineyard and a join is used to add this value to its field in the vineyard shapefile.

Vector data

In order to add the soil and bedrock geology type to the vineyard shapefile, the appropriate shapefiles were downloaded from the CARES website. The geology shapefile is a mixed scale map based off of the Middendorf's "Geologic Map of Missouri Sesquicentennial Edition" (2003) and was digitized in 2007 and provided by the Missouri Department of Natural Resources (MoDNR) Division of Geology and Land Survey. The soils data was also provided by the CARES website from the USDA – Soil Survey Geographic (SSURGO) Data Base. The data was originated by the NRCS at a scale of 1:24,000 and uploaded in 2007. The soils shapefile separates each soil type by name followed by a comma and the slope range in percent, another comma and any notes about flooding. This creates a soils map that is more confusing than necessary so each soil type is merged together based on the name, deleting the information on slope and flooding after the comma. This left only the name and soil type (Menfro silt loam, for example) as the identifier for each polygon.

These shapefiles are presented in vector data format in the maps but were converted to raster format with a cell size of 10 meters using the maximum area cell assignment, meaning the feature within the cell with largest area will control the attribute assigned to that cell. The bedrock and soil types are given a number code after conversion into a raster. Then the zonal statistics table is produced using the vineyard shapefile as the zones. The result is a majority code for each vineyard. A join must be performed in order to first add the majority number code to the vineyard shapefile, then the actual majority bedrock or soil type can then be added with a second join. A third join with the original vector file will allow for the other data related to geology to be added. For example, this includes the age, era, system, geologic name, and general bedrock type from the original geology shapefile. The percentage of vineyards on each soil type is then calculated by hand from the attribute table, and the distribution of values was analyzed by reviewing the histograms produced by the statistics calculator (Appendix B).

Vineyard cluster analysis

After finding all the vineyards in my study areas and creating the vineyard plot shapefile, cluster analysis was performed using the Moran's I tool, which is used to evaluate spatial autocorrelation (O'Sullivan and Unwin, 2003). The first law of geography is that close objects are more related than far objects, resulting in positive spatial autocorrelation for many things on earth including vineyards and wineries. This phenomenon is noticeable when reviewing winery locations in any state, as a winery owner will tend to start a business where wineries already exist. This tool established if points are clustered, dispersed, or random in space based on the attribute values that the points have. The null hypothesis used is that there is no spatial relationship between the locations of vineyard and their values for elevation, slope, aspect, curvature, soil, and bedrock types. Moran's I was calculated using these attribute values and the deviation of the attribute values from the mean and the spatial weight between the feature values using the equation:

$$I = \frac{n}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

(O'Sullivan and Unwin, 2003)

The values given are between positive and negative 1 with +1 being clustered and having positive autocorrelation and -1 being dispersed and having negative autocorrelation. The z-score provides a value that helps to determine if the null hypothesis can be rejected based on statistical significance and how strongly you can reject that hypothesis is determined by the largess of the z-score (O'Sullivan and Unwin, 2003). By using the mean and standard deviation you can determine the values for the z-score that tell you the points and their attribute values are randomly dispersed or not. If the z-score is outside the values based on your confidence interval you can reject he null hypothesis and determine that further explanation for the spatial relationship between the points should be found (O'Sullivan and Unwin, 2003).

Winery cluster analysis

The locations of wineries in Missouri were first plotted in Arc Map using the 2000 Missouri Department of Transportation (MoDOT) roads shapefile found on MSDIS. The address given on each winery's website and driving directions were used to verify the plotted locations of the wineries. In order to create a service area for each winery, a network dataset was created using the roads shapefile. The attribute table for the wineries was given two fields, one for the region it belongs to according to the experts on the Missouri wine website and one for the number of notable wines that it sells as an attractiveness value, also from the Missouri wine website (Ruess and Kleinschmidt, 2009). The address, phone, and website for each winery was also added the attribute table for future use.

Cluster analysis was completed using average nearest neighbor script tool that is found in the analyzing patterns tools in the spatial statistics toolbox. This function uses mean nearest-neighbor distance to describe whether there is clustering or not. If the value in this case is less than 1 the objects are clustered, if the value is greater than 1 the objects are more evenly spaced (O'Sullivan and Unwin, 2003). The index is calculated by the observed distance divided by the expected distance which is based on the mean and standard deviation of the distances between wineries. The distance is calculated using Pythagoras's theorem and the mean nearest neighbor distance:

$$d(s_i s_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

(O'Sullivan and Unwin, 2003)

$$\bar{d}_{min} = \frac{\sum_{i=1}^{n} d_{min}(s_i)}{n}$$

(O'Sullivan and Unwin, 2003)

The measuring geographic distributions tools in the spatial statistics toolbox were also used to assess the winery spatial distribution. The mean center, standard distance, and central features tools were all found and calculated. A directional distribution ellipse was also made. These same statistics were calculated using the number of notable wines as a weight of attractiveness for each winery, which is based on the number of awards they have received. Mean center is the central location based on the spatial locations of all the wineries. Standard distance, using one standard deviation, creates and circle in which 68% of all the other wineries occur.

Central feature tool finds the winery that is located in the center of all the wineries of Missouri. By using a weight, these values can shift toward the winery locations that have the most notable wines. The density tools in the spatial analyst toolbox create raster layers showing the areas where there are more wineries based on the area. A point density and kernel density were both created. The kernel density map was used for the analysis because the point density map was more generalized and did not show the cluster densities as well as the kernel density map. The kernel density was also created based on the number of notable wines for each winery in order to see the clusters and their relative densities based on the attractiveness weight of the wineries.

Finally, service areas for each winery were made based on the roads network created from the MoDOT roads shapefile. The network analyst was implemented and the set up included creating a cost attribute of drive distance based on the length of the line segments that made the road. These line segments were measured in meters so the service area was drawn with breaks in 5 kilometer increments. Other settings include generalized polygons with no trimming, overlapping polygons from different wineries, drive distance calculated away from the winery, with u-turns allowed nowhere.

Suitability map data

Two data types can be used to create suitability maps. These are the raster format and the vector format. In order to use either, all the data has to be in that format. For this study, the raster method was primarily used. The *terroir* analysis and the physical characteristics of the vineyards are calculated using the elevation, slope, aspect, curvature, geology and soil surfaces. The range used is the minimum and maximum values found for each area and is used for numerical values like elevation, and slope. The ranges are then the "best value" for these physical characteristics for vineyards in that area or AVA. The highest occurrence percentage of each possible aspect and curvature, after reclassification, is the "best value" for the aspect of the vineyards in each area. For non-numeric parameters like soil and geology, every soil and geology type used by current vineyards is considered "best values" for these physical characteristics. These "best values" are only based on the current locations of vineyard in each area and the data that is extracted remotely using a GIS (Appendix C).

The raster method requires all vector files to first be converted into raster data sets using the polygon to raster tool in the conversion tools to raster toolbox. Soil and bedrock geology types are given number codes, also used earlier to add this data to the vineyard shapefile. Map algebra from the spatial analyst toolbox is used to single out areas with the preferred "best values" based on the statistics from the vineyard shapefile using simple logical terminology (and/or). This creates several raster data sets with two values, 0 (not best) or 1 (best). Map algebra is then used again to combine every preferred area to create a map of locations consisting of all the preferred physical characteristics for vineyards in that area or AVA (Appendix D).

The Vector method uses the select, intersect, and dissolve tools from the analysis toolbox. First, the slope, aspect, and curvature layers must be re-classified in order to be able to convert the raster files into polygon shapefiles. The preferred “best values” are then selected from each new layer. The area with all preferred “best values” is found by intersecting all the layers for elevation, slope, aspect, curvature, geology, and soil and the boundaries are dissolved (Figure 13). This method was used but is not included since both methods essentially give the same results. For ease, the raster method was preferred. A possible addition to the creation of suitability maps would be a precise road network shapefile. This information is not available at the precision that is required for this project but may be added in the future since vineyards will not be planted on roads and this could decrease the potential acreage by a great deal. A land zoning shape file would help outline actual available agricultural land and decrease the potential acreage as well. In order to calculate the acreage available in each study area, the final potential raster files were converted to vector format.

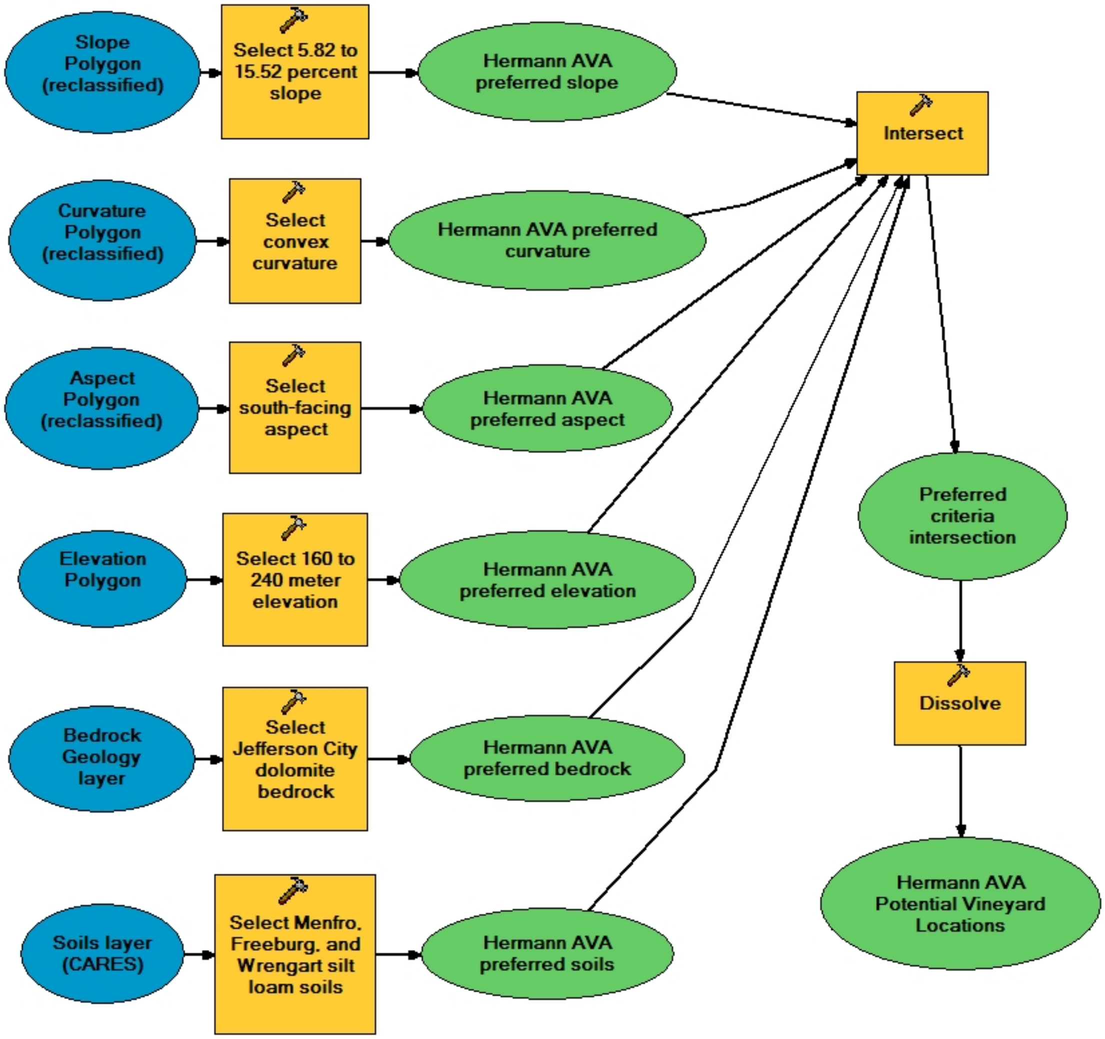


Figure 13. Flow chart using vector surfaces and the select and intersect tools from the Analysis toolbox. This model will find potential vineyard locations in the Hermann AVA using criteria based on the current vineyard locations.

CHAPTER 4 – RESULTS

Overview

The geodatabases for the Augusta AVA, Hermann AVA, Les Bourgeois Vineyards, and St. Francois and Ste. Genevieve counties contain the vineyards, wineries, and the AVA boundary shapefiles as well as the mosaicked DEMs, Digital Raster Graphics (DRGs) of topographic map images, and aerial photography used in this project. All intermediate raster and vector files used in the creation of the suitability maps are also included in the geodatabases. The winery shapefile contains the address and contact information attributes for future use in a query-based Missouri winery website. These geodatabases were used to store the information needed to evaluate vineyard placement create suitability maps.

The vineyard shapefile for each area contains the physical characteristics of each vineyard in each study area(Appendix B). Most information was obtained from the aerial photography, DEMs, and other maps created by the United States Geological Survey (USGS), Missouri Department of Natural Resources (MoDNR), Division of Geology and Land Survey (DGLS), and the Geological Survey Program (GSP) and provided by the Missouri Spatial Data Information Service (MSDIS) and the Center for Applied Research and Environmental Systems (CARES) websites. Ownership and varietal for each vineyard were added where available from field work and row orientation, slope, aspect, curvature, soil, and bedrock geology were obtained using remote sensing. The acreage under vine for each winery or for the AVA as a whole as well as other statistics is easily calculated from the vineyard shapefile (Appendix C).

Augusta AVA results

There are 65 vineyards in the Augusta AVA. These vineyards total 168.2 acres (68. ha) under vine. The largest tract is 9.9 acres (4.0 ha) and the smallest is approximately 0.2 acres (0.1 ha). Elevation ranges from 544.2 feet (165.9 m) to 670.0 feet (204.2 m) and the mean elevation is 598.2 ± 31.4 ft (182.3 ± 9.57 m). Values for slope range from 1° (0 percent rise or %) to 14.3° (25.5%); the average slope is 6.9° ± 2.8° (11.9 ± 5.0 %). Inside the AVA, the mostly used aspect that the majority of each vineyard faces is the south (52%). The eastern aspect is also used with 26% of the vineyards mostly facing that direction. Western and northern aspects are also used at 14% and 8% respectively. 69% of the vineyards are on convex topography, but 20 of the vineyards are mostly on concave surfaces (Figures 14-16).

Approximately 32% of the vineyards in the Augusta AVA have a southeastern row orientation, 30% east-west, 20% north-south, and 18% northeastern. The Menfro silt loam is the most common soil type that a majority of the vineyards are planted on. 75% are situated on this soil with only 9% on the Gatewood-Gasconade-Crider complex, and 6% on both the Holstein loam and Winfield silt loam, and 2% on both the Gasconade rock outcrops and Westerville silt loam. The only two bedrock geology types that are utilized are the Ordovician Jefferson City and Cotter dolomites and the St. Peter and Everton formations (Figures 14-16) (Appendix C).

The 26 vineyards in the area surrounding the Augusta AVA have many commonalities with the vineyards inside the AVA. The mean slope for these vineyards outside the AVA is 8.0° ± 3.9° (14.3 ± 7.6%) and the range in slope is 4.5° (7.99 %) to 23.9° (46.4 %). The range in elevation is 487.5 ft (148.6 m) to 640.2 ft (195.2 m), and the mean elevation is 562.6 ± 36.8 ft (171.5 ± 11.2 m). There are approximately 30 acres of

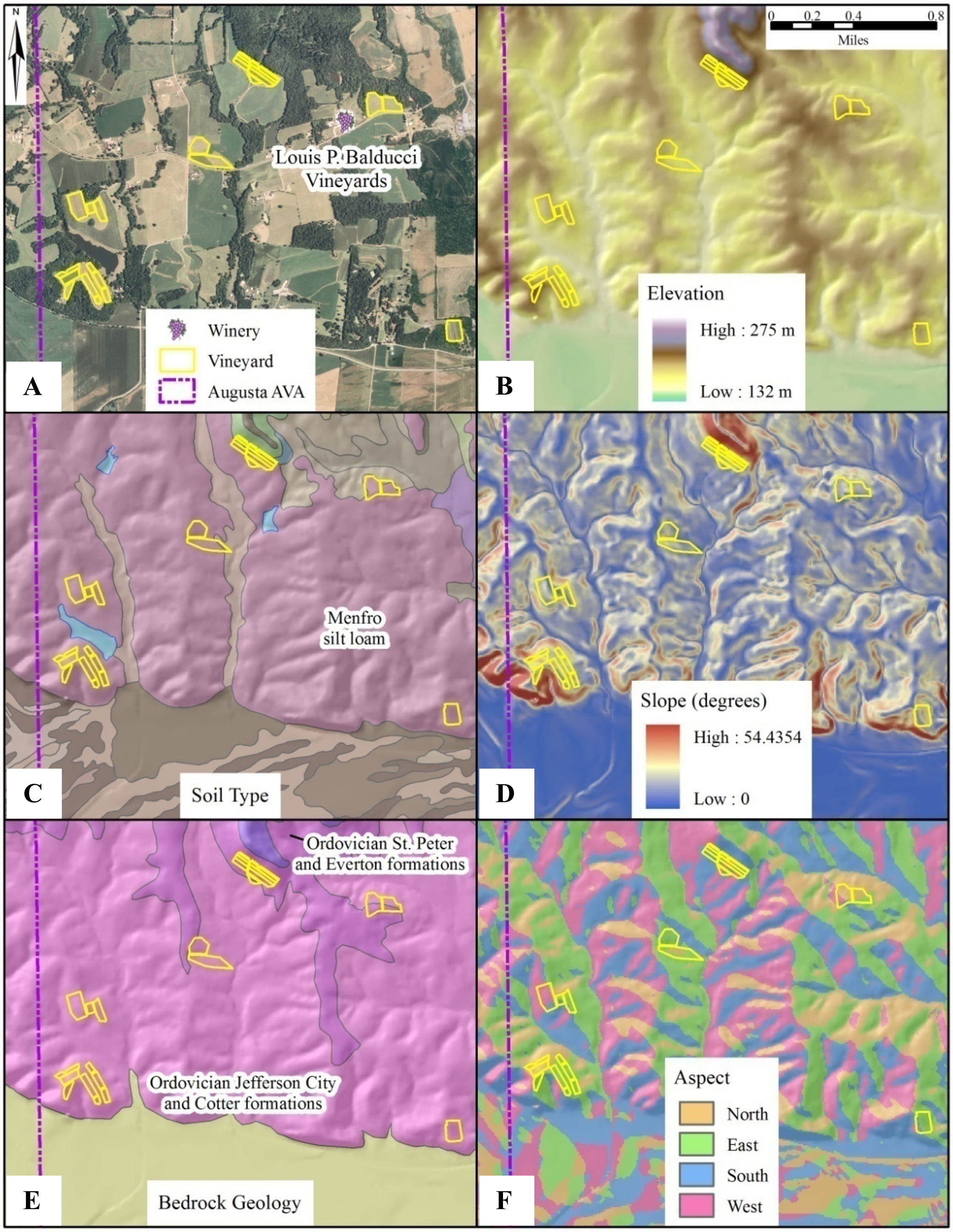


Figure 14. Northwestern portion of the Augusta AVA. Luis P. Balducci Vineyards and independently owned vineyards shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM.

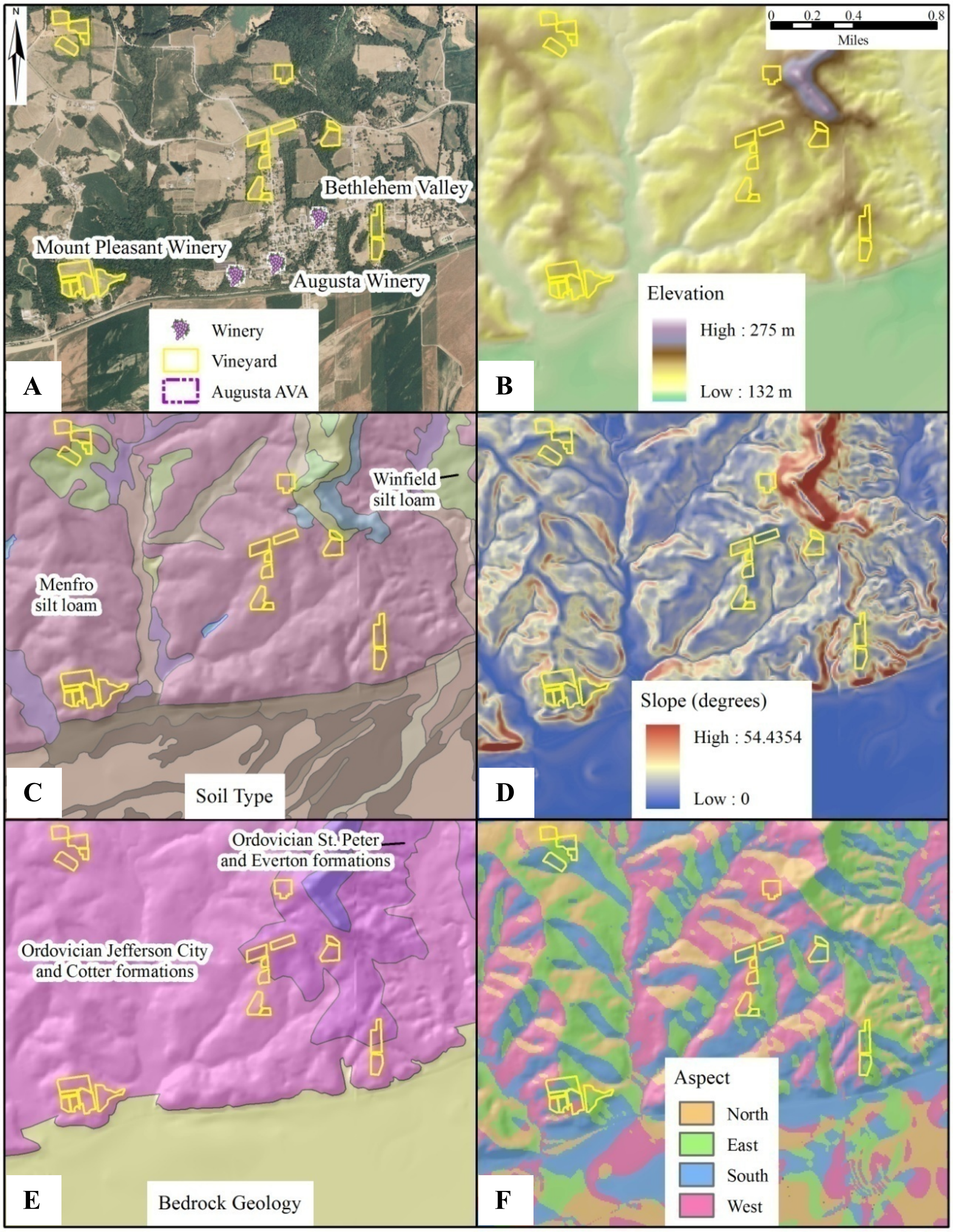


Figure 15. Central portion of the Augusta AVA. Mount Pleasant Winery, Augusta Winery, and Bethlehem Valley and independently owned vineyards shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM.

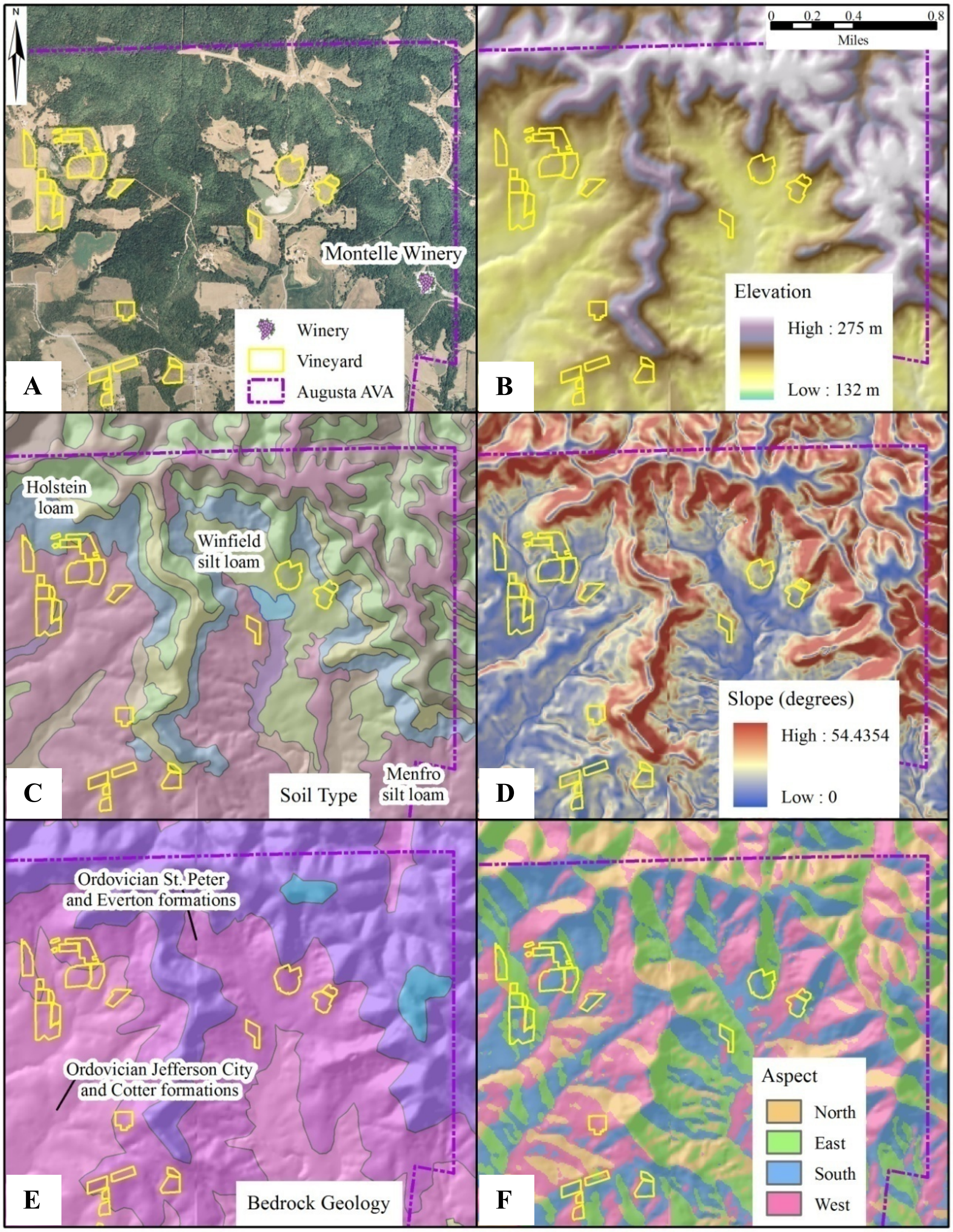


Figure 16. Eastern portion of the Augusta AVA. Montelle Winery and independently owned vineyards shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM.

vines within a short distance of the AVA boundary and 58% have eastern aspects (15 of the 26 vineyards) with only 5 (19%) facing north, 4 (15%) facing west, and 2 (8%) facing south. Approximately 77% of these vineyards are planted on convex surfaces and only 23% are on concave. North-south row orientations are most used at 46%; 27% have a southeastern row orientation, 23% have northeastern, and 4 % east-west. The only soil type that is used by these vineyards outside the AVA is the Menfro silt loam and the Ordovician Jefferson City and Cotter dolomites (69%) and Ordovician undifferentiated (27%) bedrock type. One vineyard is planted on Quaternary alluvium (Figure 17).

The vineyards inside and outside the Augusta AVA have very similar physical characteristics. These commonalities justify using the values from all 91 vineyards to create the suitability maps. Therefore, the suitability map for the Augusta AVA area was created from the ranges in elevation and slope, the two most used aspects, and all major soil and bedrock geology types used. The range for elevation is 487.6 ft (148.6 m) to 670.0 ft (204.2 m). The range for the slope is 1.1° (0 %) to 23.9° (46.4 %). Southern and eastern aspects were selected and the Menfro silt loam, Gatewood-Gasconade-Crider complex, Holstein, and Winfield soil types were used. The Ordovician Jefferson City and Cotter dolomites and the St. Peter and Everton formations were used as well. A legend for soil and geology map colors is found in Figure 18. Curvature was not used since many vineyards are partially plotted on both convex and concave topography. In this area there is potential for 16,836 acres of vines to be planted based on the best elevation, aspect, slope, soil and geology that are currently used for vineyards in the area (Figure 19).

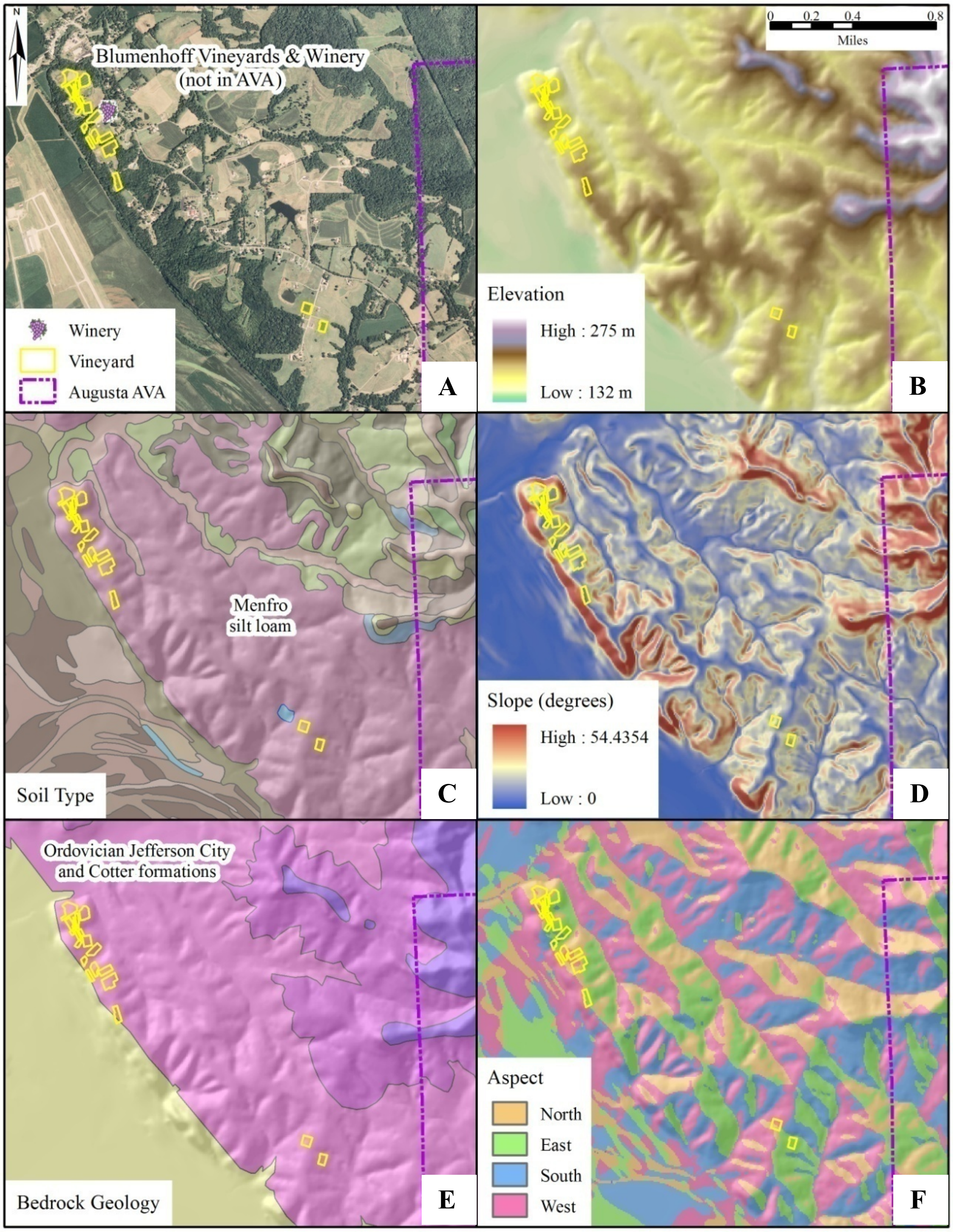


Figure 17. Bethlehem Vineyards & Winery outside of the Augusta AVA and independently owned vineyards shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM.

Augusta AVA
Soil Type Legend

- Water
- Cedargap silt loam
- Crider silt loam
- Dockery silt loam
- Gasconade-Rock outcrop complex
- Gatewood-Gasconade-Crider complex
- Goss gravelly silt loam
- Goss silt loam
- Holstein loam
- Menfro silt loam
- Menfro-Goss silt loams
- Sensabaugh silt loam
- Weller silt loam
- Westerville silt loam
- Winfield silt loam
- Winfield silty clay loam
- Arents
- Armster silt loam
- Auxvasse silt loam
- Blake silty clay loam
- Blake-Haynie-Waldron complex
- Blake-Waldron complex
- Chilhowie, Gasconade, and Crider soils
- Booker clay
- Calwoods silt loam
- Calwoods silty clay loam
- Carr fine sandy loam
- Cedargap gravelly silt loam
- Coland clay loam
- Deible silt loam
- Freeburg silt loam
- Gasconade channery silty clay loam
- Gatewood very gravelly silt loam
- Gladden silt loam
- Goss soils
- Goss very gravelly silt loam
- Hartville silt loam
- Hatton silt loam
- Haymond silt loam
- Haynie silt loam
- Haynie very fine sandy loam
- Haynie-Blake complex
- Haynie-Waldron complex
- Hodge loamy fine sand
- Hodge-Blake complex
- Hodge-Haynie complex
- Holstein-Rock outcrop complex
- Kennebec silt loam
- Keswick silt loam
- Lindley loam
- Marion silt loam
- Menfro-Gatewood complex
- Mexico silt loam
- Modale silt loam
- Moko-Rock outcrop complex
- Nodaway silt loam
- Putnam silt loam
- Racoon silt loam
- Tanglenook silty clay loam
- Twomile silt loam,
- Union silt loam
- Useful silt loam
- Useful-Gatewood complex
- Waldron silty clay
- Waldron-Booker silty clays
- Wrengart silt loam
- Pits or quarry

Augusta AVA
Bedrock Geology Legend

- Quaternary alluvium
- Pennsylvanian, undifferentiated
- Pennsylvanian, Cabaniss Subgroup
- Mississippian, Meramecian Series
- Mississippian, Osagean Series
- Mississippian, Kinderhookian Series
- Devonian System
- Ordovician System, undifferentiated
- Ordovician, Maquoketa and Kimmswick formations
- Ordovician, Decorah and Plattin formations
- Ordovician, Joachim and Dutchtown formations
- Ordovician, St. Peter and Everton formations
- Ordovician, Jefferson City and Cotter formations
- Ordovician, Roubidoux formation
- Ordovician, Gasconade Dolomite

Figure 18. Soil Type (soils in the vicinity of vineyards are given brighter colors) and Bedrock Geology legends for Figures 14-17.

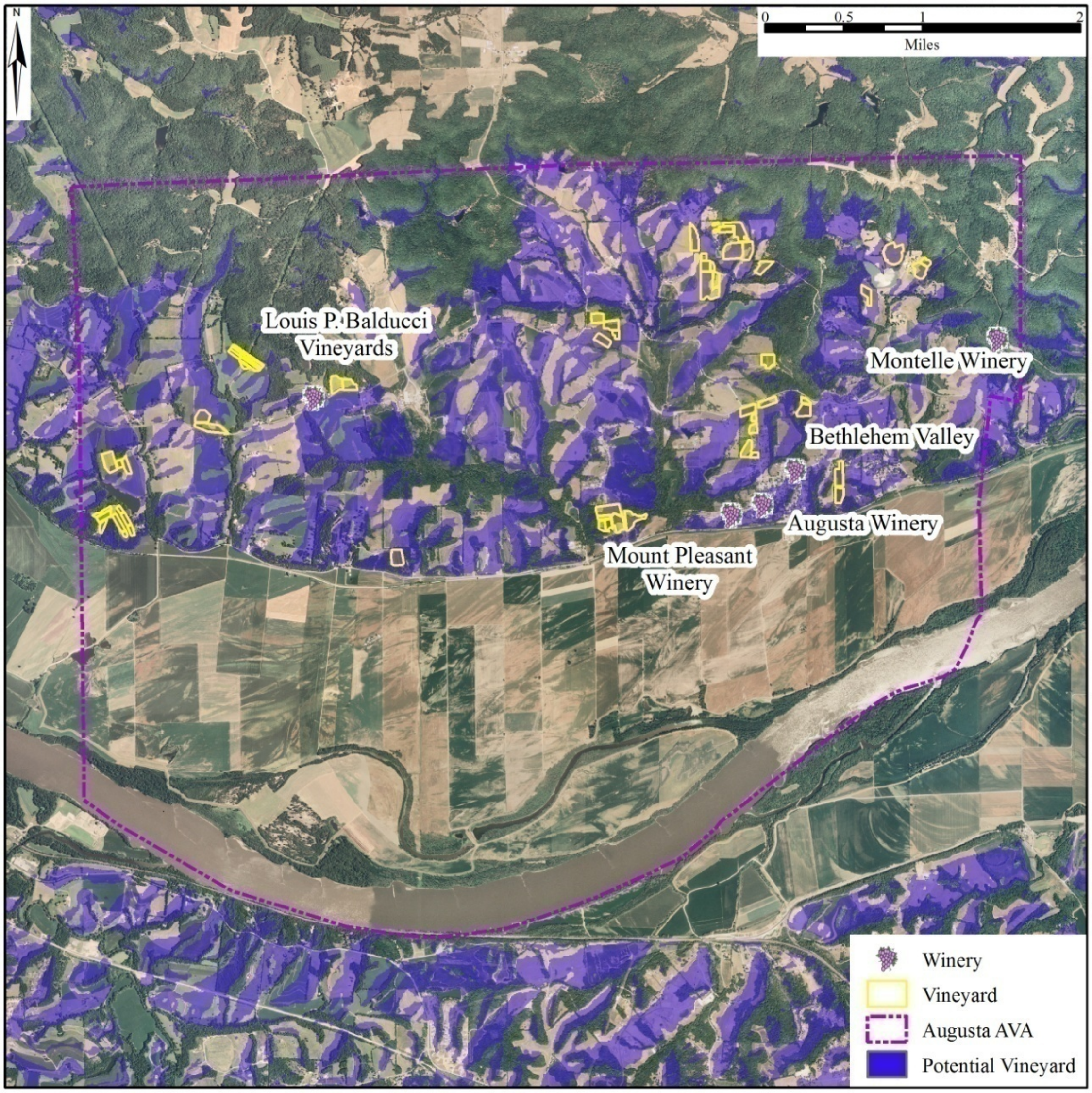


Figure 19. Augusta AVA suitability map created using the elevation, slope, and aspect raster datasets as well as soil and bedrock geology vector files converted to raster format.

Hermann AVA Results

There are 52 vineyards in the Hermann AVA totaling 186.5 acres (75.5 ha) under vine. The largest tract is 19.8 acres (8.0 ha) and the smallest is approximately 0.5 acres (0.2 ha). Elevation ranges from 530.6 ft (161.7 m) to 936.4 ft (284.4 m) (Figure 20). The slope of the vineyards ranges from 1.3° to 13.8°; the average slope is 5.7° ± 2.7° (Figure

21). The majority (70%) of the vineyards are planted on convex slopes and a row orientation of northeast is preferred (southeast is the second most common row orientation) (Figure 21). The Menfro silt loam (65%), Wrengart silt loam (28%), and Beemont gravelly silt loam (7%) are used for vineyards in this AVA. The vineyards in both AVAs are planted on resistant dolomite bluffs that overlook the river. The preferred

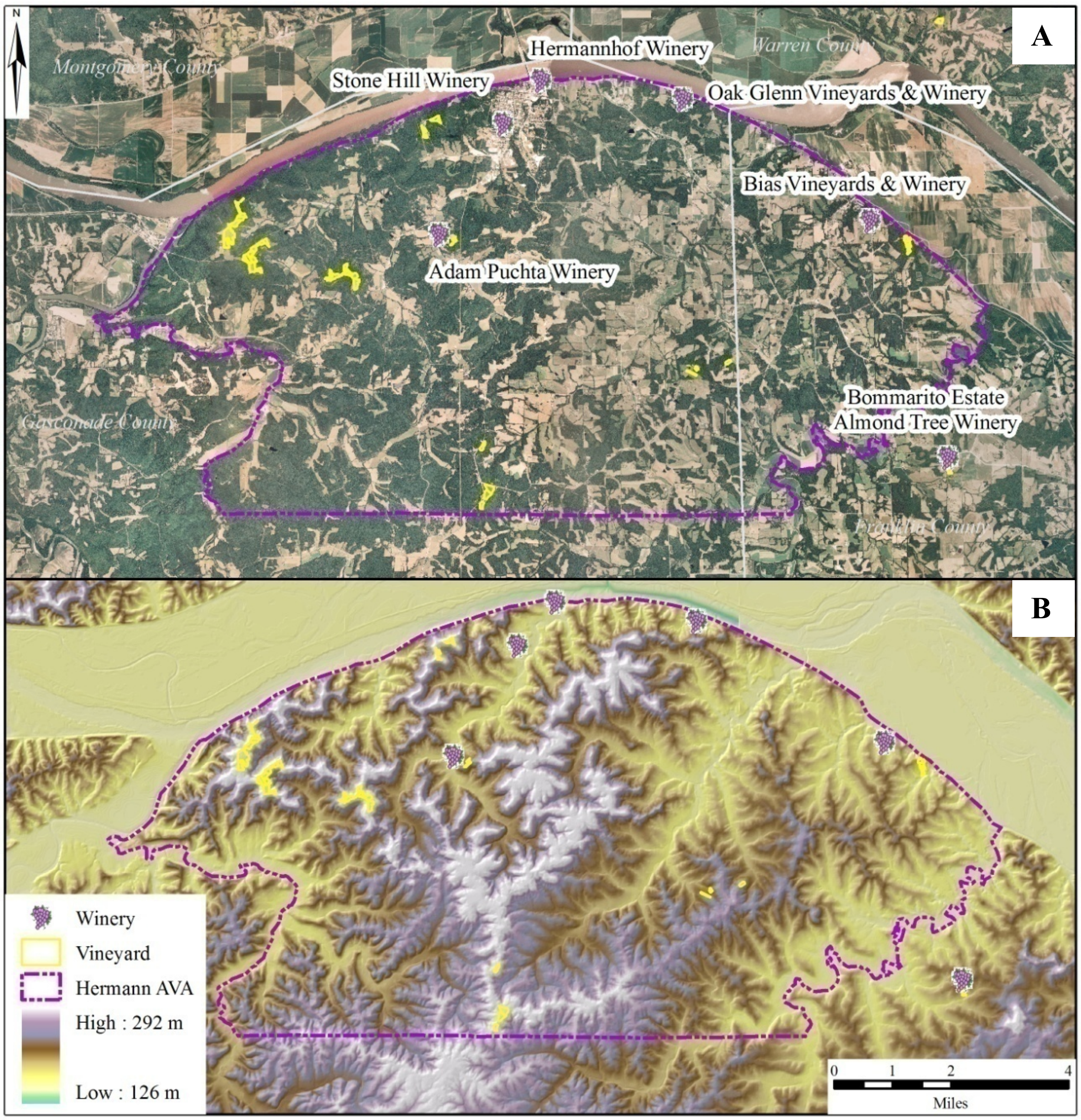


Figure 20. Hermann AVA place on the A) NAIP aerial photography and B) a DEM.

bedrock is the Ordovician Jefferson City and Cotter dolomites (74%), the Ordovician St. Peter Sandstone and Everton Formation (20%), and the Pennsylvanian System, undifferentiated (4%). One vineyard is planted on Quaternary alluvium but this could be a map contact error from the scale of the map and resolution of the analysis (Figure 22). A legend of the soil and geology map colors is found in Figure 23.

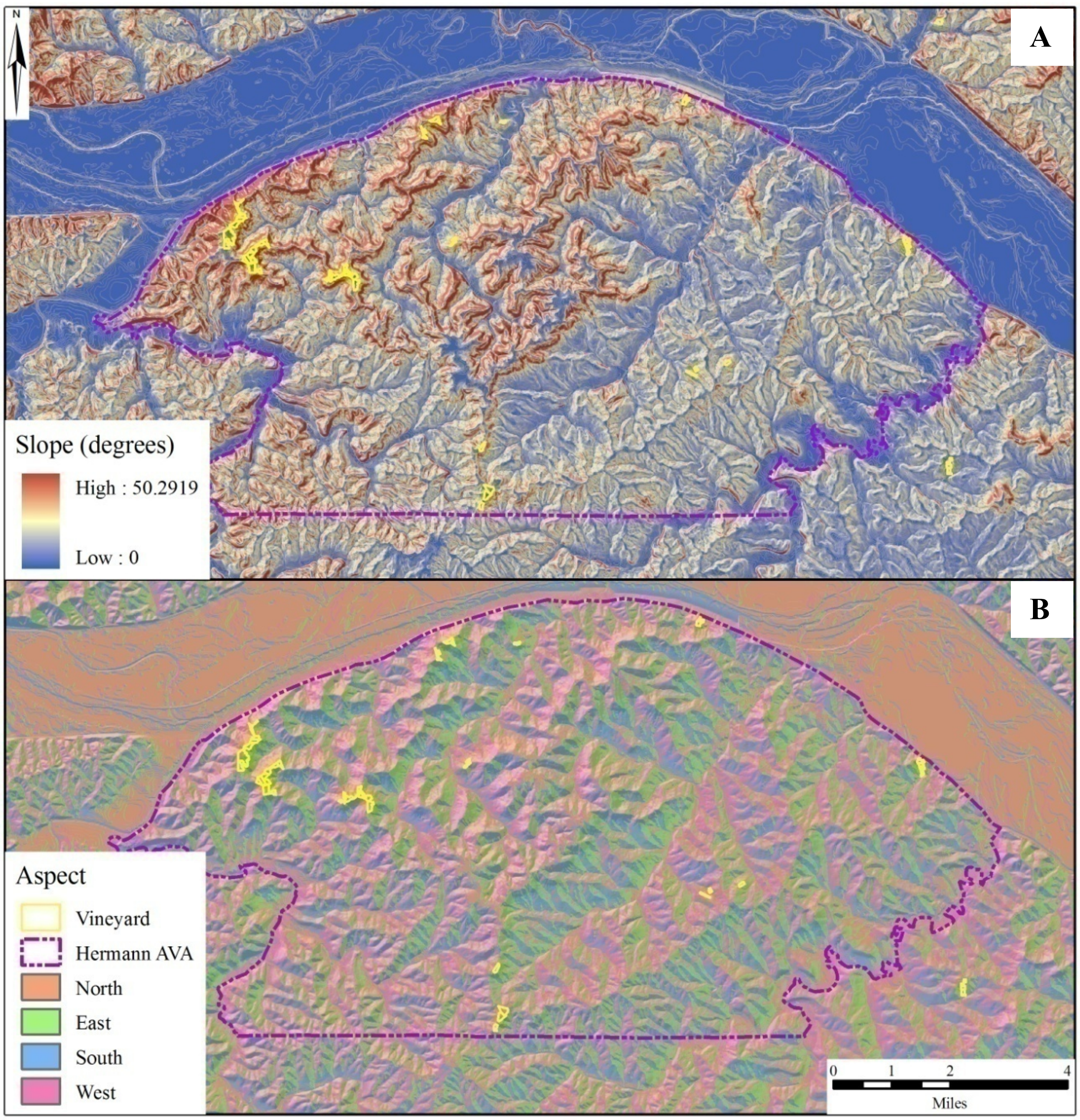


Figure 21. Hermann AVA place on A) slope and b) aspect surfaces created from the DEM.

The vineyards that are located outside of the Hermann AVA boundary have a range in acreage from 0.2 (0.1 ha) to 5.1 (2.1 ha). The total number of acres is 34.4 (13.9 ha). The mean elevation for these 17 vineyards is 623.6 ± 26.0 ft (190.1 ± 7.9 m) with a range from 563.2 ft (171.7 m) to 675.0 ft (205.8 m). The mean slope is 6.1° ± 1.5° with a range between 3.8° and 9.9°. The aspect for these vineyards is mostly to the south and.

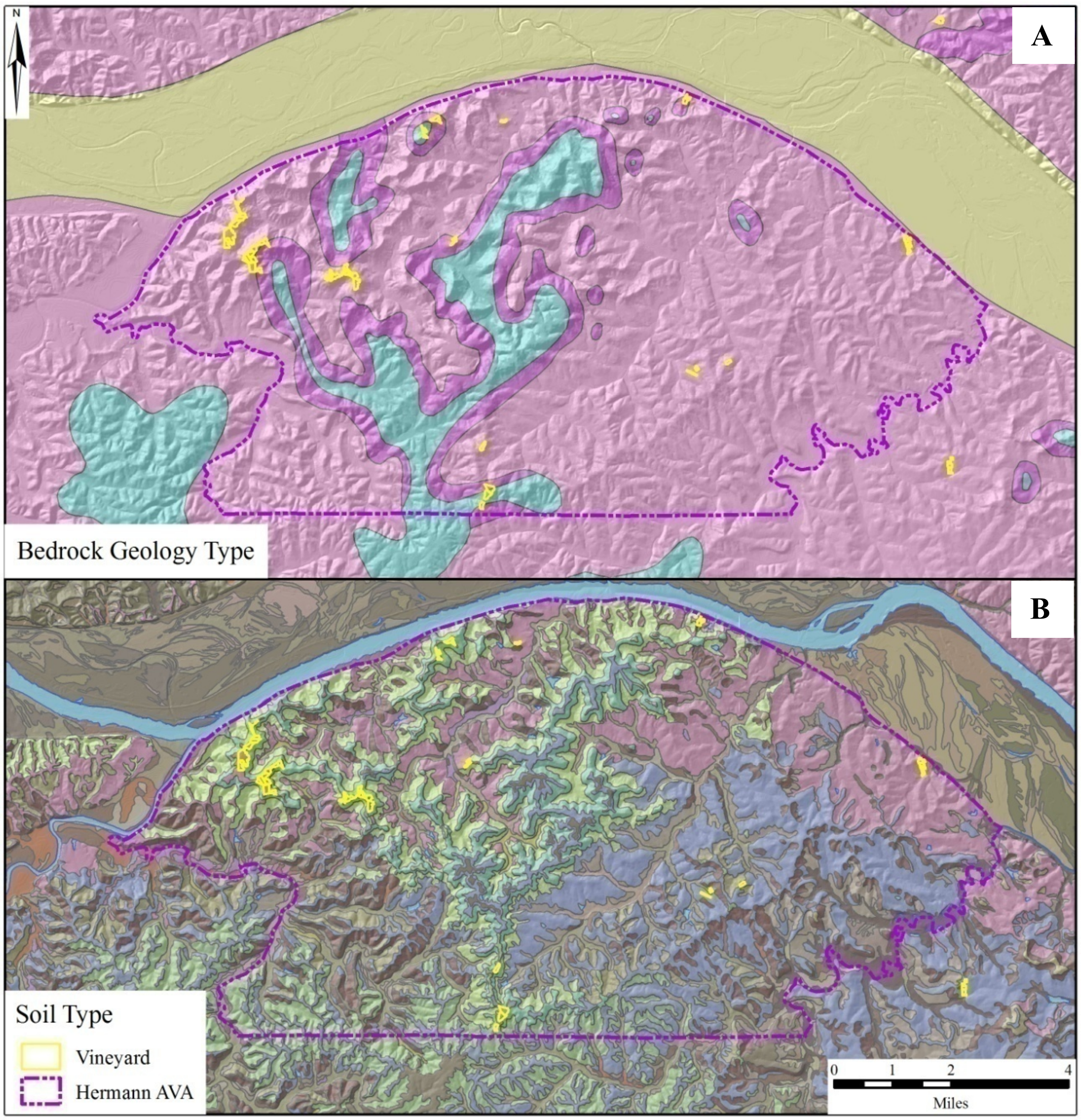


Figure 22. Hermann AVA place on A) bedrock geology map (Middendorf, 2003) and B) soil type map (USDA – NRCS, 2007).

secondly to the east and they are mostly all situated on surfaces that are mostly convex The preferred soil type is the Menfro silt loam (71%) or the Wrengart silt loam (29%). The only bedrock type that is used outside of the AVA is the Ordovician Jefferson City and Cotter dolomites.

The data from the 71 vineyards in the Hermann AVA and surrounding

Figure 23. Soil Type (soils in the vicinity of vineyards are given brighter colors) and Bedrock Geology legends for Figure 22.

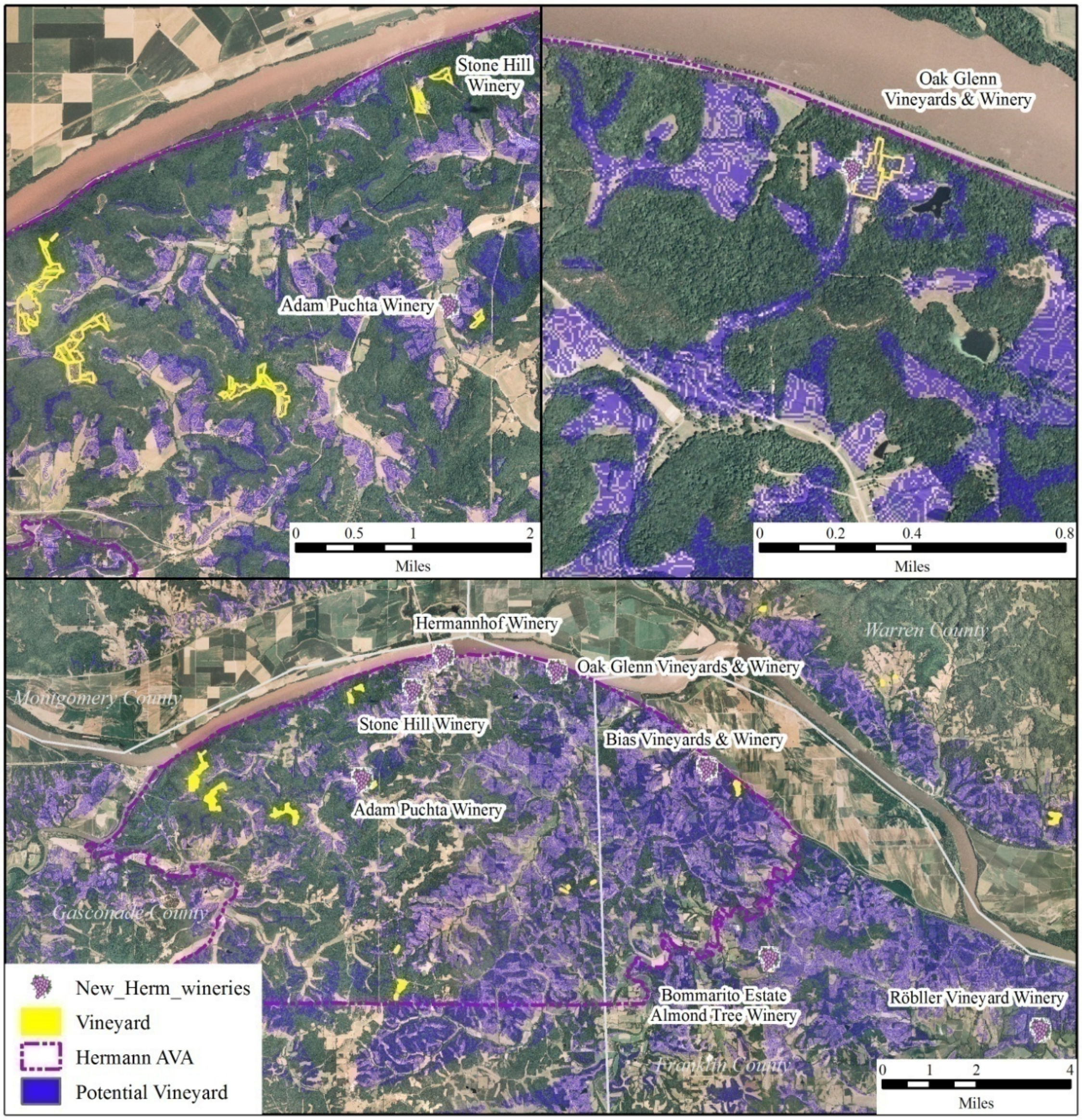


Figure 24. Hermann AVA suitability map over the NAIP aerial photography showing potential vineyard placement locations.

areas was used to create the suitability maps for the AVA (Figure 24). These vineyards totaled 220.9 acres under vine (89.4 ha) with an average vineyard size of 3.1 ± 2.9 acres (1.3 ± 1.2 ha). The slope ranges from 1.3 to 13.8 and the elevation ranges from 161.7 to 285.4 m. The most used aspects are to the south and east and the majority of the vineyards are placed on mostly convex surfaces. The Menfro silt loam, Wrengart silt loam, and Beemont gravelly silt loams were all used. The Jefferson City and Cotter dolomites as well as the St. Peter Sandstone and Everton Formation were the bedrock units of choice as well.

The vineyards in the Augusta AVA and Hermann AVA are grown on similar soils, preferring the silt loams that form over a stretch of glacial loess and quaternary alluvium along the Missouri River. The red wines produced from the Chambourcin and Norton/Cynthiana varietals and the whites produced from the Chardonel, Seyval Blanc, Vidal Blanc, and Vignoles varietals all have similar flavors from these two AVAs. The similarities in soil and geology would have an effect on the product and explain the resemblance in the flavor of many wines from these two regions. Because of the similarities between the wines and the physical characteristics of terroir between the vineyards inside and outside the Augusta AVA, the boundaries could be redrawn to include Sugar Creek Winery and Vineyards to the east as well as Blumenhof Vineyards and Winery to the west.

In Hermann, the vineyards outside the AVA were not taste tested so no conclusions can be drawn from the flavors of the wine. The physical characteristics of *terroir* that were studied (topography, soil, and geology) are different between the vineyards inside and outside the Hermann AVA as well as between AVAs so a larger AVA in the Hermann region or a larger AVA incorporation both Augusta and Hermann should not be made. The *terroirs* of these two AVAs are unique from each other based on some of the physical characteristics in the study and each should have their own *terroir* description.

Rocheport results

The Rocheport area only consists of one winery, Les Bourgeois Vineyard and Winery. There are six vineyards ranging in size from only 0.3 acres (0.1 ha) to 10.3 (4.2 ha) acres. The mean size is 4.7 ± 3.6 acres (1.9 ± 1.4 ha). The range of average vineyard slope is 2.5° (4.3 %) to 6.9° (12.1 %). The overall average vineyard slope for the entire estate is 4.2° ± 1.5° (7.4 ± 2.6 %). The range of the vineyard elevation is 753 ft (229.7 m) to 789 ft (240.4 m) with an overall average for the entire estate being 773.5 ± 14.2 ft (235.8 ± 4.3 m) (Figure 25). The curvature of every vineyard is mostly convex (Figure 26), with some vineyards having a rolling terrain with multiple aspects. The aspect of each vineyard varies within each plot and most have approximately a quarter of each plot facing north, south, east, and west (Figure 27). Because of the convex nature of these vineyards, place on the tops of hills and have multiple aspects, this data is not used to create the suitability maps (Figure 28).

Les Bourgeois Vineyards are all planted on Mississippian age Osagean Series limestone. More specifically the Keokuk, Burlington, and Pierson limestone formations are located in this area. The quaternary geology is mostly cherty clay residuum formed from the Mississippian limestone, but glacial loess and alluvium are also in the immediate vicinity of the vineyards. Overlying the quaternary deposits are the Menfro and Winfield silt loams, which are the preferred soils. In comparison to the AVA's, Les Bourgeois Vineyards have very similar attributes and area also situated on bluffs in close proximity to the Missouri River. Further studies on the vineyards along the Missouri River will see if these commonalities continue. Other physical characteristics of the

Rocheport vineyards are unique from the Hermann and Augusta AVAs, especially the geology, so this area would not be included in the *terroir* description of either AVA.

After gathering all of the data for Les Bourgeois Vineyards, which includes elevation, slope, curvature, aspect, geology and soils, a geodatabase was created to store the final vector and raster files. A preliminary suitability map using the elevation,

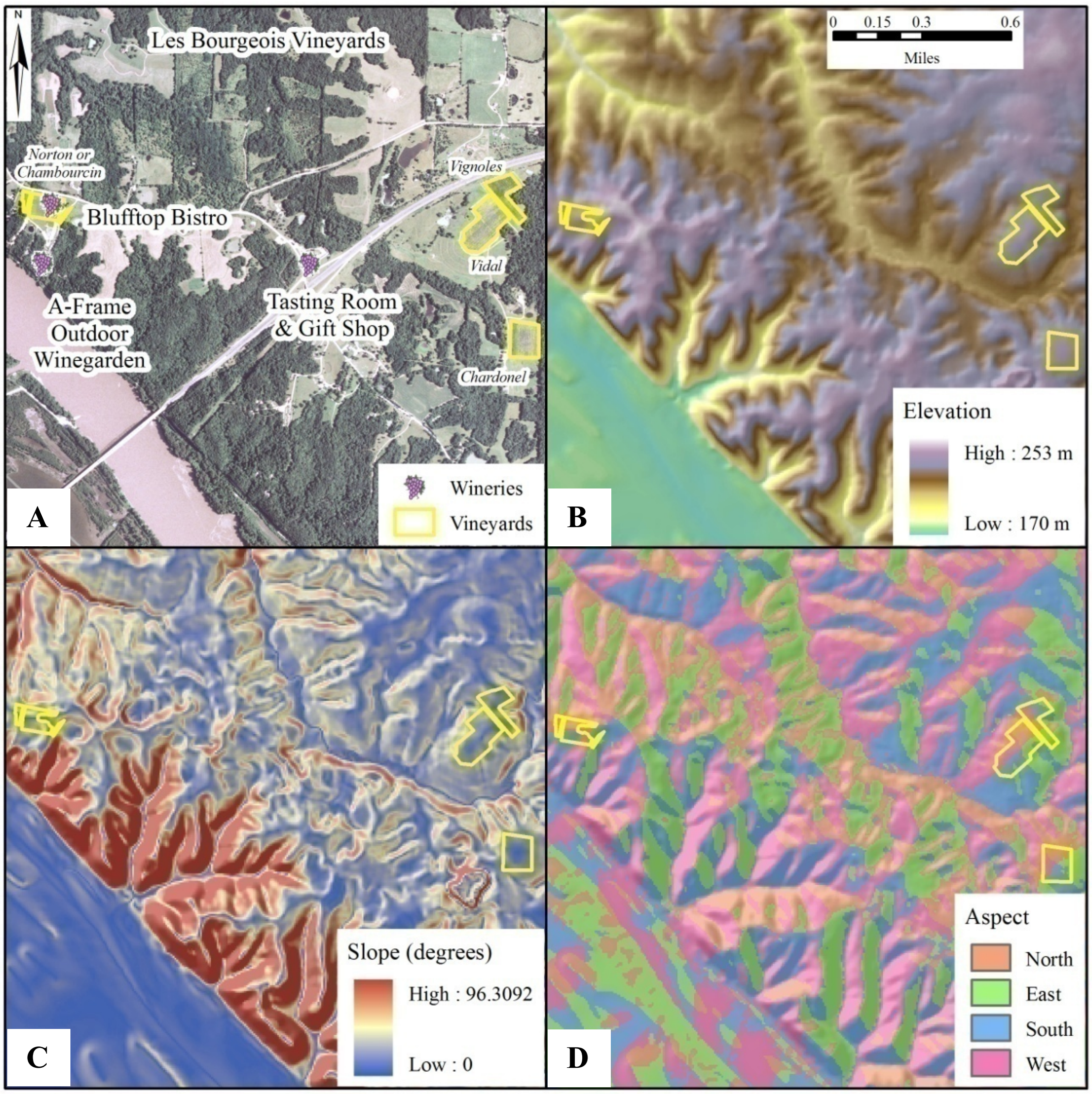


Figure 25. Les Bourgeois Vineyards, Rocheport, MO plotted on A) NAIP aerial photography with winery establishments and grape varietal, B) DEM, C) slope surface, and D) aspect surface.

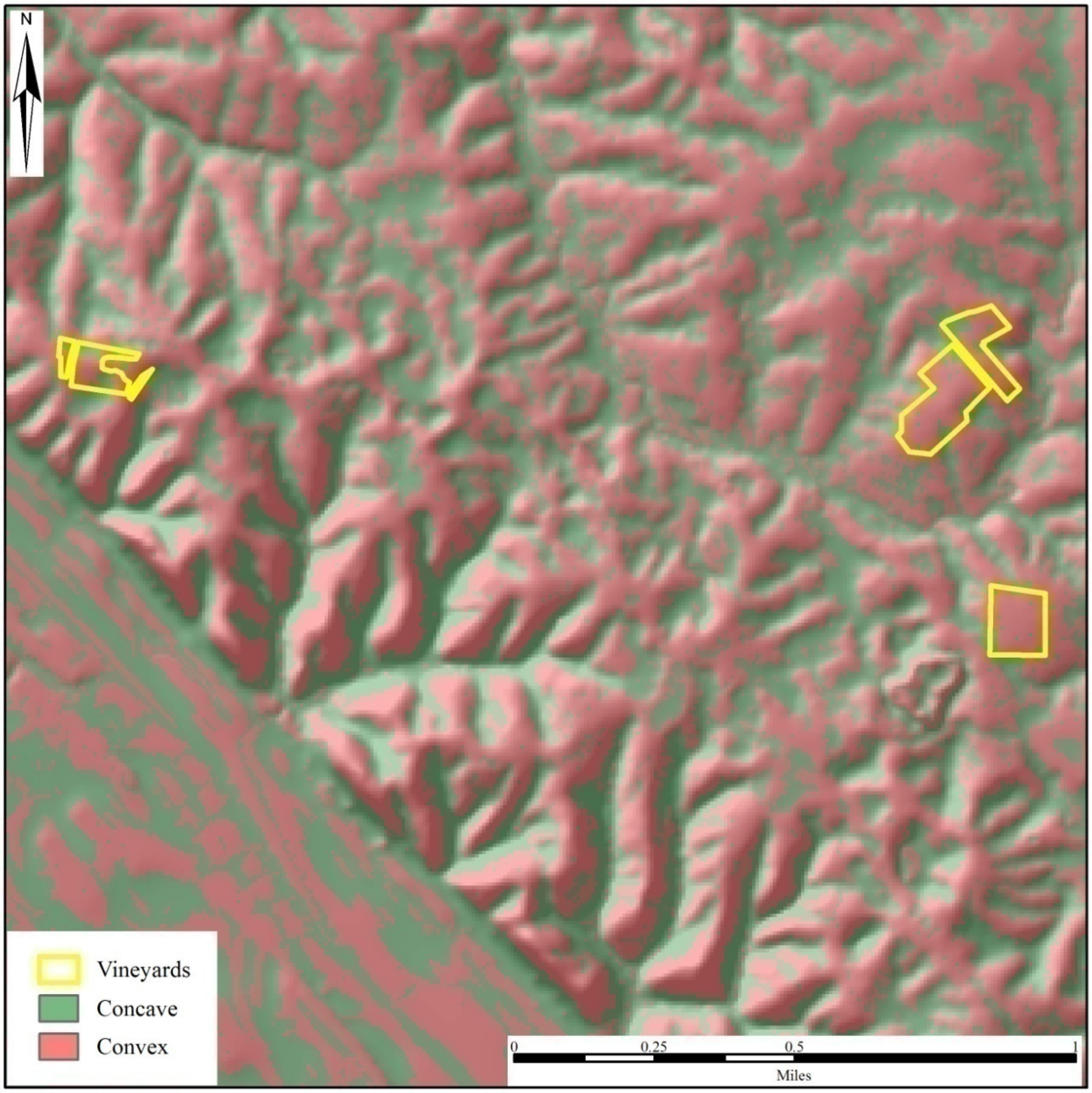


Figure 26. Les Bourgeois Vineyards on the map of topographic curvature. The majority of pixels within each vineyard will be the curvature of the vineyard. These vineyards are all on mostly convex pixels, and therefore are on a convex surface.

geology and soils data was created for this area (Figure 28). This Figure shows many more acres of land in the Les Bourgeois Vineyards area that are suitable for vineyards according to the current elevation, soil, and geology on which the current vineyards are planted. In this area there are approximately 680 acres that have all the suitable attributes

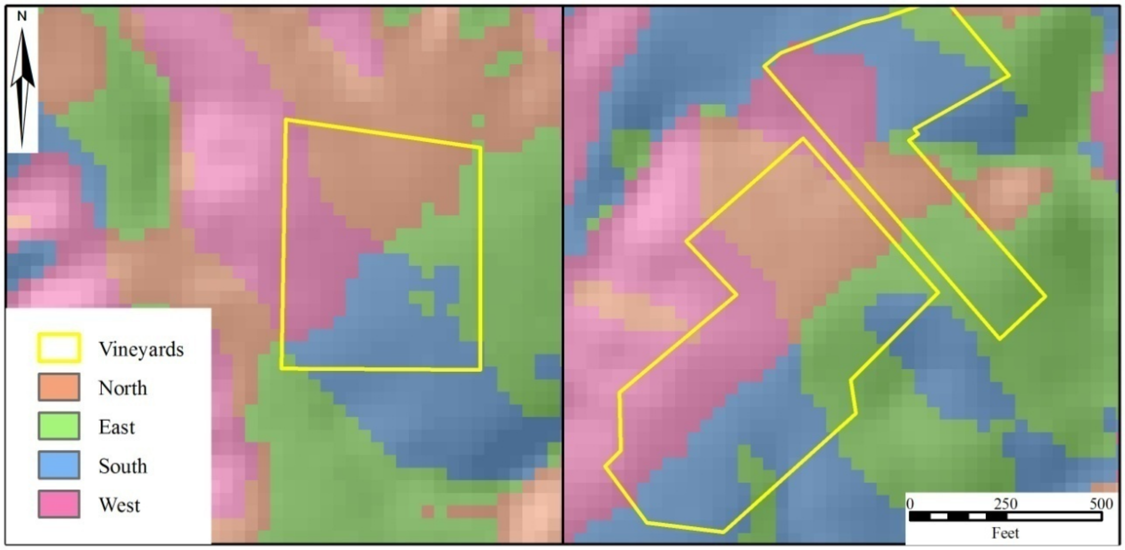


Figure 27. Three of Les Bourgeois Vineyards plotted on an aspect map showing that when the vineyard is convex and at the top of a hill, it will have all four aspects.

currently being used. Since Les Bourgeois imports many of their grapes, it would be beneficial to their business to use this suitability map to acquire more land and grow more grapes of their own. Once they accomplish this, their wine may reflect the *terroir* of that region.

St. Francois and Ste. Genevieve counties results

St. Francois and Ste. Genevieve counties are large areas, and wineries are clustered in the two counties. Figures 29-32 show smaller portions of the study area. The vineyards in the St. Francois County study area belong to Marco Vineyard, St. Francois Winery (Figure 29), Sand Creek Vineyard, and Twin Oaks Vineyard and Winery (Figure 30). There are 17 vineyards totaling 38.5 acres (15.6 ha). The smallest vineyard is 0.7 acres (0.3 ha) and the largest is 5.2 acres (2.1 ha) with an average of 2.3 ± 1.5 acres (0.9 ± 0.6 ha).

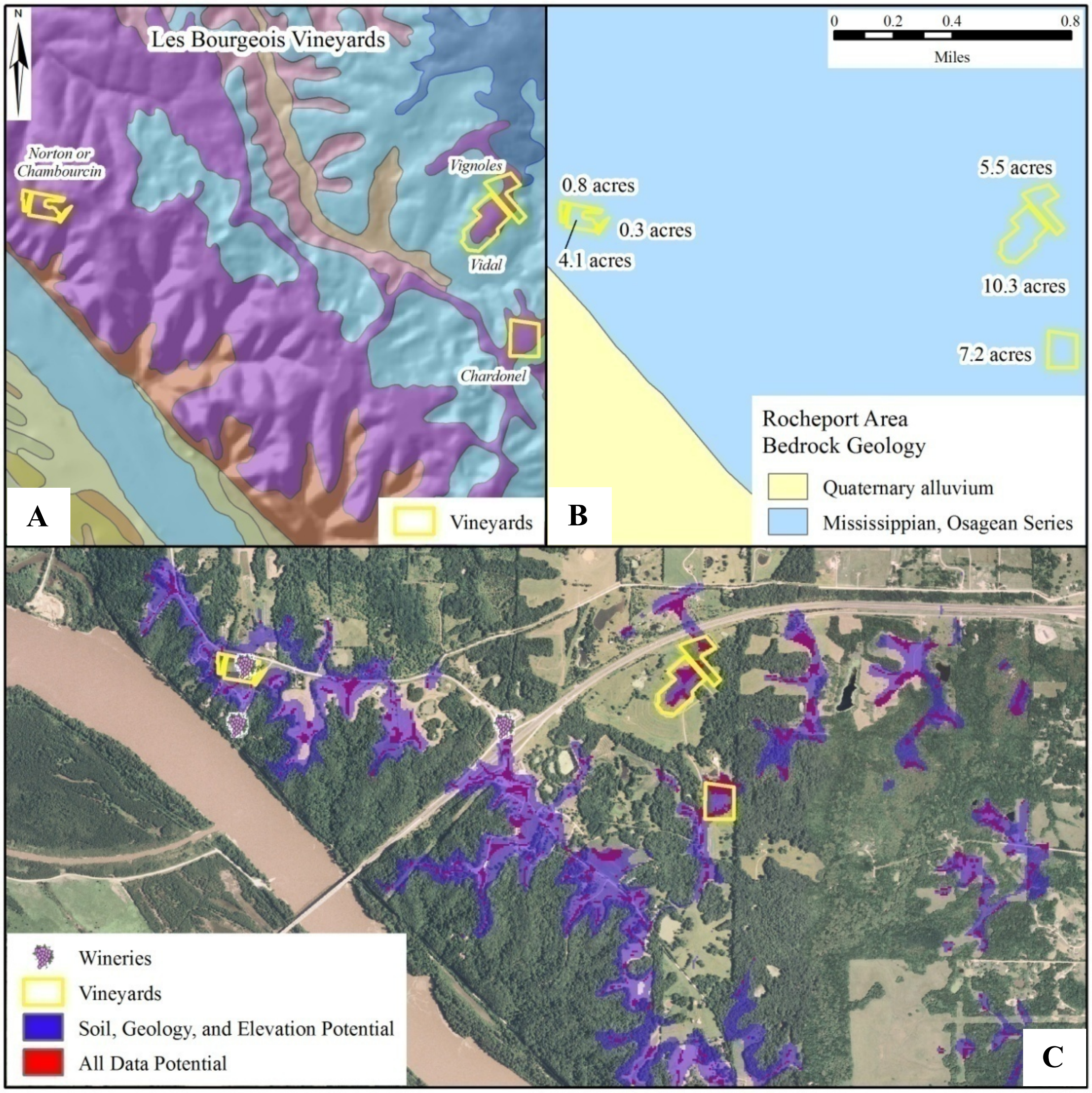


Figure 28. Les Bourgeois Vineyards plotted on the A) soil type map (USDA – NRCS, 2007), B) bedrock geology map (Middendorf, 2003), and C) suitability map over the NAIP aerial photography showing potential vineyard placement locations.

The mean elevation for the vineyards in St. Francois County is 916.3 ± 23.6 ft (279.3 ± 7.2 m) with a maximum elevation of 944.8 ft (288.0 m) and a minimum elevation of 867.8 ft (264.5 m). The mean slope for these vineyards is 3.1 ± 1.1° (5.4 ± 2.0 %) with a maximum slope of 4.8° (8.5 %) and minimum slope of 0.7° (1.3 %). All of

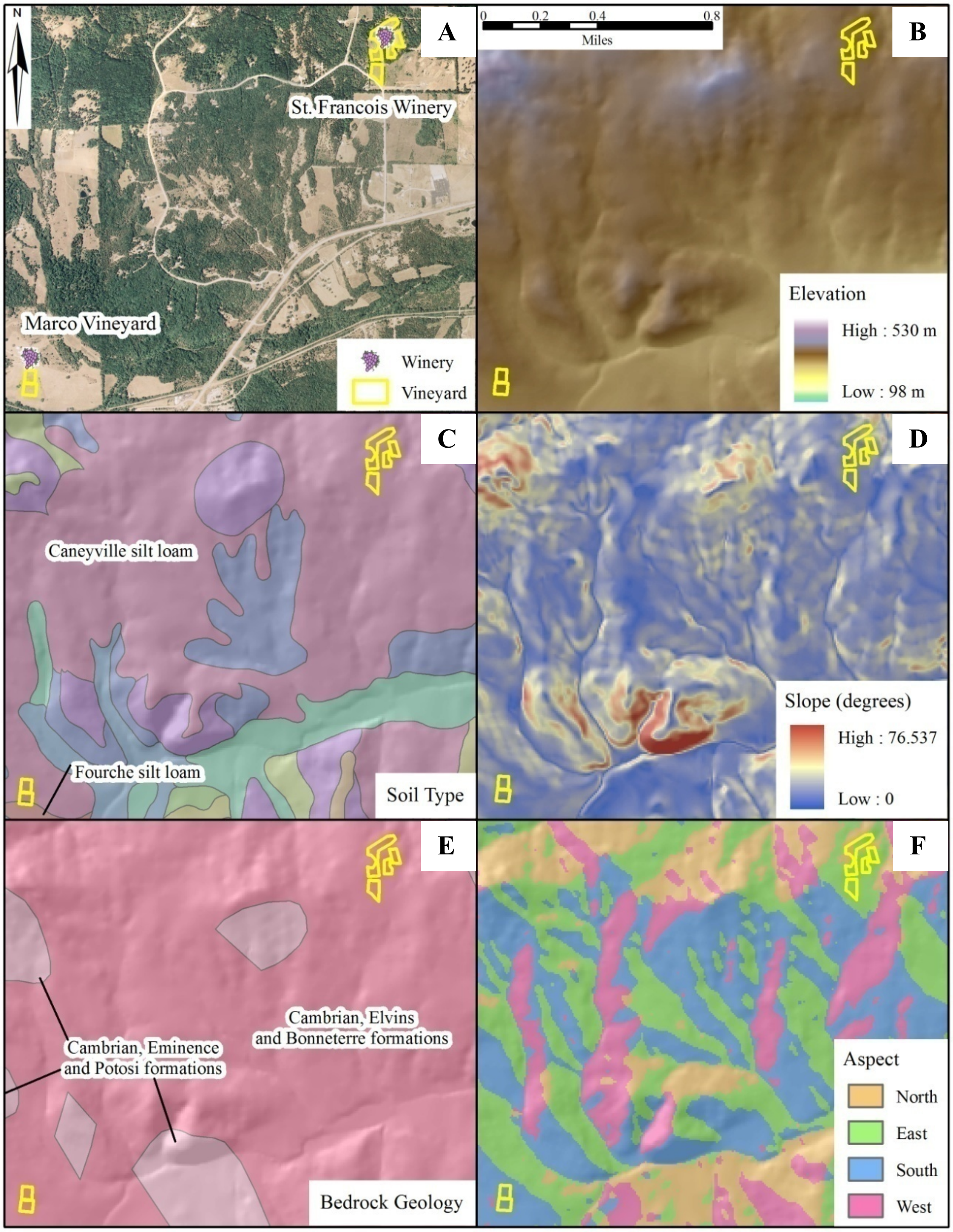


Figure 29. St. Francois Winery and Marco Vineyard in St. Francois County shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM. Figure 19 contains the Soil and Bedrock Geology legends.

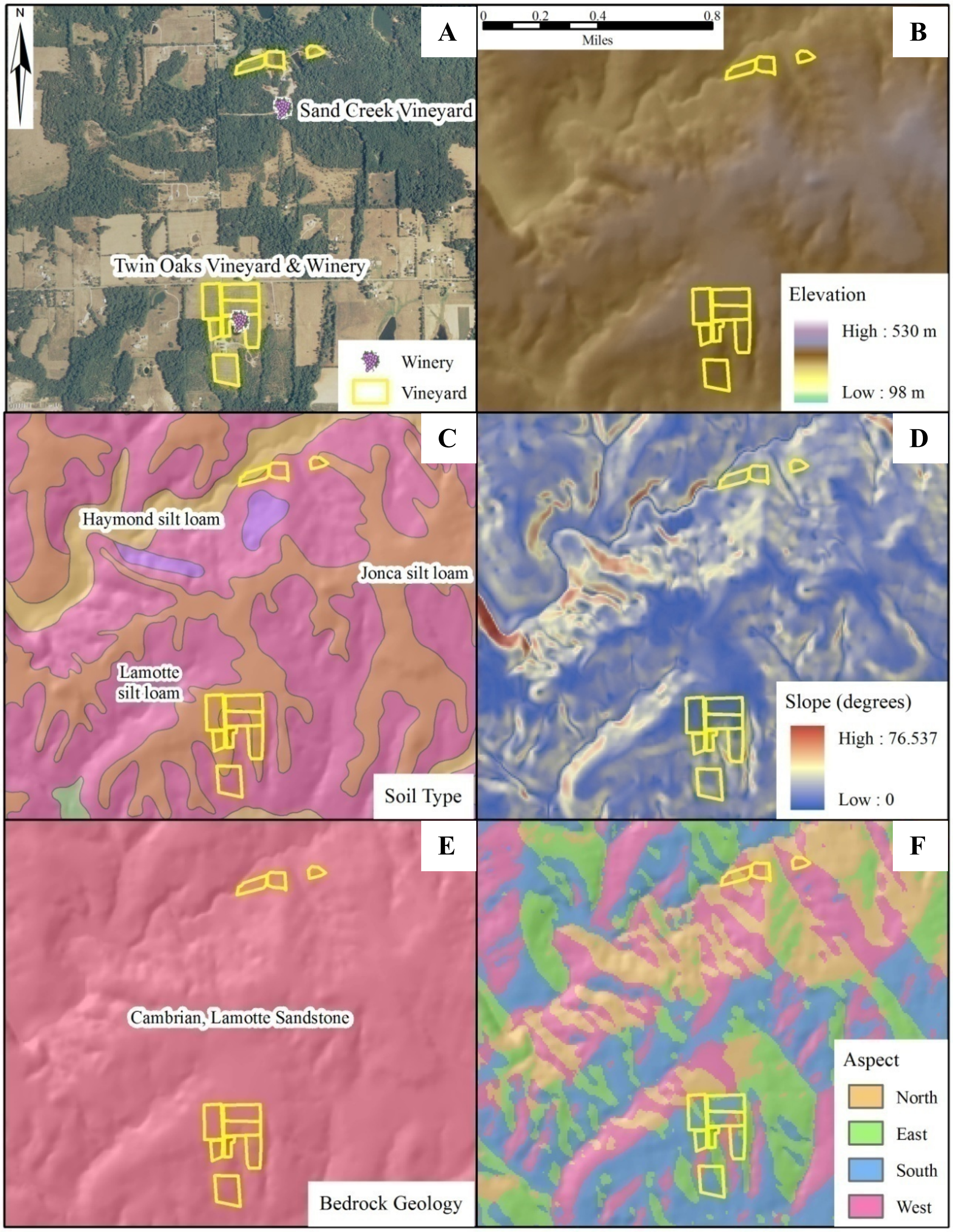


Figure 30. Sand Creek Vineyard and Twin Oaks Vineyard and Winery in St. Francois County shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM. Figure 19 contains the Soil and Bedrock Geology legends.

these vineyards are placed on a convex surface with the exception of one. The aspects were mostly south (47%) or east (35%) with a few facing the west (18%).

Also, based on majority within the vineyard, are the soil and geology statistics. The most common soil type for St. Francois County was the Caneyville silt loam, then the Lamotte silt loam, Jonca silt loam, and one vineyard was situated on Haymond silt loam. The major bedrock units used for vineyards in this area was the Cambrian Lamotte Sandstone and the Elvins Group and Bonneterre Formation. The Elvins Group (Davis Dolomite and Derby-Doerun Formation) and Bonneterre Formation consist of mostly dolomite. The orientation of these vineyards varied from north-south direction (53%), east-west direction (35%), or the northeast direction (12%) (Figures 29 and 30).

In Ste. Genevieve County, 47 vineyards were found and analyzed in the study. These vineyards belong to Crown Valley Winery (Figure 31) and Chaumette Vineyards and Winery and Charleville Vineyard, Winery, and Microbrewery (Figure 32) as well as Cave Vineyard (not in Figures). The vineyards in this area utilize all possible row orientations with the most used being the east-west direction (34%), and northeast direction as the least used (14%). In this area the maximum vineyard size is 24.4 acres (9.9 ha), the minimum is 0.4 acres (0.2 ha), and the mean vineyard size is 5.9 ± 6.0 acres (2.4 ± 2.4 ha).

The total acreage is 275.4 (111.5 ha). The mean slope is 5.1 ± 2.5° (8.9 ± 4.4 %) with a minimum of 1.7° (3 %) and maximum of 10.6° (18.7 %). The range in elevation for the vineyards in Ste. Genevieve County is greater than in St. Francois County. The mean elevation is 712.7 ± 43.8 ft (217.2 ± 13.3 m), the lowest elevation is 618.1 ft (188.4 m) and the highest elevation is 816.5 ft (248.9 m). Only 21% of these vineyards are

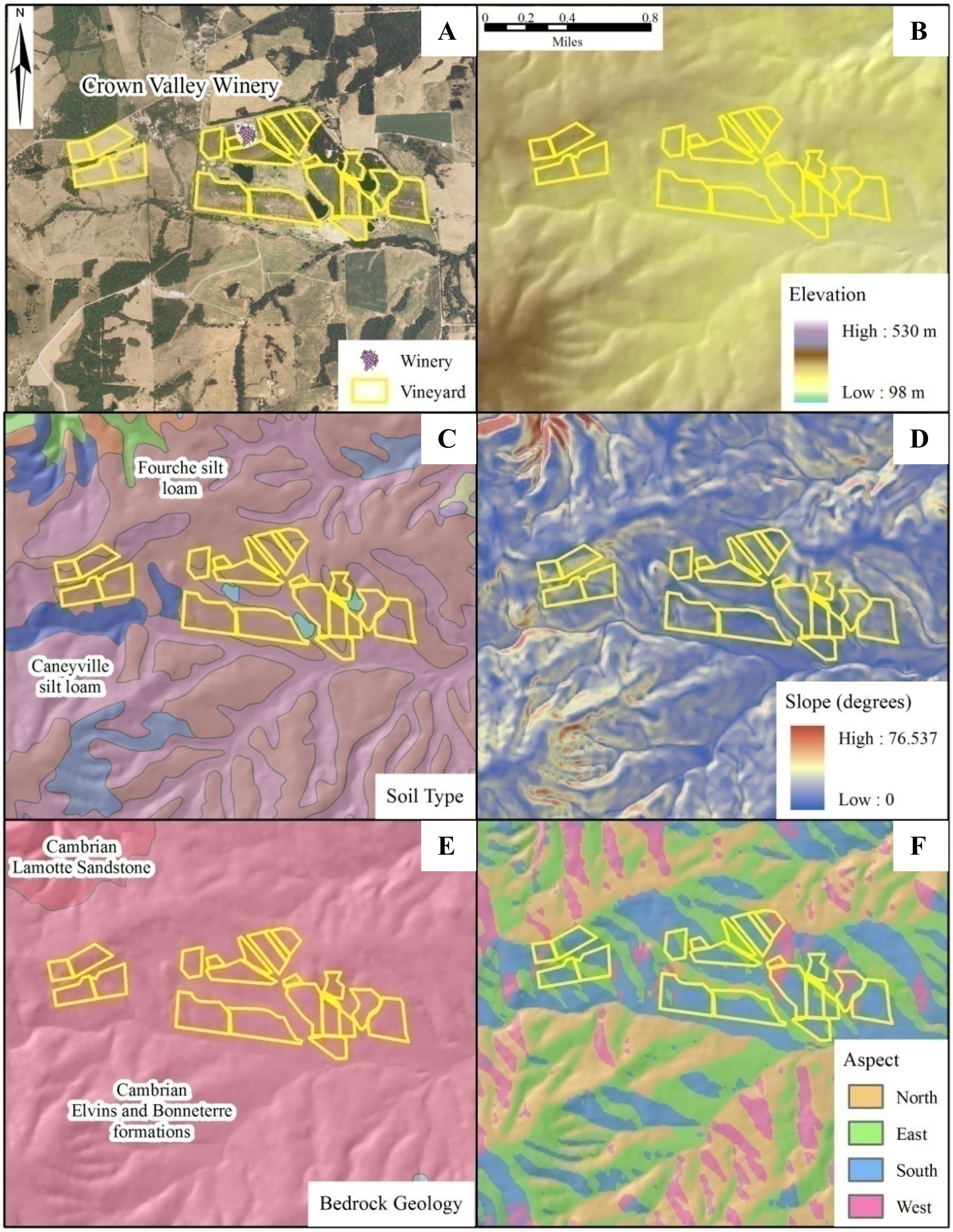


Figure 31. Crown Valley Winery in Ste. Genevieve County shown on A) aerial photography, B) Soil map (USDA – NRCS, 2007), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM. Figure 19 contains the Soil and Bedrock Geology legends.

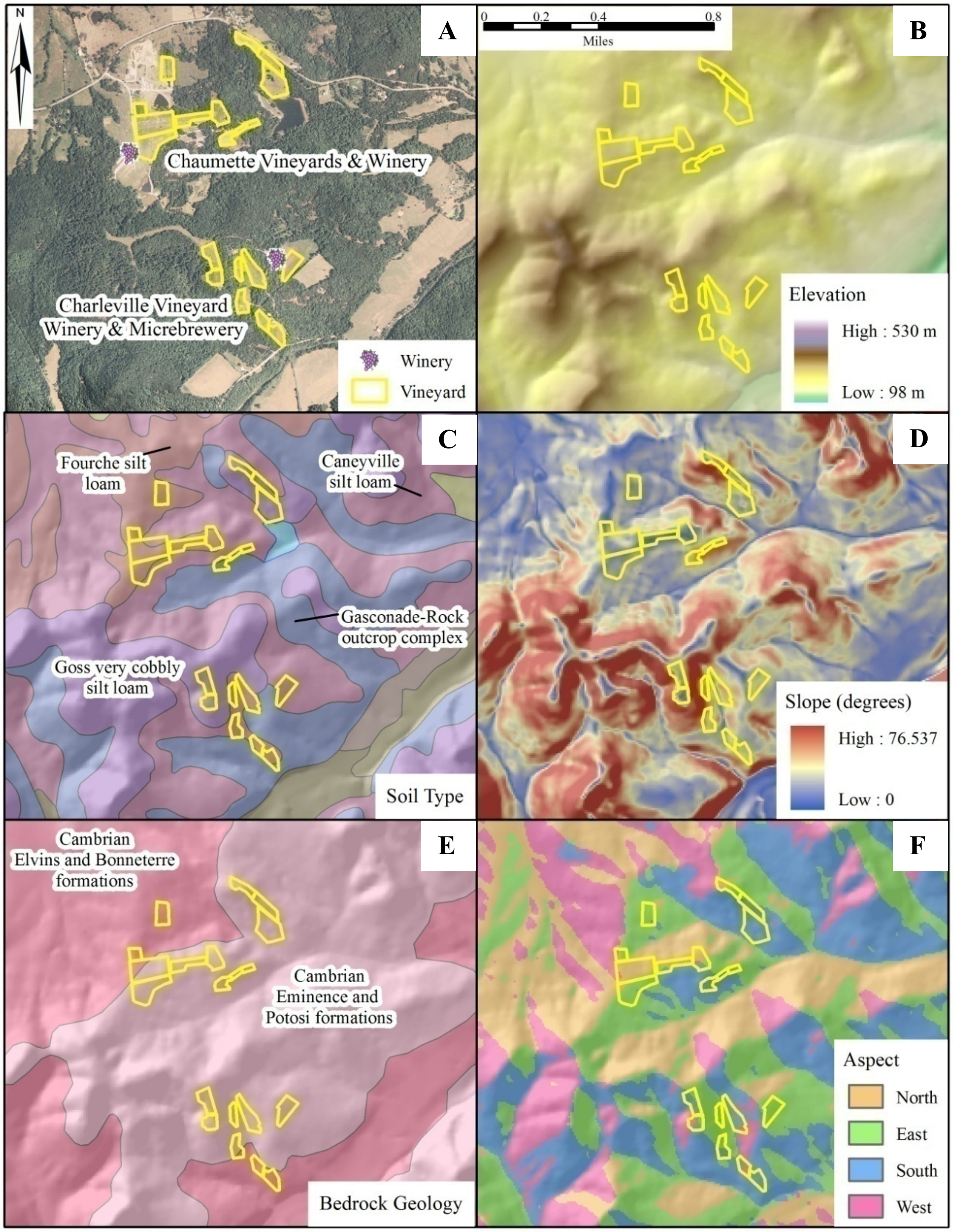


Figure 32. Chaumette Vineyards and Winery and Charleville Vineyard, Winery, and Microbrewery in Ste. Genevieve County shown on A) aerial photography, B) Soil map (NRCS), C) Bedrock Geology map (Middendorf, 2003), D) DEM, E) slope map, and F) aspect map both created from the DEM. Figure 19 contains the Soil and Bedrock Geology legends.

placed in a concave location, the majority are on a convex slope (not shown). The aspect for each vineyard is based on the majority and only 6% have a western aspect, 9% have a north-facing slope, 19% face east, and 66% have a southern aspect (Figures 31 and 32). One vineyard is planted on the Gasconade-Rock outcrop complex, four vineyards on the Wrengart silt loam, and 6 vineyards on Goss very cobbly silt loam. 20 vineyards (43%) area planted on the Fourche silt loam and 16 (34%) area planted on the Caneyville silt loam. The bedrock geology type that is mostly planted on are mostly composed of Cambrian age dolomite and include the Gasconade Dolomite (11%), the Eminence and Potosi formations (32%), and the Elvins Group (Davis Dolomite and Derby-Doerun Formation) and Bonneterre Formation (57%) (Figures 31 and 32). The legend for the soil and geology map colors is found in Figure 33.

As a whole the St. Francois and Ste. Genevieve area has 64 vineyards and 313.9 acres (111.5 ha) under vine ranging from small plots of 0.4 acres (0.2 ha) to 24.4 acres (9.9 ha). The mean slope for the entire area is 4.57 ± 2.36° (8.0 ± 4.2 %) and the range of slope is 0.7° (1.3 %) to 10.56° (18.7 %). The mean elevation is 766.8 ± 98.2 ft (233.7 ± 30.0 m) and the range of elevations is 618.1 ft (188.4 m) to 944.8 ft (288.0 m). For the entire area, 61% of the vineyards have a southern aspect and 24% have an eastern aspect. The two most common soil types used are the Caneyville and Fourche silt loams totaling 67% of the vineyards, but the Goss very cobbly silt loam, Wrengart silt loam, Lamotte silt loam, and Jonca silt loam are widely used for vineyards in this area. The most common bedrock geology types used are Elvins Group (Davis Dolomite and Derby-Doerun Formation) and Bonneterre Formation, Eminence and Potosi formations, Lamotte Sandstone, and Gasconade Dolomite.

The ranges for numerical values and the most popular curvature and most popular aspects values are used for the suitability maps as well as all soil types and bedrock geology types (Figure 34). The potential additional acreage in this area totals 45,862 acres and the area considered was not the entire two counties, suggesting that many more acres are available. As shown, each winery has the potential to expand production in their

St. Francois and Ste. Genevieve Counties
Soil Type Legend

- Water
- Caneyville silt loam
- Crider silt loam
- Elsah silt loam
- Fourche silt loam
- Gasconade-Rock outcrop complex
- Goss very cobbly silt loam
- Haymond silt loam
- Hildebrecht silt loam
- Jonca silt loam
- Lamotte silt loam
- Lily loam
- Midco gravelly loam
- Ramsey fine sandy loam
- Ramsey-Rock outcrop complex
- Wilbur silt loam
- Wilderness gravelly silt loam
- Auxvasse silt loam
- Beaucoup silty clay loam
- Bloomsdale silt loam
- Carr fine sandy loam
- Deible silt loam
- Delassus silt loam
- Freeburg silt loam
- Gasconade-Menfro complex
- Gerald silt loam
- Goss-Menfro complex
- Hassler-Syenite complex
- Haynie silt loam
- Horsecreek silt loam
- Irondale gravelly silt loam
- Kaintuck fine sandy loam
- Knobtop silt loam
- Lily-Ramsey complex
- Loughboro silt loam
- Menfro silt loam
- Midco gravelly silt loam
- Midco very gravelly sandy loam
- Minnith silt loam
- Nameoki silty clay loam
- Nicholson silt loam
- Psamments
- Racket loam
- Rueter gravelly silt loam
- Rueter-Sonsac complex
- Syenite silt loam
- Tiff gravelly clay
- Udorthents-Pits complex
- Union silt loam
- Wabash silty clay
- Wrengart silt loam
- Pits and Dumps

St. Francois and Ste. Genevieve Counties
Bedrock Geology Legend

- Quaternary alluvium
- Mississippian, Chesterian Series
- Mississippian, Meramecian Series
- Mississippian, Osagean Series
- Mississippian, Kinderhookian Series
- Devonian System
- Silurian System
- Ordovician, Maquoketa and Kimmswick formations
- Ordovician, Decorah and Plattin formations
- Ordovician, Joachim and Dutchtown formations
- Ordovician, St. Peter and Everton formations
- Ordovician, Jefferson City and Cotter formations
- Ordovician, Roubidoux formation
- Ordovician, Gasconade Dolomite
- Cambrian, Elvins and Bonneterre formations
- Cambrian, Eminence and Potosi formations
- Cambrian, Lamotte Sandstone
- Precambrian diabase, St. Francois Mountains
- Precambrian volcanic, St. Francois Mountains
- Precambrian intrusive, St. Francois Mountains

Figure 33. Soil Type (soils in the vicinity of vineyards are given brighter colors) and Bedrock Geology legends for Figures 15-18.

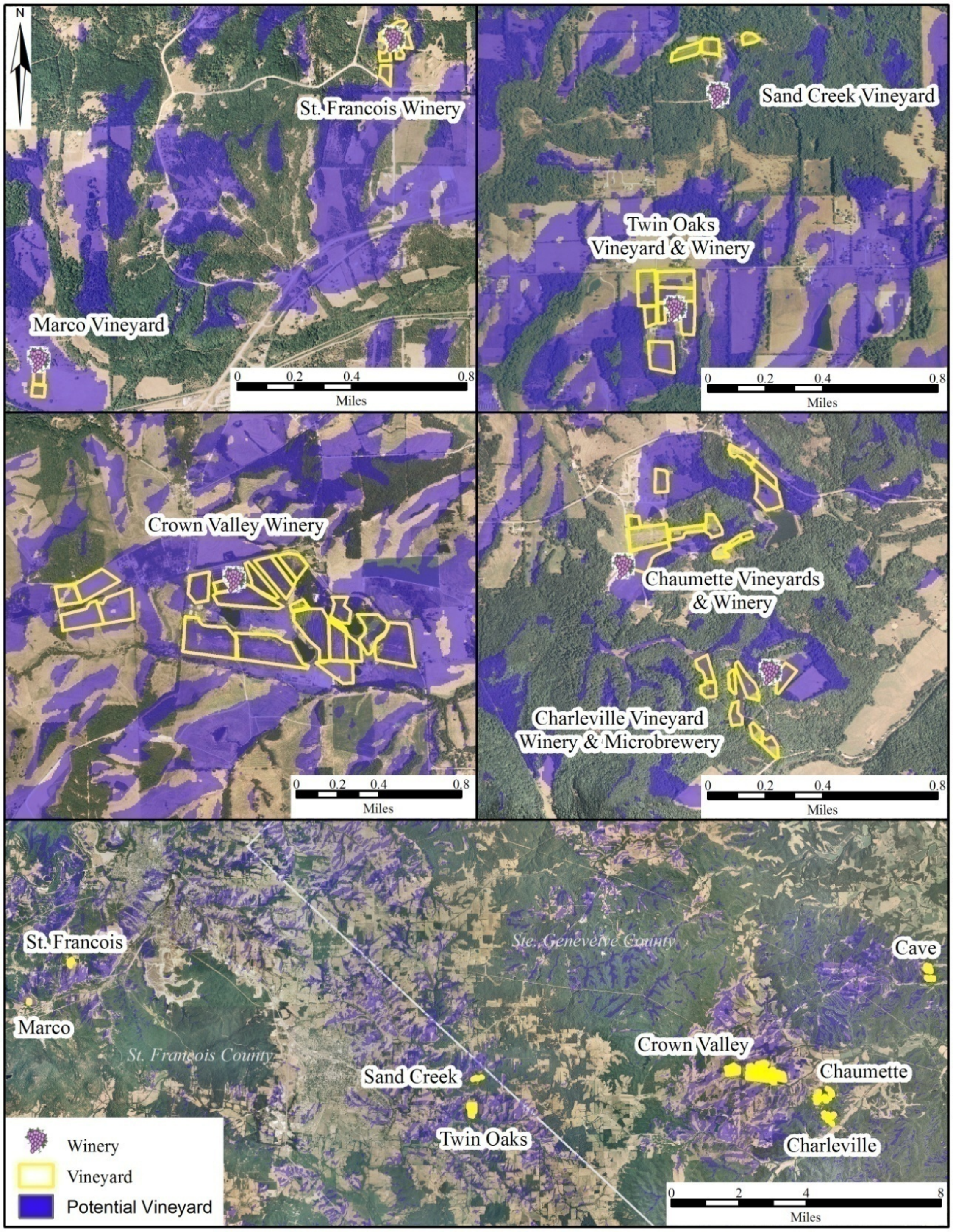


Figure 34. A suitability map created for the St. Francois and Ste Genevieve Counties based on elevation, slope, aspect, soil and bedrock geology types that are currently being used.

immediate vicinity. This suitability map is based on the data from the two counties combined, even though they have unique *terroir* characteristics. Separate *terroir* descriptions for each county should be made because of their unique physical characteristics.

Vineyard spatial analysis

Performing spatial analyses in a GIS is a fairly quick process. In preliminary attempts to see if the vineyards in and around an AVA had any autocorrelation based on bedrock and soil type, and elevation and slope, all vineyards were found to be clustered. The results for the Moran's I spatial autocorrelation calculation are either positive, signifying positive autocorrelation, or negative, signifying the opposite. In this case all Moran's I values were positive and the z-scores calculated for each attribute in each AVA were very large, indicating that these vineyards are clustered at the 99% confidence interval (Table 2).

Table 2. Results from the Moran's I spatial autocorrelation tool on vineyard attributes in the Augusta and Hermann AVAs and surrounding areas.

	Augusta AVA		Hermann AVA	
Attribute	Moran's I	z-score	Moran's I	z-score
Elevation	0.67	12.80	0.52	9.82
Slope	0.36	6.94	0.22	4.16
Soil	0.36	7.16	0.25	4.73
Bedrock	0.73	11.20	0.69	12.70

This same analysis was quickly performed on all the vineyards found in the study, from all the study areas combined. In this case, Moran's I signifies that there is positive spatial autocorrelation between vineyards based on all attributes (elevation, slope, aspect, curvature, soil, and geology). Again, the z-scores were very high, indicated that these vineyards are clustered at the 99% confidence interval as well (Table 3). Since the z-scores were outside the calculated confidence interval, further explanation for the clustering of these vineyards should be found. This explanation could be based on the concept of *terroir* that is presented in this research. Cluster analysis was also done using the average nearest neighbor tool which found the vineyards to be clustered, had an observed mean distance/expected mean distance equal to 0.03, and a z-score of -28.5 indicated that there is less than 1% chance that vineyard placement was due to random chance. This agrees with the thought that vineyard locations are not randomly dispersed in the state, but are placed based on precise physical parameters in order to produce quality wine (i.e. *terroir*).

Table 3. Moran's I spatial autocorrelation tool results on all vineyards found in the study from the Augusta and Hermann AVAs, Rocheport area, and St. Francois and Ste. Genevieve counties.

Attribute	Moran's I	z-score
Acres	0.39	10.86
Elevation	0.70	18.54
Slope	0.74	19.60
Aspect	0.81	21.33
Curvature	0.33	8.65
Soil	0.56	15.07
Geology	0.84	22.01

Winery spatial analysis

Cluster analysis using average nearest neighbor distance index shows that the wineries are clustered with less than 1% likelihood that the clustering pattern is random. The observed mean distance/expected mean distance is equal to 0.66. The expected distance is the average distance between neighbors in a hypothetical random distribution. If the index is less than 1 the pattern exhibits clustering. The z-score gives the significance of the statistical results. The z-score for the wineries is -5.58 standard deviations indicating that the chance that the pattern is the result of random chance is less likely (O'Sulllivan and Unwin, 2003).

The spatial statistics results, shown in Figure 35, found that Phoenix Winery and Vineyards is the central feature. This winery is located in Owensville, which is in Gasconade County. When weighted using the attractiveness of the wineries based on the number of notable wines the central feature moves to Röbller Vineyard Winery in New Haven, Franklin County. The mean center for wineries in Missouri is located in Osage County and the standard distance around the mean center includes 57 Counties out of 115. The standard distance shows the area that includes 68% of the wineries in Missouri. Using weight of attractiveness to calculate the mean center and standard distance the mean center moved to Gasconade County and the standard distance area is smaller and contains 41 Counties. The directional distribution results indicated that there is a prominent directional distribution of wineries in the NW-SE direction along the Missouri River.

According to Figure 35, it can be hypothesized that the movement of the central feature and the mean center toward the area known as the Hermann and Augusta AVAs

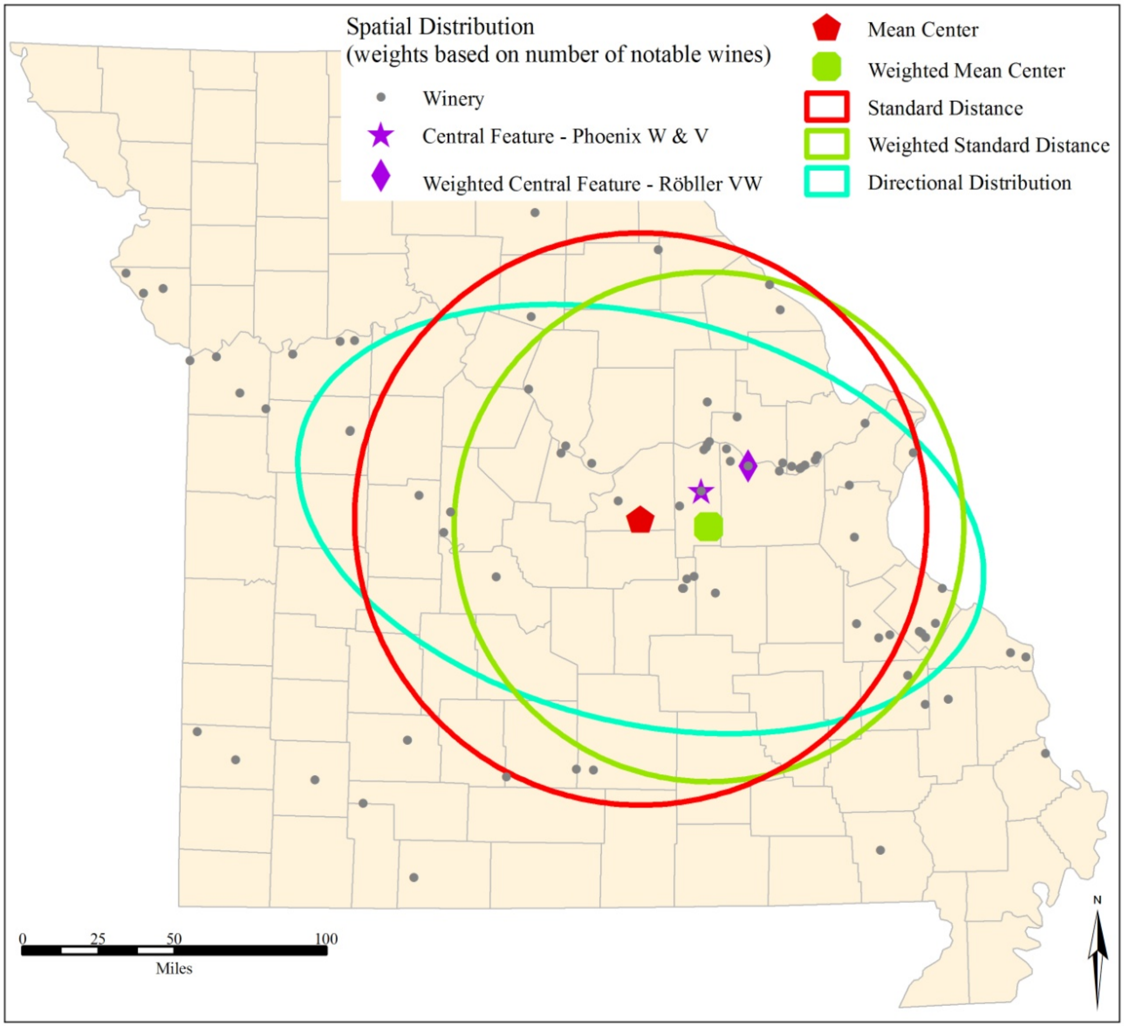


Figure 35. Map showing the spatial statistics calculated for Missouri wineries. Notice how the weighted central feature and weighted mean center both shift toward the Hermann and Augusta wine regions.

can be attributed to the long history of these areas for producing quality wines. This area has the most densely concentrated wineries based on the area, as shown in the kernel density map (Figure 36). The standard distance for the weighted mean center is also smaller because the wineries in the St. Francois and Ste. Genevieve counties are highly clustered and therefore 68% of the wineries are contained by a smaller radius.

The kernel density shows the areas where there are more wineries based on area. The kernel density is shown using the natural breaks classifier in 5 separate classes.

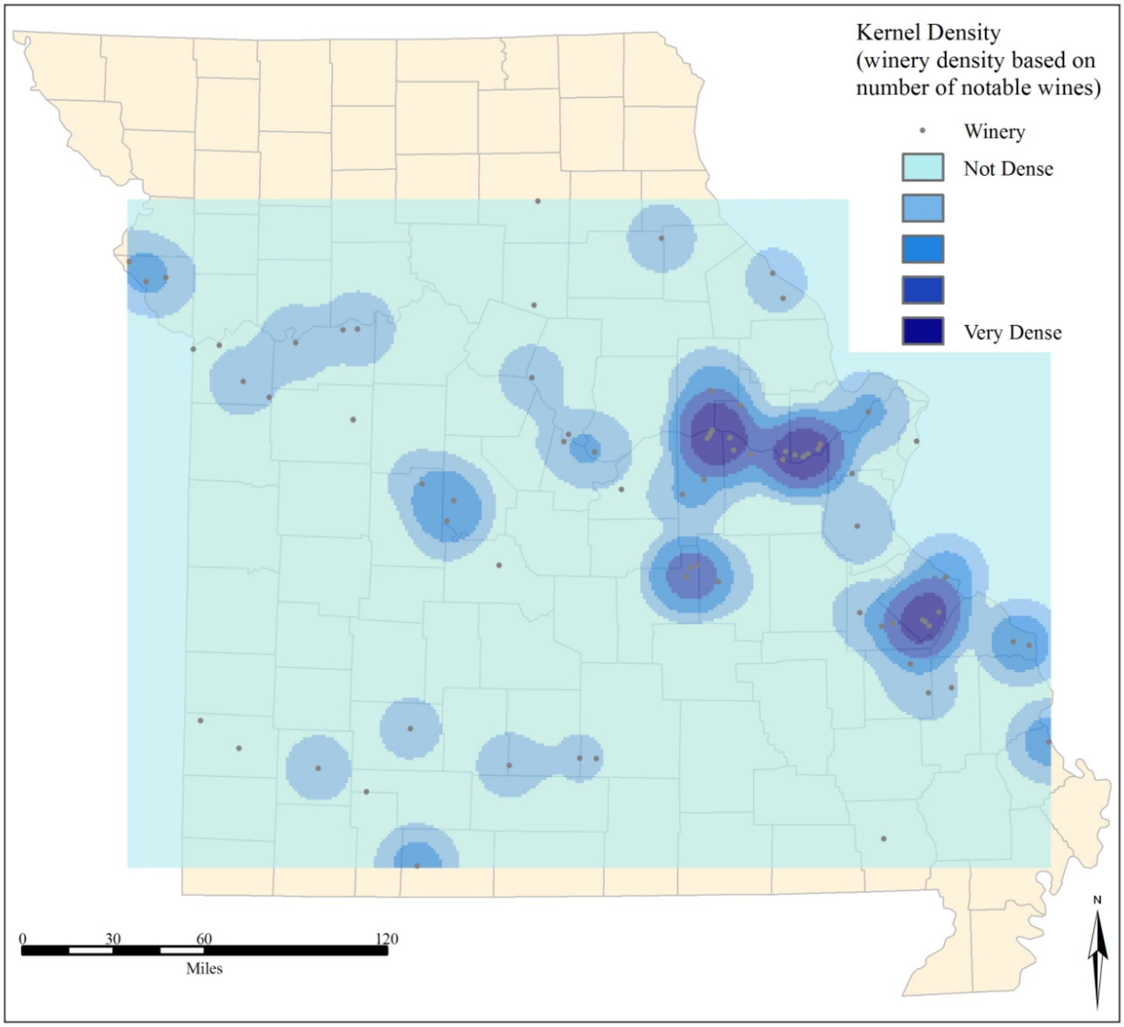


Figure 36. Kernel Density map showing where wineries are more densely concentrated by the darker blue colors.

Using this symbology allows for the most densely concentrated wineries to be shown as well as the only slightly concentrated winery areas. Wineries at the edge of the kernel density raster surface are incorrectly shown in darker colors but only because the area is smaller since it is cut off. This is only a problem for the wineries at the western edge, southern edge. and eastern edge of the map.

It is widely known that wine-lovers enjoy day trips were they can tour multiple wineries. Many of these wine tours are already promoted online at the official Missouri wine website. The wineries in these wine tours are grouped based on their wine region. As it is shown in Figure 37, the wine region attributed to each winery is not always accurate. Some wineries are labeled as being in a region that is many miles away and some are not in a wine region at all. This could be because there are tasting rooms for those wineries that I am unaware of or the winery is very new and the website has not been updated. According to the relative locations of the wineries, a new wine region map was created by visual analysis of the map (Figure 38). A new wine region has formed on the eastern side of the state, north of St. Louis.

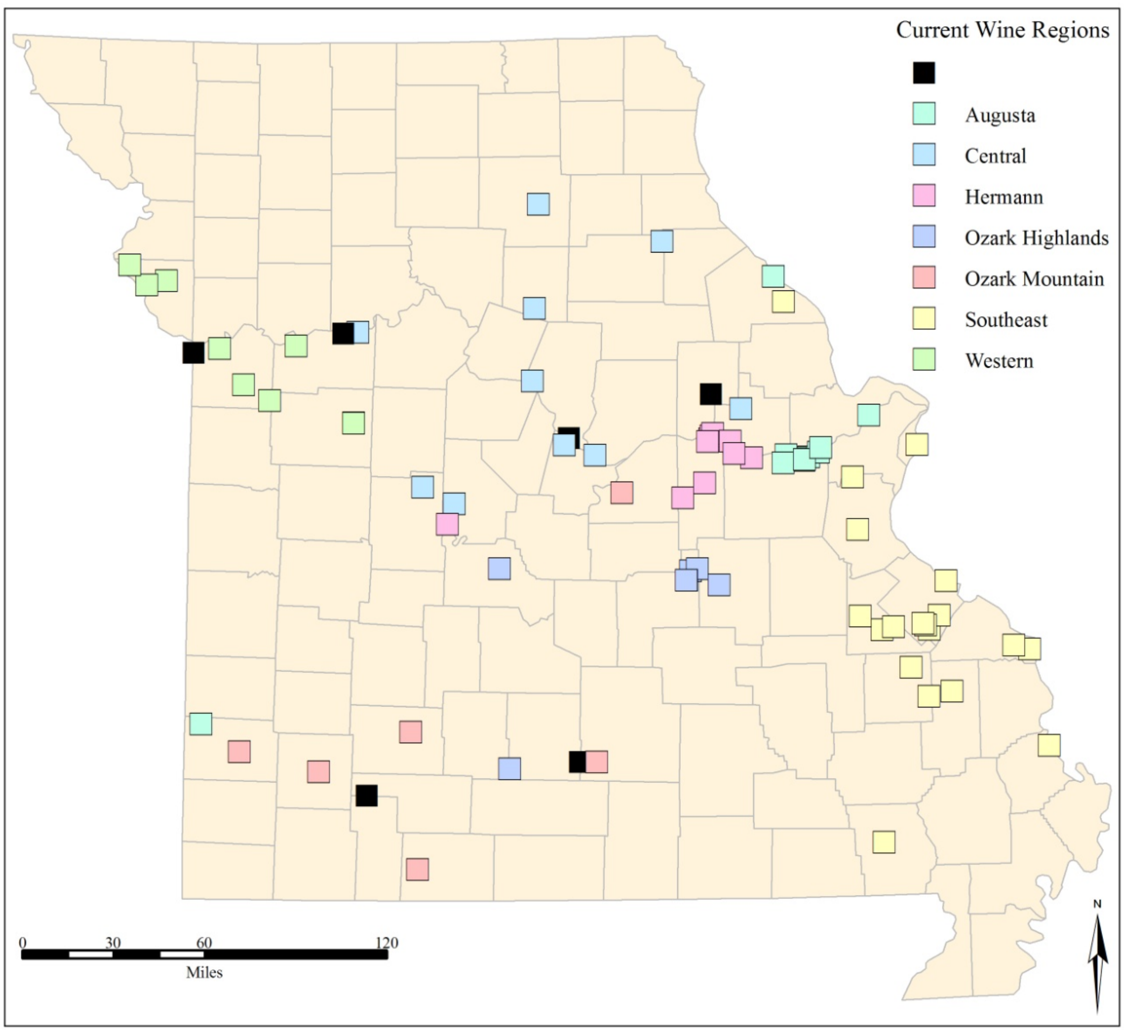


Figure. 37. Wineries in Missouri categorized by the region as designated on the Missouri wines website (Ruess and Kleinschmidt, 2009).

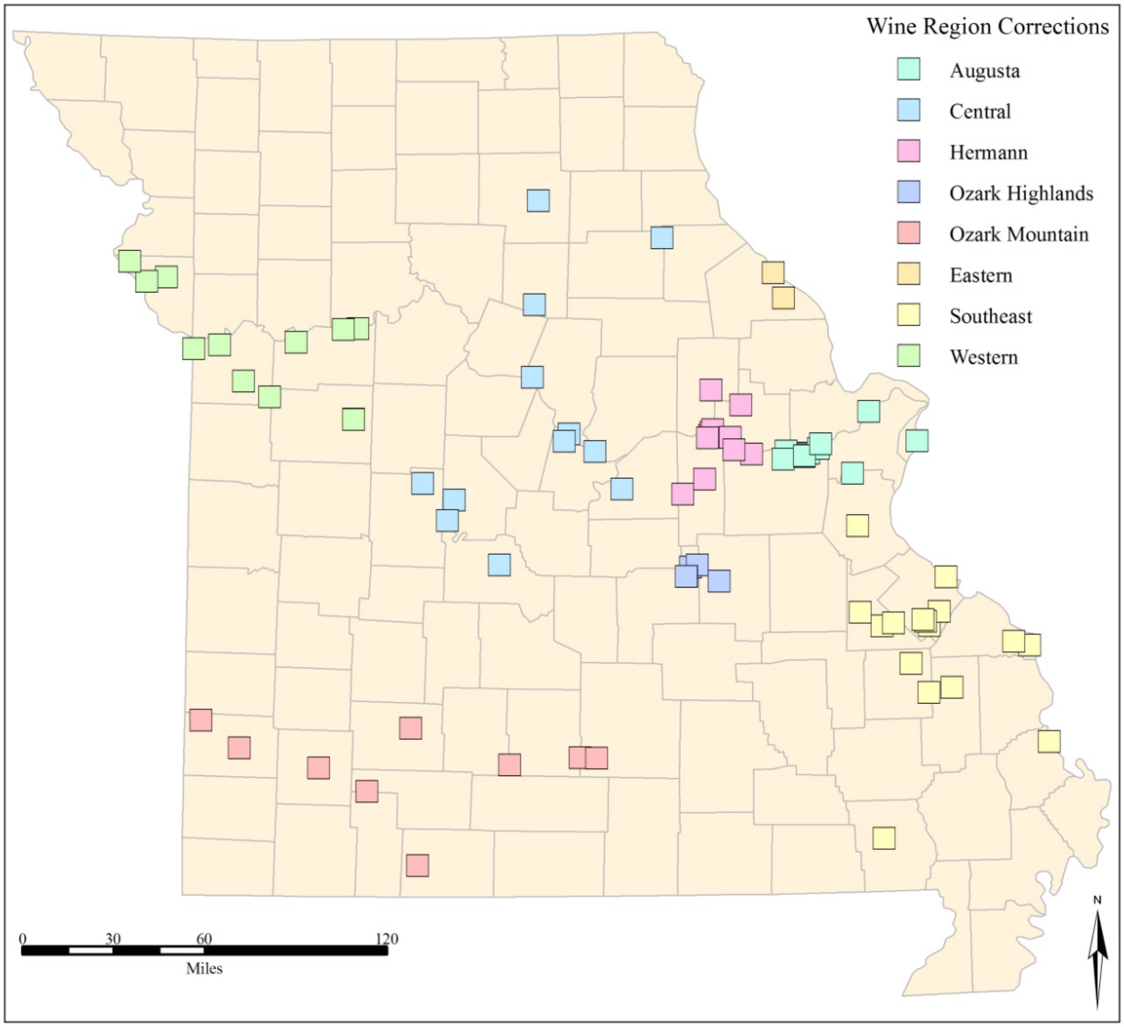


Figure 38. Wineries in Missouri designated to each wine region based on general placement properties in Missouri. This map suggests a new wine region in the east, north of St. Louis, be created (modified from a map based on Ruess and Kleinschmidt, 2009).

Service area analysis for each winery is shown as five concentric polygons in 5 kilometer increments (Figure 39). The service area is based on the road network dataset and the drive distance from each winery. Many of these polygons overlap creating an almost solid polygon trending in the NW-SE direction along the Missouri River like the direction distribution statistic.

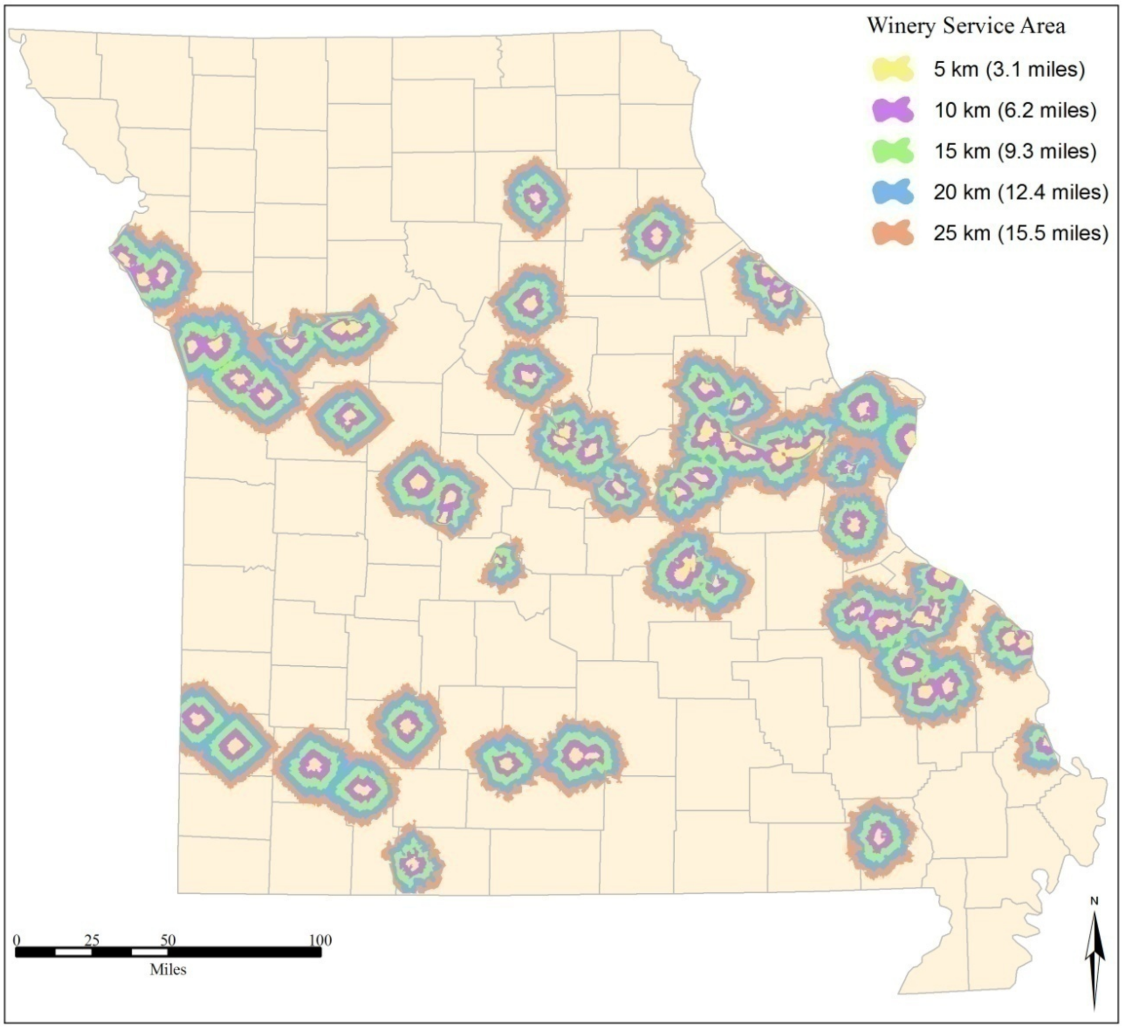


Figure 39. Service area map for Missouri wineries based on road network and driving distance time. Winery tours would be best planned where the service area polygons overlap.

The kernel density and service area map can be used to create possible one day wine tours in Missouri. These are shown in Figure 40 and overlap some of the current wine tours. The area of Missouri where these wine tours are concentrated is in a NW-SE direction along the Missouri River. It was my original intent to find areas where there were no wineries and to suggest building new ones at that location, but now I would suggest starting a winery in the areas where the wineries are already somewhat concentrated in order to enhance the wine tour of that region. Using just this information, I would suggest that an AVA be created near the Kansas City area and in the St. Francois and Ste. Genevieve counties since the clustering probably has to do with unique *terroir* characteristics and not random chance as determined by Moran's I and average nearest neighbor calculations for the vineyards found in this study.

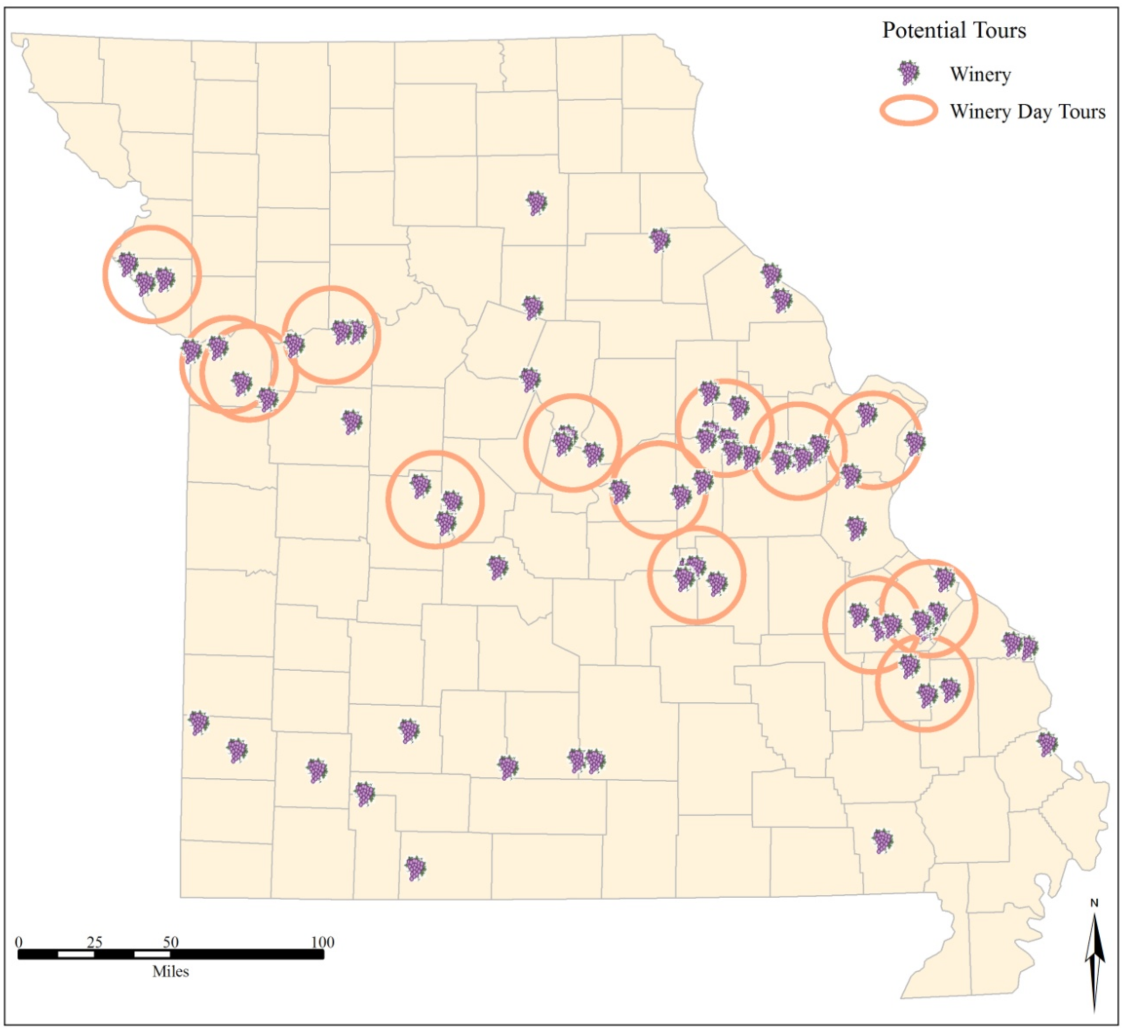


Figure 40. Possible wine tours in Missouri based on the kernel density and service area analysis.

CHAPTER 5 – DISCUSSION

Spatial relationships

It is suggested that each AVA appellation should be unique and that this uniqueness is a result of the *terroir* in that area. *Terroir*, as stated before, includes cultural and physical characteristics of the land. In order to determine if *terroir* exists in the current AVAs and other wine regions there must be a significant difference between the physical characteristics of vineyards in the AVA compared to outside the AVA. In the case of the Augusta AVA there does not seem to be a significant difference between many of the physical characteristics of *terroir*. The average elevation used for vineyards in the AVA is 182.3 ± 9.6 m and outside the average elevation is 171.5 ± 11.2 m. The average slope inside the AVA is 6.9° ± 2.8° and outside the average is 8.0° ± 3.9°. The soil type that is mostly used in the AVA is the Menfro silt loam and this same soil type is strictly used outside the boundary. In both cases the majority bedrock type that has vineyards planted on it is the Ordovician Jefferson City dolomite.

The most used aspects (direction of the slope) in the Augusta AVA are to the south and, secondly, to the east. Outside the AVA the eastern aspect is used the most, but this significance is not very significant considering the problems with determining the aspect. The southern aspect is the most used because of the hours of sunlight the canopy will receive if facing that direction. The row orientation also has an effect on sunlight that reaches the canopy so a north-south orientation is the best so both sides receive equal sunlight. Row direction may vary based on curvature of the land and the prevalent wind direction at that location (Dami, 2005). The row orientation for vineyards inside and outside the Augusta AVA is in a variety of directions. According to the data for topography (elevation, slope, aspect, and curvature), soils, and geology, there is no significant difference between the vineyards inside the AVA and outside of it. Therefore, if the *terroir* were to be defined for the Augusta AVA it would be appropriate to re-draw the boundary to include those that are immediately outside the current boundary in the description. The cultural aspects of *terroir,* like crop management techniques and wine vinification methods may distinguish the wineries inside the AVA from the outside, but the characteristics of the land studied here do not differ significantly.

For the Hermann AVA, many of the physical characteristics are also similar between the vineyards inside and outside the AVA boundary. The slope inside the AVA is 5.7° ± 2.7° and outside the AVA is 6.1° ± 1.5°. The majority soil types include the Menfro and Wrengart silt loams for both the vineyards inside and outside the AVA and the major bedrock type used are the Ordovician Jefferson City and Cotter formations. The differences lie in the average elevation and aspects for vineyards inside and outside the AVA. The average elevation used inside the boundary is 250.2 ± 40.7 m and outside the AVA the average is 190.1 ± 7.9 m. An elevation difference of 50 m can have tremendous affects on the microclimate as well in the vineyards and therefore on the flavor and quality of the wine produced from that vineyard (Haynes, 2000). The aspects that are mostly used in the AVA are the east and south, with the eastern aspect being the most common. While these two aspects are the majority for outside the AVA as well, the southern aspect is most common, but this difference is not as significant as the difference in elevations between vineyards in and out of the AVA boundary. Therefore, according to the physical characteristics of *terroir* addressed in this research, there is a difference in elevation only between the vineyards inside the Hermann AVA and outside the boundary.

It can be concluded that this characteristic is significant and could be used to restrict the inclusion of vineyards outside the AVA boundary in the Hermann AVA *terroir* description.

If not looking at elevation difference, which can have an effect on microclimate in the vineyards, there is not a very large difference between these physical characteristics when looking at the two AVAs together. While the Hermann AVA vineyards are at a higher elevation, very similar slope, soil, and geology are all used. Another difference is that the major aspect used in the Augusta AVA is to the south while the Hermann AVA aspects are mostly to the east. Both areas utilize the Menfro silt loam as the primary soil type and place vineyards on the same type of bedrock (dolomite and sandstone). The difference, then, when describing the *terroirs* of the current Augusta and Hermann AVAs would utilize the small differences in topography as well as the cultural aspects that are different.

As stated before, both the Augusta and Hermann AVAs have a German heritage, so these cultural differences would be very few. If that is the case, the *terroir* description may cover the entire area from eastern side of the Augusta AVA to the western side of the Hermann AVA noting the elevation differences. This description could include the Rocheport area, which is even farther to the west of the Hermann AVA, because the vineyards there also have similar slope, and soil type. Although, the most common aspect in the Rocheport area is to the north and the bedrock is the Mississippian Osagean Series, which is different than dolomite and sandstone and may contribute to the flavor of the wine and ultimately the *terroir* of that region. A difference in bedrock geology alone may be enough to define a distinctive *terroir* for the Rocheport area.

According to Dami (2005), the most important aspect of soil is that it is well drained, with no standing water or perched aquifer. A suitable soil will also have a pH in the range of 5.5 to 6.5 (Linhoff, 2005). The major geology types in the studied wine regions of Missouri are dolomite, sandstone, or limestone. These rock types all have porosity that contributes to the drainage of the soil and also contribute to the structure and pH of the soil. Dolomite has abundant fracture porosity because of the dolomitization process that replaces some of the calcium ions in limestone with magnesium ions (Bates and Jackson, 1984). Since magnesium ions are smaller in size than calcium ions, the volume of the crystals making up the rock decreases. This causes fractures to form throughout the dolomite, which in turn allows water to drain from the overlying soil. Sandstone, composed of medium sized sand grains and, depending on the cement used to hold these grains together, usually has a great amount of internal porosity as well as permeability (Chernicoff, 1999). Limestone, as well, is easily dissolved with slightly acidic water which creates karst porosity (Chernicoff, 1999). These three rock types are therefore very well-suited for vineyard placement.

In St. Francois and Ste. Genevieve counties there are significant differences between the physical characteristics of the vineyard sites. Firstly, the St. Francois County vineyards are located at an average elevation of 279.3 ± 7.2 m and the Ste. Genevieve County vineyards are at 217.2 ± 13.3 m elevation, a difference of over 60 m. The average slope that is used in St. Francois County is 3.1° ± 1.1° and the average slope used in Ste. Genevieve County is 5.1° ± 2.5°. The most used aspect is different between areas, with the south and eastern aspects both used equally in St. Francois County and two-thirds of the vineyards in Ste. Genevieve County only face south. These two areas both use the

Caneyville silt loam, but the Ste. Genevieve County vineyards are mostly planted on the Fourche silt loam and the second most common is the Caneyville, and some St. Francois vineyards are also planted on the Lamotte silt loam that overlies the Lamotte Sandstone.

The bedrock for each county is also different. The vineyards in St. Francois County are planted on Cambrian Lamotte Sandstone, the Elvins Group, and the Bonneterre Formation, while the Ste. Genevieve County vineyards are mostly planted on the Elvins Group and Bonneterre Formation and the Eminence and Potosi formations. In Ste. Genevieve, there are diatremes and some Precambrian St. Francis Mountain diabase dikes in the vicinity of the vineyards, which change the bedrock type significantly. These diatremes are ultramafic pipe breccias that intrude the Cambrian dolomites. The geologic structure believed to be responsible for these diatremes is reactivation of igneous activity around the perimeter of the proposed Hawn Caldera, which is a circular structure that can be seen on a DEM of the area. The Ste. Genevieve area is different than the St. Francois County vineyards and situated upon a unique structure that provides soils, elevation, and topographic elements that are consistent throughout that area. If the concept of *terroir* were to be used to create an AVA boundary, the Ste. Genevieve County vineyard area that is contained by the rim of this caldera would be unique and a viable AVA. This area also has unique geology (dolomite and diatremes); an already popular widely located soil type, and has many convex ridge-tops at the appropriate elevation. A proposed AVA boundary would encircle the Crown Valley, Chaumette, and Charleville vineyards (Figure 41).

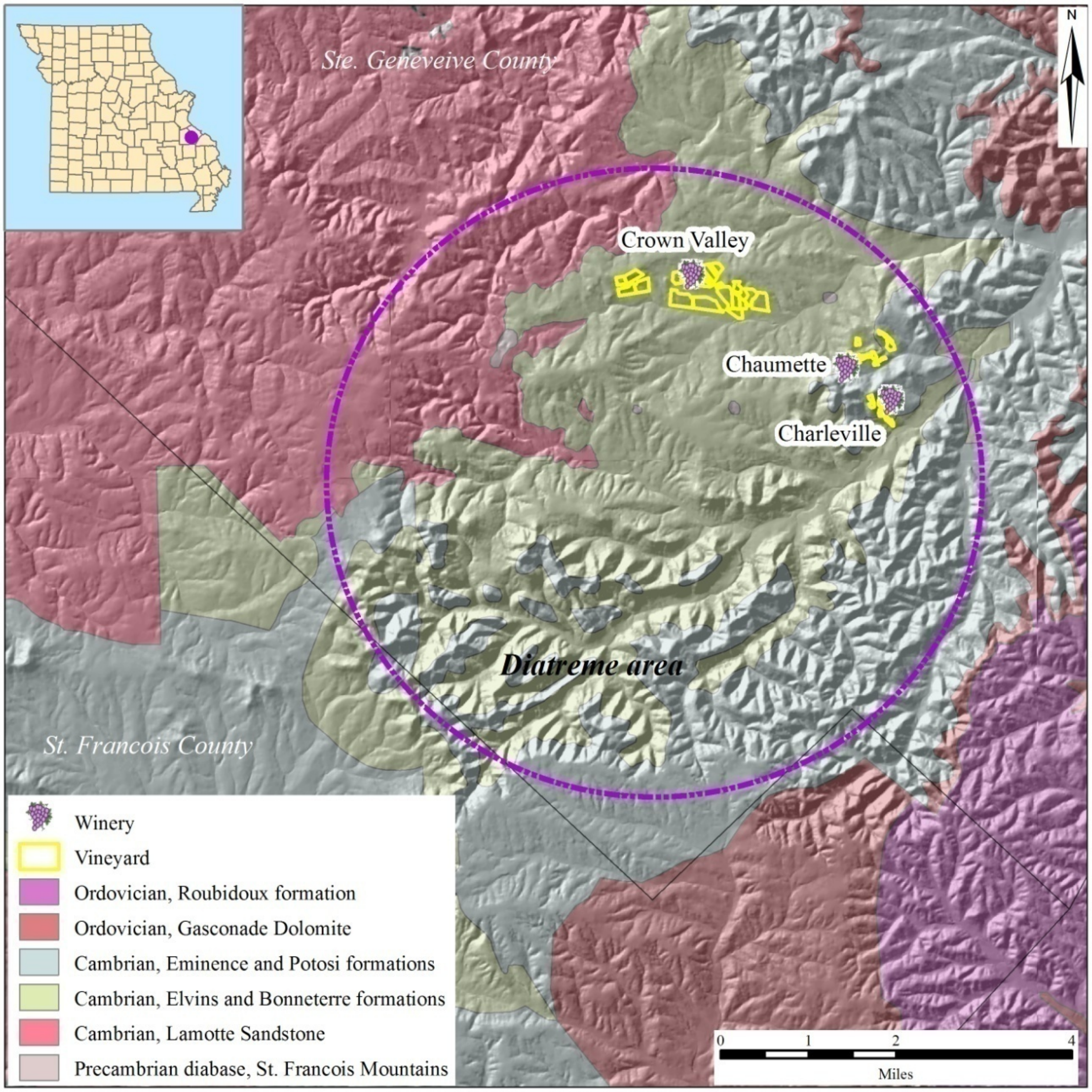


Figure 41. Proposed boundary (in dashed purple) for an AVA that includes Crown Valley, Chaumette, and Charleville Wineries and whose boundary is based on the outline of the Hawn Caldera, a unique structure that includes diatremes.

Data accuracy

Certain elements of this data are not to be taken for granted. Every time that a shapefile is converted into a raster or the aspect and curvature raster files are reclassified, some of the detail is lost. The soils maps, although created at a scale of 1:24000, have contacts that are estimated during the map creation process and the boundaries are fuzzy.

That is why any land owner should refer to these maps but should have a soil scientist visit the site and create a more detailed personal map before assuming that the property has the appropriate soil type for vineyard placement. The geologic map, at 1:500,000, is also not as detailed as one would want when investing in a vineyard. The vineyards that were classified as being on Quaternary alluvium are most likely wrongly classified because of the fuzzy quality of the boundaries of the geologic map. The data obtained for elevation and slope are stored in the geodatabases for each vineyard area and is based on a calculated average. Since the majority pixel value in each vineyard determines the outcome for aspect, curvature, soil and bedrock type, visual reference to the maps and field work is needed to verify the results. As seen in Les Bourgeois Vineyards, where the vineyards are placed on convex hill-tops, the majority pixel value for aspect may be to one direction but the vineyards actually face all four aspects.

Applications for addressing *terroir* using GIS include making suitability maps. Most of the methods used in other studies are created using information that is "common knowledge" in the wine industry and used a weighting scheme to find the "best", "second best," and so on for vineyard sites based on the assumed importance of each variable (Jones et al., 2004). Site specific suitability maps will help small vineyard owners grow a consistent product by planting certain varietals on the topography, soil, and geology that they already have planted. To make suitability maps in Missouri, the vineyards located in popular winery areas were used to find the information needed for the *terroir* characteristics. The mean and standard deviation limit the area's potential unnecessarily so the minimum and maximum values for variables like elevation and slope are the best. This range will represent what is currently under vine much better than the mean. It is also prudent to use all the soil and geology types that are under vine and not only the type that is most popular. As stated before, the potential acreage found with these suitability parameters is much more than what is actually available. Detailed road networks and land zoning maps should be used to exclude impervious concrete and asphalt surfaces and land that is not zoned for agriculture.

Future studies

Many more vineyards are located across the state and a database of each one and their attributes could be beneficial not just for research, but for the general interest of the public in *terroir* studies. The detailed analysis of the Ozark Highlands AVA, and other areas in the Ozark Mountain AVA, as well as other select areas in Missouri where many vineyards are located, like the Kansas City area, should be carried out. Future studies of the concept of *terroir* in Missouri include focusing on vine vigor assessment using NDVI and LAI from false-color satellite images similar to the studies of Dobrowski et al. (2002) in Australia. Specific soil and wine chemistry analysis should also be completed to find any possible chemical connections between the soil and the wine, which will add to the evidence supporting the concept of *terroir* in Missouri and in the United States in general.

Trace element and heavy metal studies are becoming more common when comparing wine and the soil that the grapes were grown on and this specific study would be very beneficial in the prolific wine regions of Missouri to accurately explain the flavors of their wines in relation to *terroir* (Parat, 2002). Also, by locating all vineyards in Missouri and acquiring pest and disease problems for each vineyard, the spread of these pests and disease across regions can be mapped and spatial relationships may lead to understanding how to prevent these disease. There are many more possible avenues of study on Missouri *terroir* using GIS and remote sensing which will use the collaboration of many disciplines of science.

CHAPTER 6 – CONCLUSIONS

Does terroir exist in Missouri? The concept of *terroir* is in constant debate in the United States, but the relationship between geology, soil, topography, and wine is hard to ignore. This is a question that can first be addressed by finding if and what type of commonalities are results of vineyard placement. This project used the current positions of vineyards in Missouri to find if there are underlying commonalities between their spatial locations. The vineyards and wineries in Missouri are clustered and exist based on cultural history and it can be shown from this research that they also have commonalities between bedrock geology, soil types, and topography. Since these physical attributes are used to describe *terroir* in other places, it can be concluded that the word could be used when referring to these Missouri viticultural areas.

It can be concluded that the vineyards in each AVA are clustered based on their physical characteristics. These include some of the physical parameters that are stated to have an effect on distinguishing the *terroir* of one vineyard from another. Specifically, the physical characteristics that were addressed in this study are the bedrock geology, soils, elevation, slope, aspect, and curvature. There are commonalities between vineyards located along the Missouri River in the Augusta AVA, Hermann AVA, and Rocheport area and a general description of that regions *terroir* could be made. This analysis also determined that in the St. Francois and Ste. Genevieve counties area, while there is a cluster of wineries, the physical characteristics that influence vineyard placement are unique between the counties. This uniqueness can be used to support the creation of an AVA, based on a cultural history of wine making and commonalities in topography, soil, and bedrock geology and geologic structure. There are definite commonalities between these vineyards but the concept of *terroir* is not fully addressed with only geology, soils, and topography. Since there are many wine-makers and vineyard managers involved in the cultural aspect of *terroir* in Missouri, there is much more data that is needed to separate the large regions of common *terroir* variables and the smaller *terroirs* that can occur on each winery's property. When these small *terroirs* are determined they can be used to distinguish between the *vins de pays* from the *grand crus* like in France (Haynes, 2000). Using the vineyard placement and statistics based on their spatial relationships, much more accurate AVA boundaries could be drawn in order to enhance the wine industry in Missouri.

REFERENCES

Anderson, K.H., 1979, Geologic Map of Missouri; Missouri Department of Natural Resources, Division of Geology and Land Survey, SGM-1979, 1:500,000.

Andrés-de Prado, R. de, Yuste-Rojas, M., Sort, X., Andrés-Lacueva, C., Torres, M., and Lamuela-Raventós, R.M., 2007, Effect of Soil Type on Wines Produced from *Vitis vinifera* L. Cv. Grenache in Commercial Vineyards: Journal of Agricultural and Food Chemistry, v. 55, p. 779-786.

Bargmann, C.J., 2003, Geology and Wine 7. Geology and Wine Production in the Coastal Region, Western Cape Province, South Africa: Geoscience Canada, v., 30, n. 4., p. 161-182.

Barham, E., 2002, Translating terroir: the global challenge of French AOC labeling: Journal of Rural Studies, v. 19, p. 127-138.

Barnard, K.N., and Evans, K.R., 2008a, Missouri's Terroir: Mapping the Physical Geography of the Augusta American Viticultural Area (AVA): Geological Society of America Abstracts with Program, Vol. 40, No. 5, p. 16.

Barnard, K.N., and Evans, K.R., 2008b, *Terroir* in Missouri's American Viticultural Areas Based on Remote Sensing Techniques: Geological Association of Canada Abstracts Vol. 33, p. 13.

Barnard, K.N., Evans, K.R., and Davis, G.H., 2008c, GIS Analysis of Les Bourgeois Vineyards, Les Bourgeois Vineyards, Missouri *in* Frontiers in Geology: Association of Missouri Geologists 55th Annual Meeting Field Trip Guidebook, p. 44-69.

Bates, R.L., and Jackson, J.A., 1984, Dictionary of Geological Terms, Third Edition: New York, Random House, Inc., 571 p.

Bowen, P.A., Bogdanoff, C.P., Estergaard, B.F., Marsh, S.G., Usher, K.B., Smith, C.A.S., and Frank, G., 2005, Geology and Wine 10. Use of Geographic Information System Technology to Assess Viticulture Performance in the Okanagan and Similkameen Valleys, British Columbia: Geoscience Canada, v. 32, n. 4, p. 161-176.

Bridges, D.L. and Hogan, J.P., 2008, Characterization of the Ultramafic Diatremes and Dikes of the Avon Magmatic District, Southeastern Missouri, USA: Geological Society of America Abstracts with Programs, v. 40, n. 3, p. 12.

Brooks, C., and Merenlender, A., 2000, How the GIS was used to map and quantify policy impacts: California Agriculture, v. 54, n. 3, p. 19-20.

Busacca, A.J., and Meinert, L.D., 2003, Wine and geology – Terroir of Washington State, *in* Swanson, T.W., ed., Western Cordillera and adjacent areas: Boulder, Colorado, Geological Society of America Field Guide 4, p. 69-85.

Chernicoff, S., 1999, Geology: An Introduction to Physical Geology, Second Edition: Boston, New York, Houghton Mifflin Company, 596 p.

Christensen, D., 2000, The World of Wine: Can chemical analysis confirm a wine's authenticity? : Science News 2000, v. 157, n. 1, p. 12.

Congalton, R.G., 1991, A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data: Remote Sensing of Environment, v. 37, p. 35-46.

Dami, I., Bordelon, B., Ferree, D.C., Brown, M., Ellis, M.A., Williams, R.N., Doohan, D., 2005, Midwest Grape Production Guide, Bulletin 919: Ohio State University Extension, 155 p.

Ditter, J.G., 2005, Reforming the French Wine Industry: Could clusters work?, Cahiers du CEREN, v. 13, p. 39-54.

Dobrowski, S.Z., Ustin, S.L., and Wolpert, J.A., 2002, Remote estimation of vine canopy density in vertically shoot-positioned vineyards: determining optimal vegetation indices: Australian Journal of Grape and Wine Research, v. 8, p. 117-125.

Dobrowski, S.Z., Ustin, S.L., and Wolpert, J.A., 2003, Grapevine dormant pruning weight prediction using remotely sensed data: Australian Journal of Grape and Wine Research, v. 9, p. 177-182.

Douglas, D., Cliff, M.A., and Reynolds, A.G., 2001, Canadian terroir: characterization of Riesling wines from the Niagara Peninsula: Food Research International, v. 34, p. 559-563.

Dufor, B., 2007, Exploring Missouri Wine Country: Les Bourgeois Vineyards, Pebble Publishing, 336 p.

Eccher, J. and Hollingshead, J., 2008, A Tour Of Missouri Wineries: Columbia, Estate Publishers Limited, 172 p.

Eggers, N.J., Greenough, J.D., and Cernak, T., 2006, Classification of British Columbia's Okanagan Chardonnay Wines by Origin Using Volatile Components *in* Fine Wine and Terroir: The Geoscience Perspective, ed. Macqueen, R.W. and Meinert, L.D.: Newfoundland and Labrador, Geological Association of Canada c/o Department of Earth Sciences, Memorial University of Newfoundland, 247 p.

Fischer, U., Roth, D., and Christmann, M., 1999, The impact of geographic origin, vintage and wine estate on sensory properties of *Vitis vinifera* cv. Riesling wines: Food Quality and Preference, v. 10, p. 281-288.

Gillerman, V.S., Wilkins, D., Shellie, K., and Bitner, R., 2006, Geology and Wine 11. Terroir of the Western Snake River Plain, Idaho, USA: Geoscience Canada, v. 33, n. 1, p. 37-48.

Greenough, J.D., Mallory-Greenough, L.M., and Fryer, B.J., 2005, Geology and Wine 9. Regional Trace Element Fingerprinting of Canadian Wines: Geoscience Canada, v. 32, n. 3, p. 129-137.

Haynes, S.J., 1999, Geology and Wine 1. Concept of Terroir and the Role of Geology: Geoscience Canada, v. 26, n. 4, p. 190-194.

Haynes, S.J., 2000, Geology and Wine 2. A geological foundation for *terroirs* and potential sub-*appellations* of Niagara Peninsula wines, Ontario, Canada: Geoscience Canada, v. 27, n. 2, p. 67-87.

Heaton, E., and Merenlender A., 2000, Modeling vineyard expansion, potential habitat fragmentation: California Agriculture, v. 54, n. 3, p. 12-19.

Heywood, I., Cornelius, S., and Carver, S., 2006, An Introduction To Geographical Information Systems, 3rd ed.: England, Pearson Education Limited, 426 p.

Johnson, L., Pierce, L., Michaelis, A., Scholasch, T., and Nemani, R., 2006, Remote Sensing and Water Balance Modeling in California Drip-Irrigation Vineyards: Proceedings, ASCE World Environmental and Water Resources Congress, Omaha, NE, 21-25 May.

Jones, G.V., Snead, N., and Nelson, P., 2004, Geology and Wine 8. Modeling Viticultural Landscapes: A GIS Analysis of the Terroir Potential in the Umpqua Valley of Oregon: Geoscience Canada, v. 31, n. 4, p. 167-178.

Joyce, E.B., 2004, Integrating soils, regolith and slope dynamics in the study of the terroir of wine regions in central Victoria, Australia, *in* Roach, I.C., ed., Regolith 2004: CRC LEME, p. 157-160.

Kontkanen, D., Reynolds, A.G., Cliff, M.A., King, M., 2005, Canadian terroir: sensory characterization of Bordeaux-style red wine varieties in the Niagara Peninsula: Food Research International, v. 38, p. 417-425.

Linhoff, B., 2005, Soil acidity in vineyards of the Finger Lakes of New York: 18th Annual Keck Symposium, http://keck.wooster.edu/publications.

MacNeil, K., 2001, The Wine Bible: New York, Workman Publishing, 910 p.

Maltman, A., 2003, Wine, beer and whisky: the role of geology; Geology Today, v. 19, n. 1, p. 22-29.

Meinert, LD., and Busacca, A.J., 2000, Geology and Wine 3. Terroirs of the Walla Walla Valley appellation, southeastern Washington State, USA: Geoscience Canada, v. 27, n. 4, p.149-171.

Meinert, L.D., and Busacca, A.J., 2002, Geology and Wine 6. Terroir of the Red Mountain Appellation, Central Washington State, U.S.A.: Geoscience Canada, v. 29, n. 4, p. 149-168.

Meinert, L., Curtin, T., 2005, Terroir of the Finger Lakes of New York: 18th Annual Keck Symposium, http://keck.wooster.edu/publications.

Merenlender, A., 2000, Mapping vineyard expansion provides information on agriculture and the environment: California Agriculture, v. 54, n. 3, p. 7-12.

Middendorf, M.A., ed., 2003, Geologic map of Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, 1 sheet.

Minor, Paul, E., 1995, Soil Science: Evaluation, Interpretation, and Management of Soil; Instructional Materials Laboratory, University of Missouri – Columbia, 104 p.

Missouri Department of Conservation, 1994, State Physiographic Regions of Missouri. Retrieved June 2, 2009 from http://www.msdis.missouri.edu/

Mueller, R.A.E., and Sumner, D.A., 2006, Cluster of Grapes and Wine: 3rd International Wine Business Research Conference, Montpellier, 6-7-8 July 2006.

O'Sullivan, D. and Unwin, D., 2003, Geographic Information Analysis: New Jersey, John Wiley and Sons, Inc., 436 p.

Paine, D.P. and Kiser, J.D., 2003, Aerial Photography and Image Interpretation: Wiley, 2nd edition, 648 p.

Parat, C., Chaussod, R., Lévêque, J., Dousset, S., and Andreux, F., 2002, The relationship between copper accumulated in vineyard calcareous soils and soil organic matter and iron: European Journal of Soil Science, v. 53, p. 663-669.

Pereira, G.E., Gaudillere, J.P., Leeuwen, C.V., Hilbert, G., Lavialle, O., Maucourt, M., Deborde, C., Moing, A., and Rolin, D., 2005, ^{1}H NMR and Chemometrics To Characterize Mature Grape Berries in Four Wine-Growing Areas in Bordeaux, France: Journal of Agricultural and Food Chemistry, v. 53, p. 6382-6389.

Pollack, Joe, 2007, Lucian Dressel – A talk with the man behind the first AVA in the U.S. Retrieved March 28, 2009 from http://wine.appellationamerica.com/wine-review/473/Lucian-Dressel-interview.html

Pomeral, C., 1989, The Wines and Winelands of France; Geological journeys: London, Robertson McCarta Limited, 370 p.

Reynolds, A.G., Senchuk, I.V., van der Reest, C., de Savigny, C., 2007, Use of GPS and GIS for Elucidation of the Basis for Terroir: Spatial Variation in an Ontario Riesling Vineyard: American Journal of Enology and Viticulture, v. 58, n.2, p. 145-162.

Robert, P., Rey-Debove, J., and Rey, A., 2008, Le nouveau Petit Robert de la langue francaise 2009: Educa Books/ Le Robert, 2838 p.

Ruess, C. and Kleinschmidt, C., (n.d.) Missouri Wine Regions. Retrieved March 4, 2009 from http://www.missouriwinecountry.com/regions/

Sabon, I., De Revel, G., Kotseridis, Y., and Bertrand, A., 2002, Determination of Volatile Compounds in Grenache Wines in Relation with Different Terroirs in the Rhone Valley: Journal of Agricultural and Food Chemistry, v. 50, p. 6341-6345.

Schlosser, J., Reynolds, A.G., King, M., and Cliff, M., 2005, Canadian terroir: sensory characterization of Chardonnay in the Niagara Peninsula: Food Research International, v. 38, p. 11-18.

Seguin, G., 1986, 'Terroirs' and pedology of wine growing: Experientia, v. 42, p. 861-873.

Singer, M. J., and D.N. Munns. 2005. Soils: An Introduction: 6th ed. Prentice Hall, Upper Saddle, N.J., 464 p.

Swinchatt, J., Howell, D.G., and Silacci, M., 2006, A review of Napa Valley, California, Terroir *in* Fine Wine and Terroir: The Geoscience Perspective, ed. Macqueen, R.W. and Meinert, L.D.: Newfoundland and Labrador, Geological Association of Canada c/o Department of Earth Sciences, Memorial University of Newfoundland, 247 p.

TTB - Alcohol and Tobacco Tax and Trade Bureau, 2007, Authorized wine appellations of origin – U.S. Viticultural Areas: U.S. Department of the Treasury, 9 p.

USDA - NRCS Soil Survey Staff, (2007), Natural Resources Conservation Service, United States Department of Agriculture, Official Soil Series Descriptions. Retrieved March 30, 2009 from http://soils.usda.gov/technical/classification/osd/index.html.

Vilanova, M., Zamuz, S., Vilariño, F., and Sieiro, C., 2007, Effect of *terroir* on the volatiles of *Vitis vinifera* cv. Albariño: Journal of the Science of Food and Agriculture, v. 87, p. 1252-1256.

West, J.B., Ehleringer, J.R., and Cerling, T.E., 2007, Geography and Vintage Predicted by a Novel GIS Model of Wine $\delta^{18}O$: Journal of Agriculture and Food Chemistry, v. 55, p. 7075-7083.

Watkins, R.L., Vernon F. Meyer and Assoc., Inc., 1997, Vineyard site suitability in Eastern California: GeoJournal, v. 43, i. 3, p. 229-239.

Wilson, J.E., 1998, Terroir: The role of geology, climate, and culture in the making of French wines: London, Mitchell Beazley, 336 p.

Young, F.J., Radatz, C.A., Marshall, C.A., 2001, Soil survey of Boone County, Missouri: U.S. Department of Agriculture, Natural Resources Conservation Service, 318 p.

Zarco-Tejada, P.J., Berjón, A., López-Lozano, R., Miller, J.R., Martín, P., Cachorro, V., González, M.R., and de Frutos, A., 2005, Assessing vineyard condition with hyperspectral indices: Leaf and canopy reflectance simulation in a row-structured discontinuous canopy: Remote Sensing of Environment, v. 99, p. 271-287.

APPENDICES

Appendix A – Boundary Descriptions

The official boundaries for the Approved American Viticultural Areas of Missouri in order of admittance as an official AVA are described below in the terms provided by the Alcohol and Tobacco Tax and Trade Bureau, Treasury (TTB). Viticultural Areas listed in this appendix are approved for use as appellations of origin.

Augusta AVA boundary description.

(a) *Name.* The name of the viticultural area described in this section is "Augusta."

(b) *Approved maps.* The approved maps for the Augusta viticultural area are two U.S.G.S. maps. They are titled:

(1) "Washington East, Missouri", 7.5 minute quadrangle; and

(2) "Labadie, Missouri", 7.5 minute quadrangle.

(c) *Boundaries.* The boundaries of the Augusta viticultural area are located in the State of Missouri and are as follows:

(1) The beginning point of the boundary is the intersection of the St. Charles County line, the Warren County line and the Franklin County line.

(2) The western boundary is the St. Charles County-Warren County line from the beginning point to the township line identified on the approved maps as "T45N/T44N."

(3) The northern boundary is the township line "T45N/T44N" from the St. Charles County-Warren County line to the range line identified on the approved maps as "R1E/R2E."

(4) The eastern boundary is the range line “R1E/R2E” from township line “T45N/T44N” extended to the St. Charles County-Franklin County line.

(5) The southern boundary is the St. Charles County-Franklin County line from the extension of range line “R1E/R2E” to the beginning point.

[T.D. ATF–72, 45 FR 41633, June 20, 1980]

Hermann AVA boundary description.

(a) *Name.* The name of the viticultural area described in this section is “Hermann.”

(b) *Approved maps.* The appropriate maps for determining the boundaries of the Hermann viticultural area are six U.S.G.S. Missouri Quadrangle maps, 7.5 minute series. They are entitled:

(1) Hermann (1974).

(2) Berger (1974).

(3) Gasconade (1974).

(4) Pershing (1974).

(5) Swiss (1973).

(6) Dissen (1973).

(c) *Boundaries.* The Hermann viticultural area is located in central Missouri along and south of the Missouri River, in the northern portions of Gasconade and Franklin Counties. The boundaries of the Hermann viticultural area, using landmarks and points of reference found on the appropriate U.S.G.S. maps, are as follows:

(1) Starting at the intersection of the Gasconade River with the Missouri River.

(2) Then continuing east and northeast approximately 16.5 miles along the Missouri River Pacific Railroad, as it parallels the Missouri River, to the Gasconade/Franklin County line.

(3) Then continuing along the Missouri Pacific Railroad southeast approximately 8.5 miles to the intersection Big Berger Creek.

(4) Then southwest along the winding course of Big Berger Creek for approximately 20 miles (eight miles due southwest) to Township line T.44/45N.

(5) Then west along the T.44/45N. line approximately 15.5 miles to the intersection of First Creek.

(6) Then north and northwest along the course of First Creek approximately 13.7 miles (6.5 miles straight northwest) to the intersection of the Gasconade River.

(7) Then northeast along the course of the Gasconade River approximately 3.8 miles to the beginning point.

[T.D. ATF–136, 48 FR 37372, Aug. 18, 1983, as amended by T.D. ATF–249, 52 FR 5959, Feb. 27, 1987]

Ozark Mountain AVA boundary description.

(a) *Name.* The name of the viticultural area described in this section is "Ozark Mountain."

(b) *Approved maps.* The appropriate maps for determining the boundaries of Ozark Mountain viticultural area are 11 U.S.G.S. maps in the scale of 1:250,000. They are titled—

(1) St. Louis, Missouri (1963, revised 1969);

(2) Jefferson City, Missouri (1955, revised 1970);

(3) Springfield, Missouri (1954, revised 1969);

(4) Joplin, Missouri; Kansas (1954, revised 1974);

(5) Tulsa, Oklahoma; Arkansas; Missouri; Kansas (1958, revised 1973);

(6) Fort Smith, Arkansas-Oklahoma (1978);

(7) Russellville, Arkansas (compiled in 1954);

(8) Memphis, Tennessee; Arkansas; Missouri (1953, revised 1978);

(9) Poplar Bluff, Missouri; Arkansas (1957, revised 1978);

(10) Paducah, Kentucky; Illinois; Missouri; Indiana (1949, revised 1969);

(11) Rolla, Missouri; Illinois (1954, revised 1969).

(c) *Boundary*—

(1) *General.* The Ozark Mountain viticultural area is located in Missouri, Oklahoma, and Arkansas. The starting point of the following boundary description is the point at which the Missouri River joins the Mississippi River north of St. Louis, Missouri (on the St. Louis map).

(2) *Boundary Description.*

(i) The boundary proceeds from the starting point westward along the Missouri River until it meets the Osage River;

(ii) Then further westward along the Osage River (flowing through Lake of the Ozarks and the Harry S. Truman Reservoir) until it passes adjacent to Missouri Highway 82 in Osceola, Missouri (on the Jefferson City map);

(iii) Then southwestward along Missouri Highway 82 until it intersects U.S. Highway 54 in Eldorado Springs, Missouri (on the Joplin map);

(iv) Then westward along U.S. Highway 54 until it intersects U.S. Highway 71 near Nevada, Missouri;

(v) Then southward along U.S. Highway 71 until it intersects Interstate Highway 44, approximately 5 miles south of Carthage, Missouri;

(vi) Then westward and southwestward along Interstate Highway 44 into the State of Oklahoma, and continuing southwestward until Interstate Highway 44 crosses the Neosho River near Miami, Oklahoma (on the Tulsa map);

(vii) Then southward along the Neosho River (flowing through the Lake of the Cherokees, Lake Hudson, and Fort Gibson Lake) until it flows into the Arkansas River, approximately 2 miles west of Fort Gibson, Oklahoma (on the Fort Smith map);

(viii) Then southward and eastward along the Arkansas River (flowing through the Robert S. Kerr Lake) into the State of Arkansas, and continuing eastward until the Arkansas River is joined by Vache Grasse Creek, approximately 4 miles east of Barling, Arkansas;

(ix) Then southeastward and southwestward following Vache Grasse Creek to the place where it is crossed by Arkansas Highway 10, near Greenwood, Arkansas;

(x) Then westward along Highway 10 to U.S. Highway 71. Note: Highway 10 is the primary highway leading from Greenwood to Hackett, Arkansas;

(xi) Then southward and eastward along Highway 71 until it crosses Rock Creek;

(xii) Then northeastward along Rock Creek to Petit Jean Creek;

(xiii) Then generally northeastward and eastward along Petit Jean Creek until it becomes the Petit Jean River (on the Russellville map);

(xiv) Then generally eastward along the Petit Jean River, flowing through Blue Mountain Lake, until the Petit Jean River joins the Arkansas River;

(xv) Then generally eastward along the Arkansas River to Cadron Creek;

(xvi) Then northeastward and eastward along Cadron Creek, for about 21⁄2 miles, until it passes under U.S. Highway 64, approximately 31⁄2 miles west of Conway, Arkansas;

(xvii) Then eastward along U.S. Highway 64 until it intersects U.S. Highway 67, near Beebe, Arkansas (on the Memphis map);

(xviii) Then northeastward along U.S. Highway 67 into the state of Missouri, then northward until U.S. Highway 67 intersects U.S. Highway 60, in Poplar Bluff, Missouri (on the Poplar Bluff map);

(xix) Then eastward along U.S. Highway 60 until it crosses the western boundary of Stoddard County. Note: Here that boundary is the St. Francis River;

(xx) Then northward, northeastward, and eastward along the boundary of Stoddard County until it joins the southern boundary of Cape Girardeau County (on the Cape Girardeau map);

(xxi) Then northeastward along the Cape Girardeau County boundary until it meets the Mississippi River south of Cape Girardeau, Missouri;

(xxii) Then northward along the Mississippi River to the starting point.

[T.D. ATF–231, 51 FR 24144, July 2, 1986; 51 FR 25366, July 14, 1986]

Ozark Highlands AVA boundary description.

(a) *Name.* The name of the viticultural area described in this section is "Ozark Highlands."

(b) *Approved maps.* The appropriate maps for determining the boundaries of the Ozark Highlands viticultural area are three U.S.G.S. maps of the 1:250,000 series. They are titled:

(1) Rolla, Missouri; Illinois, 1954 (revised 1969).

(2) St. Louis, Missouri; Illinois, 1963 (revised 1969).

(3) Springfield, Missouri, 1954 (revised 1969).

(c) *Boundary*—

(1) *General.* The Ozark Highlands viticultural area is located in south central Missouri. The area comprises portions of the following counties: Phelps, Maries, Osage, Gasconade, Franklin, Crawford, Texas, Shannon, Dent, Reynolds, and Pulaski. The beginning point of the following boundary description is the junction of Little Piney Creek and the Gasconade River, near Jerome, Missouri (in the northwest corner of the Rolla map).

(2) *Boundary Description.*

(i) From the beginning point, the boundary goes northward along the Gasconade River to the latitude line 38°00′ (the dividing line between the Rolla and St. Louis maps);

(ii) Then eastward along that latitude line to U.S. Highway 63;

(iii) Then northward along U.S. 63 to Spring Creek;

(iv) Then north-northwestward along Spring Creek to the Gasconade River;

(v) Then northward along the Gasconade River to a power transmission line (less than 1 mile north of Buck Elk Creek);

(vi) Then eastward and east-northeastward along that power transmission line to Missouri Route 19;

(vii) Then southward along Route 19 to the Bourbeuse River;

(viii) Then east-northeastward along the Bourbeuse River to the range line dividing R. 2 W. and R. 1 W.;

(ix) Then southward along that range line to the Meramec River;

(x) Then southwestward along the Meramec River to Huzzah Creek;

(xi) Then southward along Huzzah Creek to Dry Creek (on the Rolla map, where Missouri Route 8 crosses Huzzah Creek);

(xii) Then southward along Dry Creek to Cherry Valley Creek;

(xiii) Then south-southwestward along Cherry Valley Creek to Missouri Route 19;

(xiv) Then southward and southwestward along Route 19 to Crooked Creek;

(xv) Then northwestward along Crooked Creek to the Meramec River;

(xvi) Then southward along the Meramec River to Hutchins Creek;

(xvii) The southeastward along Hutchins Creek to its source near Missouri Route 32, across from the Howes Mill Post Office;

(xviii) Then in a straight line toward the Howes Mill Post Office to Route 32;

(xix) Then eastward along Route 32 to the range line dividing R. 3 W. and R. 2 W.;

(xx) Then southward along that range line to the township line dividing T. 33 N. and T. 32 N.;

(xxi) Then westward along that township line (which coincides, in R. 3 W., with the Reynolds County/Dent County line) to the boundary of Clark National Forest;

(xxii) Then generally southward along that national forest boundary to the Dent County/Shannon County line;

(xxiii) Then westward along that county line to the Current River;

(xxiv) Then southeastward along the Current River to Missouri Route 19;

(xxv) Then southward along Route 19 to Jack's Fork;

(xxvi) Then westward, southwestward and northwestward along Jack's Fork, taking the North Prong, to its northwestern most source;

(xxvii) Then in a straight line northwestward to the southeastern most source of Hog Creek;

(xxviii) Then northwestward along Hog Creek to the Big Piney River (on the Springfield map);

(xxix) Then northward along the Big Piney River to the township line dividing T. 35 N. and T. 36 N.;

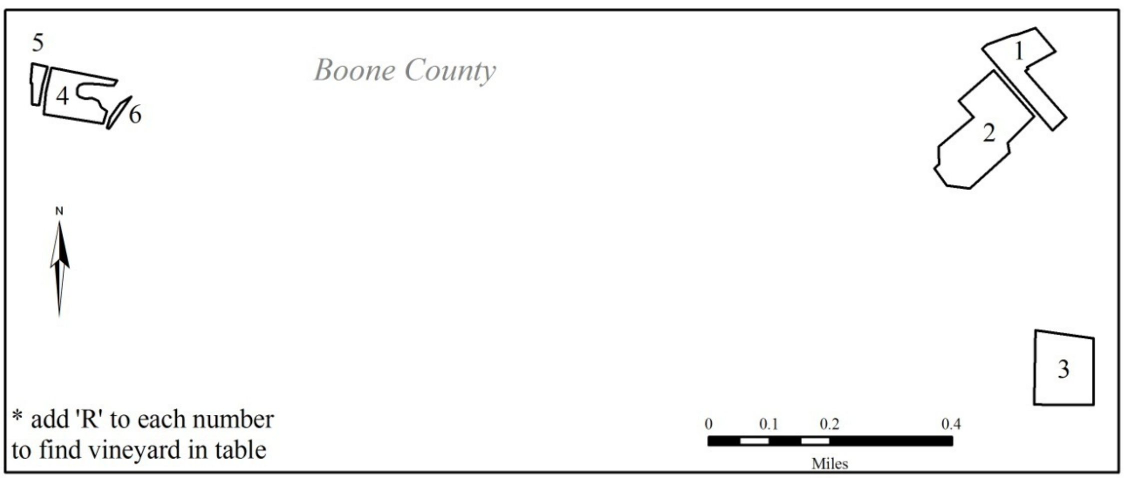
(xxx) Then eastward along that township line to Little Piney Creek (on the Rolla map);

(xxxi) Then northward and westward along Little Piney Creek to the beginning point.

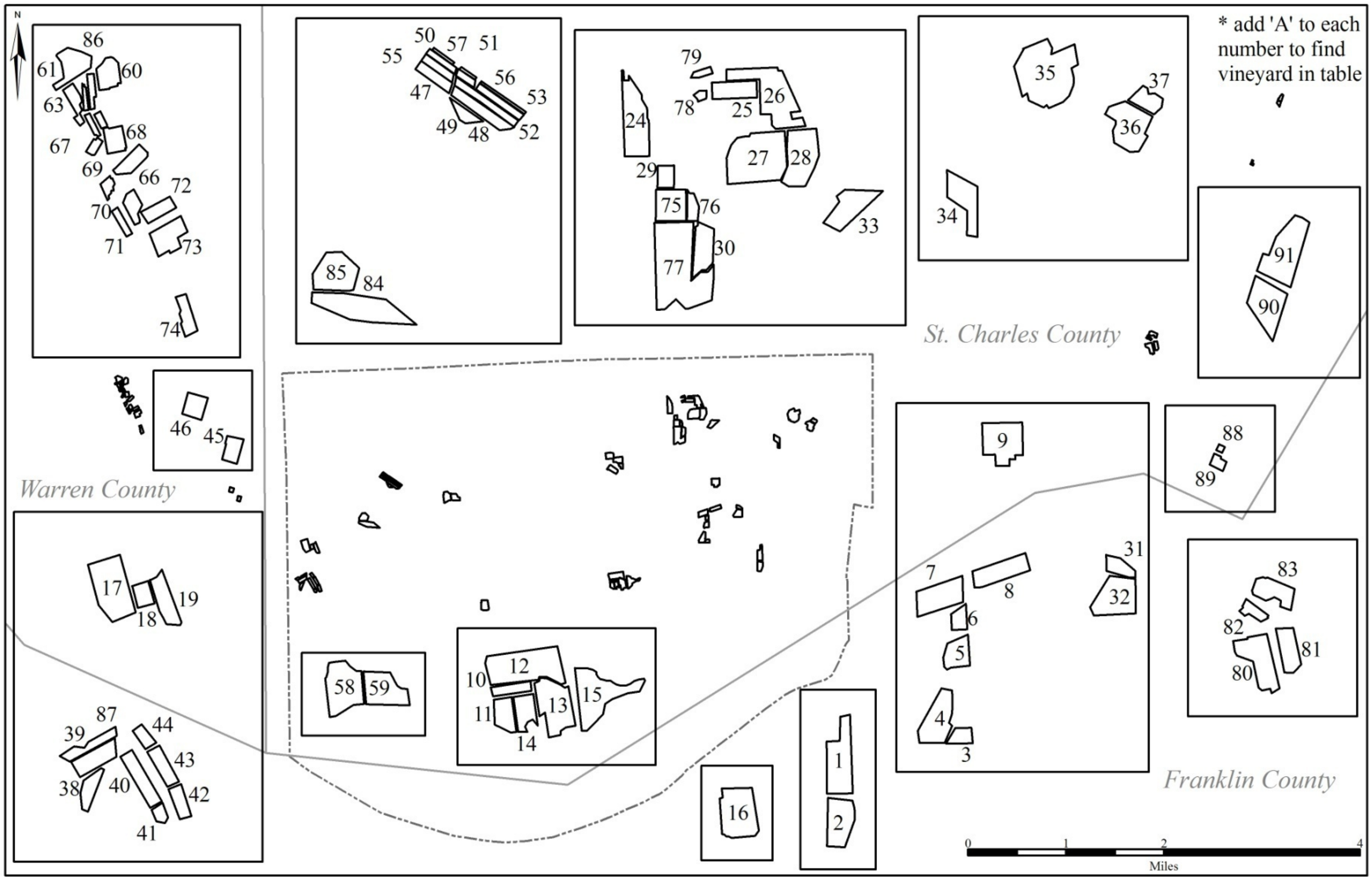
[T.D. ATF–256, 52 FR 32785, Aug. 31, 1987]

Appendix B – Vineyard Reference Maps and Data

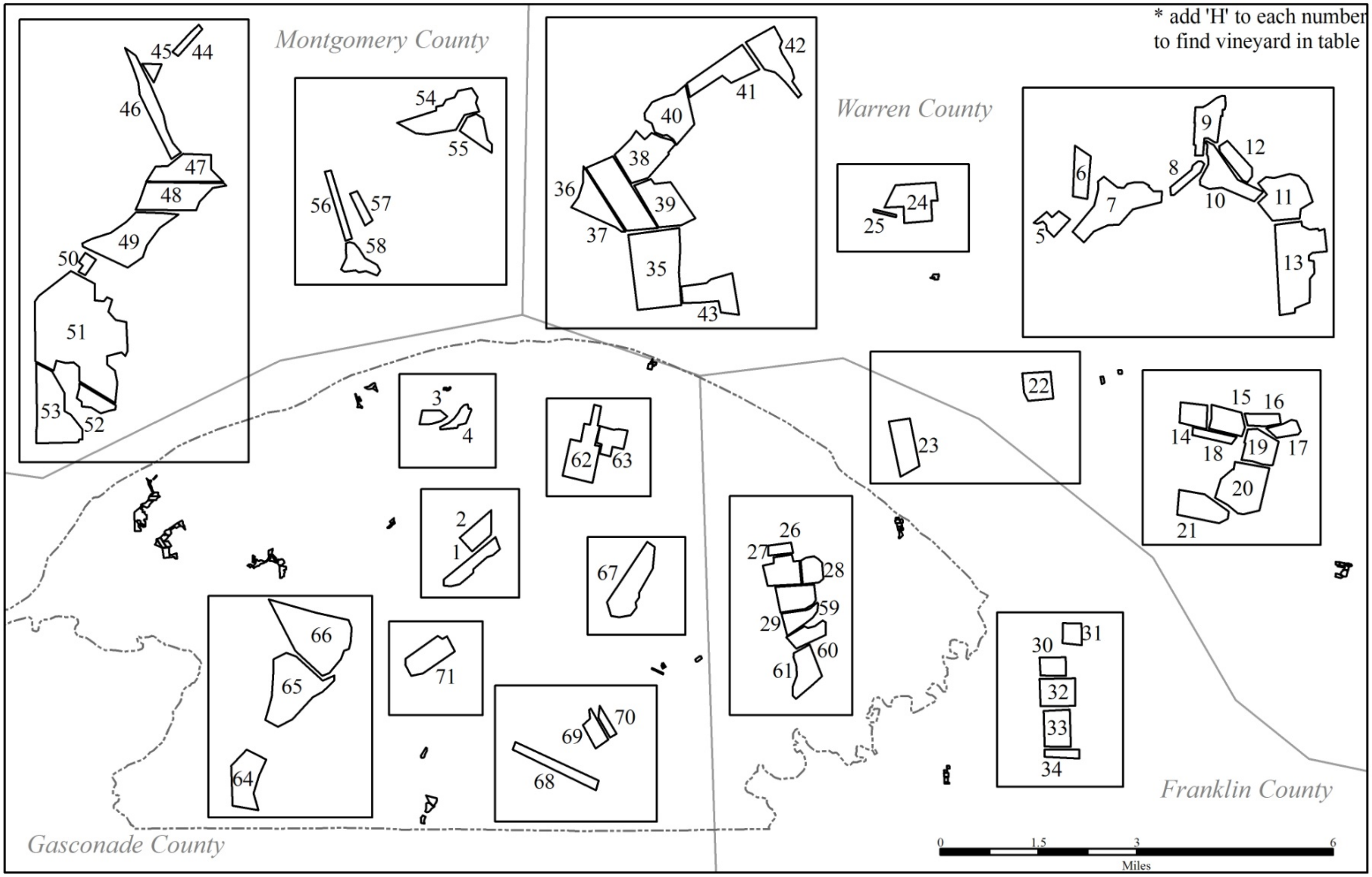
These maps are included in order to find specific information on certain *terroir* attributes for each vineyard in this study. Each vineyard is given a number and letter code based on what study area in which they are included. These codes are 1A to 91A, 1H to 72H, 1R to 6R, and 1S to 64S for the Augusta AVA and surrounding area, the Hermann AVA and surrounding area, the Rocheport area, and the St. Francois and Ste. Genevieve Counties, respectively.



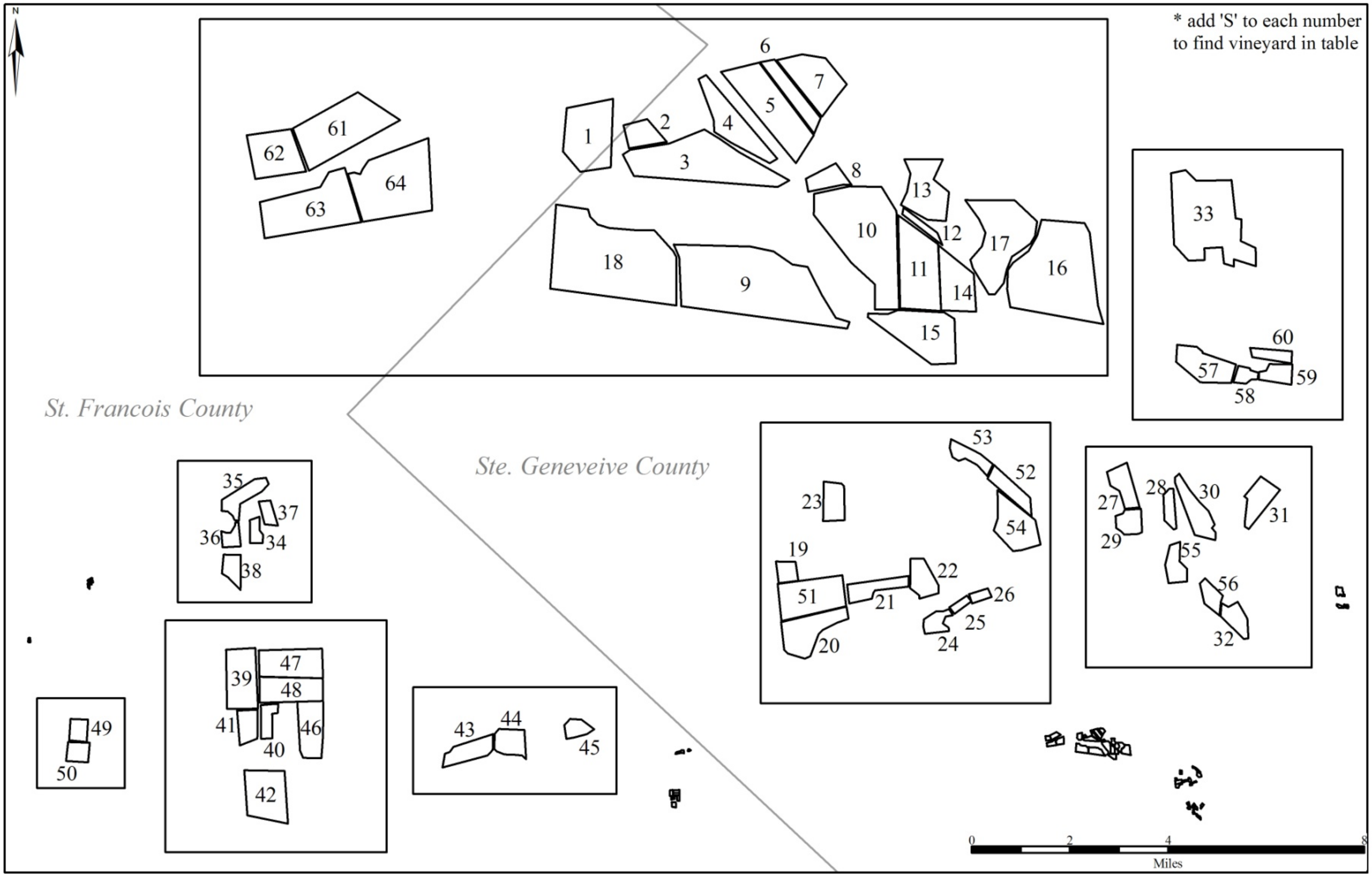
Appendix B-1. Rocheport area reference map showing Les Bourgeois Vineyards located in Boone County (1:20,000). See Appendix E for *terroir* details for each vineyard.



Appendix B-2. Augusta AVA reference map showing many vineyard clusters (1:20,000) in relation to counties and AVA boundary.



Appendix B-3. Hermann AVA reference map showing vineyard clusters (1:20,000) in relation to the counties and AVA boundary.



Appendix B-4. St. Francois and Ste. Genevieve County's reference map showing vineyard clusters (1:20,000) in relation to county boundaries.

Appendix B-5. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
1A	Mount Pleasant Winery	n/a	N	East	Convex
2A	Mount Pleasant Winery	n/a	N	South	Convex
3A	Mount Pleasant Winery	n/a	E	South	Concave
4A	Mount Pleasant Winery	n/a	NE	West	Convex
5A	Mount Pleasant Winery	n/a	N	West	Convex
6A	Mount Pleasant Winery	n/a	N	West	Convex
7A	Mount Pleasant Winery	n/a	NE	South	Convex
8A	Mount Pleasant Winery	Vidal Blanc	NE	West	Convex
9A	Independent	n/a	N	West	Convex
10A	Mount Pleasant Winery	n/a	E	South	Concave

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
11A	Mount Pleasant Winery	n/a	N	West	Convex
12A	Mount Pleasant Winery	n/a	E	South	Convex
13A	Mount Pleasant Winery	n/a	N	South	Concave
14A	Mount Pleasant Winery	n/a	N	South	Concave
15A	Mount Pleasant Winery	n/a	E	East	Convex
16A	Independent	n/a	N	East	Convex
17A	Mount Pleasant Winery	n/a	SE	West	Convex
18A	Mount Pleasant Winery	n/a	NE	South	Convex
19A	Mount Pleasant Winery	n/a	SE	East	Convex
20A	Independent	n/a	E	North	Convex

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
21A	Independent	n/a	E	South	Convex
22A	Independent	n/a	NE	South	Convex
23A	Independent	n/a	E	South	Concave
24A	Mount Pleasant Winery	n/a	N	East	Convex
25A	Mount Pleasant Winery	n/a	E	South	Convex
26A	Mount Pleasant Winery	n/a	E	South	Convex
27A	Mount Pleasant Winery	n/a	E	South	Convex
28A	Mount Pleasant Winery	n/a	N	South	Convex
29A	Mount Pleasant Winery	n/a	E	East	Convex
30A	Mount Pleasant Winery	n/a	N	East	Convex

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
31A	Mount Pleasant Winery	n/a	E	South	Convex
32A	Mount Pleasant Winery	n/a	E	South	Convex
33A	Mount Pleasant Winery	n/a	NE	South	Convex
34A	Independent	n/a	N	South	Convex
35A	Montelle Winery	n/a	NE	South	Convex
36A	Montelle Winery	n/a	SE	South	Convex
37A	Montelle Winery	n/a	SE	South	Convex
38A	Mount Pleasant Winery	n/a	NE	East	Convex
39A	Mount Pleasant Winery	n/a	NE	North	Convex
40A	Mount Pleasant Winery	n/a	SE	East	Convex

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
41A	Mount Pleasant Winery	n/a	SE	East	Convex
42A	Mount Pleasant Winery	n/a	SE	East	Concave
43A	Mount Pleasant Winery	n/a	SE	East	Concave
44A	Mount Pleasant Winery	n/a	SE	East	Convex
45A	Blumenhof Vineyards & Winery	Chambourcin	N	East	Convex
46A	Blumenhof Vineyards & Winery	Chambourcin	N	West	Concave
47A	Independent	n/a	SE	South	Concave
48A	Independent	n/a	SE	South	Concave
49A	Independent	n/a	SE	South	Convex
50A	Independent	n/a	SE	South	Concave

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
51A	Independent	n/a	SE	South	Concave
52A	Independent	n/a	SE	South	Convex
53A	Independent	n/a	SE	South	Concave
54A	Independent	n/a	SE	South	Concave
55A	Independent	n/a	SE	South	Concave
56A	Independent	n/a	SE	South	Concave
57A	Independent	n/a	SE	South	Concave
58A	Balducci Vineyards	Vidal Blanc	E	North	Convex
59A	Balducci Vineyards	Chardonel	E	North	Convex
60A	Blumenhof Vineyards & Winery	Traminette	N	East	Convex

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
61A	Blumenhof Vineyards & Winery	Traminette	N	East	Convex
62A	Blumenhof Vineyards & Winery	Traminette	N	East	Convex
63A	Blumenhof Vineyards & Winery	Traminette	SE	West	Convex
64A	Blumenhof Vineyards & Winery	Traminette	SE	East	Convex
65A	Blumenhof Vineyards & Winery	Traminette	SE	East	Concave
66A	Blumenhof Vineyards & Winery	Vignoles	NE	East	Convex
67A	Blumenhof Vineyards & Winery	Traminette	NE	East	Convex
68A	Blumenhof Vineyards & Winery	Traminette	N	East	Convex
69A	Blumenhof Vineyards & Winery	Vignoles	SE	South	Convex
70A	Blumenhof Vineyards & Winery	Chardonel	SE	West	Concave

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
71A	Blumenhof Vineyards & Winery	Chardonel	SE	North	Convex
72A	Blumenhof Vineyards & Winery	Chardonel	NE	North	Convex
73A	Blumenhof Vineyards & Winery	Chardonel	NE	North	Convex
74A	Blumenhof Vineyards & Winery	Chardonel	N	East	Convex
75A	Mount Pleasant Winery	n/a	E	East	Convex
76A	Mount Pleasant Winery	n/a	E	East	Convex
77A	Mount Pleasant Winery	n/a	E	South	Concave
78A	Mount Pleasant Winery	n/a	E	West	Concave
79A	Mount Pleasant Winery	n/a	NE	West	Convex
80A	Sugar Creek Winery	Norton	N	West	Convex

Appendix B-5. Continued. Augusta AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
81A	Sugar Creek Winery	Chambourcin	N	North	Convex
82A	Sugar Creek Winery	Vidal Blanc	E	South	Concave
83A	Sugar Creek Winery	Chardonel	SE	East	Convex
84A	Independent	Vignoles	SE	East	Concave
85A	Independent	Vignoles	NE	East	Concave
86A	Blumenhof Vineyards & Winery	Chardonel	NE	North	Convex
87A	Mount Pleasant Winery	n/a	NE	North	Convex
88A	Yellow Farmhouse Vineyards	n/a	NE	East	Concave
89A	Yellow Farmhouse Vineyards	n/a	N	East	Convex
90A	Yellow Farmhouse Vineyards	n/a	N	East	Concave
91A	Yellow Farmhouse Vineyards	n/a	N	East	Convex

Appendix B-6. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
1A	4.22	1.71	12.01	11.78	617.42	188.19
2A	3.05	1.23	6.71	7.52	585.10	178.34
3A	0.88	0.36	4.30	12.66	578.07	176.19
4A	3.40	1.37	7.21	8.78	582.13	177.43
5A	1.79	0.73	5.01	4.73	585.25	178.38
6A	0.85	0.34	2.71	11.50	593.75	180.98
7A	3.19	1.29	6.55	12.67	599.78	182.81
8A	2.74	1.11	7.21	1.91	624.11	190.23
9A	3.91	1.58	1.09	13.69	637.68	194.36
10A	1.00	0.40	7.77	12.87	561.49	171.14

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
11A	1.62	0.66	7.33	8.44	544.16	165.86
12A	6.05	2.45	4.82	11.68	583.25	177.77
13A	4.20	1.70	6.65	8.22	562.87	171.56
14A	1.65	0.67	4.69	6.23	549.24	167.41
15A	4.99	2.02	3.56	7.99	554.65	169.06
16A	4.42	1.79	4.56	15.48	584.58	178.18
17A	5.28	2.14	8.78	11.23	585.86	178.57
18A	1.04	0.42	6.40	7.08	600.49	183.03
19A	2.16	0.87	4.04	10.81	585.74	178.53
20A	2.90	1.18	6.16	12.81	572.34	174.45

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
21A	3.36	1.36	7.29	9.57	576.70	175.78
22A	3.14	1.27	5.45	11.11	558.51	170.23
23A	1.14	0.46	6.34	9.51	549.80	167.58
24A	4.52	1.83	5.43	3.49	601.77	183.42
25A	2.01	0.81	2.00	12.04	624.29	190.28
26A	5.77	2.34	6.86	10.29	628.50	191.57
27A	7.19	2.91	5.87	6.39	585.40	178.43
28A	4.33	1.75	3.65	5.90	583.49	177.85
29A	0.96	0.39	3.37	9.19	597.94	182.25
30A	2.32	0.94	5.24	7.83	566.68	172.73

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
31A	1.08	0.44	4.47	15.68	652.80	198.97
32A	3.70	1.50	8.91	11.89	618.46	188.51
33A	3.08	1.25	6.77	9.97	585.95	178.60
34A	2.98	1.21	5.68	9.21	582.93	177.68
35A	8.18	3.31	5.26	15.88	597.79	182.21
36A	3.98	1.61	9.02	10.45	597.48	182.11
37A	1.38	0.56	5.96	18.35	637.58	194.33
38A	1.33	0.54	10.39	15.61	645.14	196.64
39A	2.10	0.85	8.86	18.43	620.60	189.16
40A	2.12	0.86	10.43	13.24	599.46	182.71

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
41A	0.55	0.22	7.52	12.59	591.26	180.22
42A	1.14	0.46	7.17	17.31	554.78	169.10
43A	1.43	0.58	9.80	15.95	556.73	169.69
44A	0.72	0.29	9.06	18.25	555.38	169.28
45A	1.05	0.43	10.34	13.25	579.41	176.60
46A	1.24	0.50	7.54	13.02	591.94	180.42
47A	1.08	0.44	7.41	14.15	623.87	190.15
48A	1.97	0.80	8.05	13.43	615.05	187.47
49A	0.78	0.31	7.64	10.24	599.99	182.88
50A	0.57	0.23	5.85	22.30	656.74	200.17

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
51A	0.40	0.16	12.56	20.98	642.81	195.93
52A	1.03	0.41	11.84	16.72	643.79	196.23
53A	0.37	0.15	9.49	19.36	653.73	199.26
54A	0.16	0.06	10.95	24.39	654.66	199.54
55A	0.20	0.08	13.71	25.46	670.02	204.22
56A	1.55	0.63	14.28	15.63	628.57	191.59
57A	0.79	0.32	8.87	18.02	640.45	195.21
58A	4.25	1.72	10.21	10.90	618.65	188.56
59A	3.19	1.29	6.22	9.97	609.82	185.87
60A	1.60	0.65	5.69	7.99	566.78	172.75

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
61A	0.58	0.23	4.57	11.36	583.59	177.88
62A	0.27	0.11	6.47	10.46	594.53	181.21
63A	0.98	0.40	5.97	11.47	592.85	180.70
64A	0.36	0.15	6.53	12.39	592.59	180.62
65A	0.30	0.12	7.06	20.03	575.34	175.36
66A	1.29	0.52	11.33	16.89	552.67	168.46
67A	0.39	0.16	9.57	8.88	598.05	182.29
68A	1.26	0.51	5.07	11.22	577.89	176.14
69A	0.49	0.20	6.40	13.16	550.27	167.72
70A	1.02	0.41	7.49	12.62	552.29	168.34

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
71A	0.55	0.22	7.18	9.64	557.59	169.95
72A	1.14	0.46	5.50	8.99	577.72	176.09
73A	2.24	0.90	5.13	9.56	603.29	183.88
74A	1.27	0.51	5.46	5.90	640.19	195.13
75A	2.53	1.03	3.38	6.43	597.17	182.02
76A	0.76	0.31	3.68	14.93	579.82	176.73
77A	9.87	4.00	8.47	7.01	557.09	169.80
78A	0.25	0.10	4.01	11.02	597.59	182.14
79A	0.35	0.14	6.29	12.77	614.48	187.29
80A	3.68	1.49	7.28	25.74	537.54	163.84

Appendix B-6. Continued. Augusta AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
81A	2.03	0.82	14.06	46.35	530.63	161.74
82A	0.79	0.32	23.98	10.45	561.39	171.11
83A	2.11	0.86	5.96	6.32	578.91	176.45
84A	5.16	2.09	3.61	10.67	551.51	168.10
85A	3.74	1.51	6.08	11.82	570.28	173.82
86A	2.21	0.89	6.74	17.66	555.21	169.23
87A	1.36	0.55	9.99	18.25	596.74	181.89
88A	0.11	0.05	10.31	9.94	487.51	148.59
89A	0.44	0.18	5.67	17.84	496.66	151.38
90A	0.94	0.38	10.11	12.22	491.77	149.89
91A	1.27	0.51	6.96	16.76	501.02	152.71

Appendix B-7. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
1A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
2A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
3A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
4A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
5A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
6A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
7A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
8A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
9A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
10A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
11A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
12A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
13A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
14A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
15A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
16A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
17A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
18A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
19A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
20A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
21A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
22A	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
23A	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
24A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
25A	Holstein loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
26A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
27A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
28A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
29A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
30A	Westerville silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
31A	Gasconade-Rock outcrop complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
32A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
33A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
34A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
35A	Winfield silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
36A	Winfield silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
37A	Holstein loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
38A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
39A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
40A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
41A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
42A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
43A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
44A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
45A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
46A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
47A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
48A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
49A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
50A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
51A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
52A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
53A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
54A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
55A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
56A	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
57A	Gatewood-Gasconade-Crider complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
58A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
59A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
60A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
61A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
62A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
63A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
64A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
65A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
66A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
67A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
68A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
69A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
70A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
71A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
72A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
73A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
74A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
75A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
76A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
77A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
78A	Holstein loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
79A	Holstein loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
80A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite with oolitic chert & local sandstones

Appendix B-7. Continued. Augusta AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
81A	Menfro silt loam	Qal	Quaternary alluvium	clay, silt, sand, and gravel
82A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite
83A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite
84A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
85A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
86A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
87A	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
88A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite
89A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite
90A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite
91A	Menfro silt loam	Ou	Ordovician System, undifferentiated	dolomite

Appendix B-8. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
1H	Adam Puchta Winery	n/a	NE	West	Flat
2H	Adam Puchta Winery	n/a	NE	South	Flat
3H	Stone Hill Winery	n/a	E	South	Flat
4H	Stone Hill Winery	n/a	NE	South	Concave
5H	Stone Hill Winery	n/a	NE	South	Convex
6H	Stone Hill Winery	n/a	N	West	Convex
7H	Stone Hill Winery	n/a	NE	West	Convex
8H	Stone Hill Winery	n/a	NE	West	Convex
9H	Stone Hill Winery	n/a	N	West	Flat
10H	Stone Hill Winery	n/a	SE	North	Convex

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
11H	Stone Hill Winery	n/a	SE	East	Convex
12H	Stone Hill Winery	n/a	SE	South	Convex
13H	Stone Hill Winery	n/a	N	East	Convex
14H	Blumenhof Vineyards & Winery	n/a	E	West	Convex
15H	Blumenhof Vineyards & Winery	n/a	E	South	Convex
16H	Blumenhof Vineyards & Winery	n/a	E	South	Convex
17H	Blumenhof Vineyards & Winery	n/a	E	North	Convex
18H	Blumenhof Vineyards & Winery	n/a	E	North	Convex
19H	Blumenhof Vineyards & Winery	n/a	NE	East	Convex
20H	Blumenhof Vineyards & Winery	n/a	NE	West	Convex

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
21H	Blumenhof Vineyards & Winery	n/a	E	South	Convex
22H	Independent	n/a	E	North	Convex
23H	Independent	n/a	N	East	Convex
24H	Independent	n/a	E	North	Convex
25H	Independent	n/a	E	North	Flat
26H	Bias Vineyards	n/a	E	South	Convex
27H	Bias Vineyards	n/a	E	North	Convex
28H	Bias Vineyards	n/a	NE	North	Convex
29H	Bias Vineyards	n/a	E	North	Flat
30H	Bommarito Estate Almond Tree Winery	n/a	E	East	Concave

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
31H	Bommarito Estate Almond Tree Winery	n/a	N	North	Convex
32H	Bommarito Estate Almond Tree Winery	n/a	N	East	Convex
33H	Bommarito Estate Almond Tree Winery	n/a	N	North	Convex
34H	Bommarito Estate Almond Tree Winery	n/a	E	North	Concave
35H	Stone Hill Winery	n/a	n/a	East	Convex
36H	Stone Hill Winery	n/a	n/a	West	Flat
37H	Stone Hill Winery	n/a	n/a	South	Flat
38H	Stone Hill Winery	n/a	n/a	North	Flat
39H	Stone Hill Winery	n/a	n/a	South	Convex
40H	Stone Hill Winery	n/a	n/a	East	Convex

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
41H	Stone Hill Winery	n/a	n/a	North	Convex
42H	Stone Hill Winery	n/a	n/a	East	Convex
43H	Stone Hill Winery	n/a	n/a	East	Convex
44H	Stone Hill Winery	n/a	n/a	East	Convex
45H	Stone Hill Winery	n/a	n/a	East	Convex
46H	Stone Hill Winery	n/a	n/a	East	Convex
47H	Stone Hill Winery	n/a	n/a	South	Convex
48H	Stone Hill Winery	n/a	n/a	North	Flat
49H	Stone Hill Winery	n/a	n/a	North	Convex
50H	Stone Hill Winery	n/a	n/a	East	Convex

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
51H	Stone Hill Winery	n/a	n/a	East	Convex
52H	Stone Hill Winery	n/a	n/a	East	Convex
53H	Stone Hill Winery	n/a	n/a	East	Convex
54H	Stone Hill Winery	n/a	n/a	North	Convex
55H	Stone Hill Winery	n/a	n/a	North	Convex
56H	Stone Hill Winery	n/a	n/a	East	Convex
57H	Stone Hill Winery	n/a	n/a	East	Concave
58H	Stone Hill Winery	n/a	n/a	North	Convex
59H	Bias Vineyards	n/a	n/a	North	Flat
60H	Bias Vineyards	n/a	n/a	North	Convex

Appendix B-8. Continued. Hermann AVA and surrounding area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
61H	Bias Vineyards	n/a	n/a	North	Convex
62H	Oak Glenn Vineyards & Winery	n/a	n/a	East	Convex
63H	Oak Glenn Vineyards & Winery	n/a	n/a	East	Convex
64H	Stone Hill Winery	n/a	n/a	East	Convex
65H	Stone Hill Winery	n/a	n/a	South	Convex
66H	Stone Hill Winery	n/a	n/a	West	Flat
67H	Stone Hill Winery	n/a	n/a	West	Flat
68H	Independent	n/a	n/a	South	Concave
69H	Independent	n/a	n/a	West	Convex
70H	Independent	n/a	n/a	West	Flat
71H	Independent	n/a	n/a	East	Convex

Appendix B-9. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
1H	2.11	0.86	5.09	8.93	225.02	738.26
2H	1.64	0.66	8.42	14.81	219.62	720.52
3H	0.77	0.31	11.30	19.90	182.78	599.68
4H	0.81	0.33	12.43	21.91	179.88	590.15
5H	1.15	0.46	7.90	13.90	263.61	864.86
6H	1.92	0.78	11.46	20.18	264.78	868.72
7H	6.47	2.62	4.65	8.16	278.09	912.37
8H	0.95	0.38	8.24	14.50	278.49	913.67
9H	3.01	1.22	3.60	6.31	275.46	903.74
10H	3.58	1.45	2.66	4.65	280.55	920.44

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
11H	4.87	1.97	4.69	8.23	280.63	920.71
12H	1.58	0.64	7.87	13.84	277.24	909.59
13H	8.52	3.45	3.61	6.31	280.19	919.26
14H	1.58	0.64	5.19	9.12	182.90	600.08
15H	2.06	0.83	6.90	12.13	188.79	619.40
16H	1.05	0.43	6.58	11.56	193.37	634.40
17H	0.98	0.40	5.30	9.31	194.13	636.89
18H	0.89	0.36	8.36	14.71	186.14	610.69
19H	2.56	1.03	5.03	8.82	194.29	637.45
20H	5.10	2.06	6.34	11.15	192.97	633.09

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
21H	3.00	1.21	6.14	10.79	187.36	614.70
22H	2.04	0.82	4.95	8.69	190.83	626.09
23H	2.93	1.18	5.82	10.22	197.48	647.91
24H	3.91	1.58	6.94	12.21	178.83	586.72
25H	0.16	0.06	9.88	17.40	171.67	563.21
26H	0.64	0.26	4.23	7.42	189.60	622.05
27H	2.43	0.98	4.78	8.39	187.18	614.11
28H	1.38	0.56	4.84	8.49	185.87	609.81
29H	2.38	0.96	6.66	11.71	177.95	583.82
30H	1.24	0.50	6.16	10.82	199.78	655.46

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
31H	1.05	0.43	7.23	12.71	205.76	675.05
32H	2.58	1.04	5.13	9.00	195.29	640.71
33H	2.55	1.03	3.98	6.97	188.55	618.61
34H	0.73	0.30	3.79	6.63	183.12	600.79
35H	9.58	3.88	3.46	6.05	277.05	908.96
36H	3.03	1.23	1.92	3.32	274.91	901.93
37H	5.98	2.42	1.32	2.27	275.12	902.64
38H	4.78	1.93	5.42	9.51	274.14	899.40
39H	4.51	1.83	8.63	15.20	269.13	882.98
40H	4.55	1.84	5.20	9.12	277.15	909.29

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
41H	3.76	1.52	4.58	8.03	277.92	911.81
42H	3.65	1.48	5.14	9.02	277.27	909.67
43H	3.60	1.46	4.33	7.59	274.01	898.97
44H	0.66	0.27	4.64	8.13	270.88	888.71
45H	0.49	0.20	3.06	5.35	280.81	921.29
46H	3.14	1.27	5.93	10.42	280.42	920.00
47H	3.79	1.53	7.07	12.44	283.23	929.24
48H	4.79	1.94	3.79	6.63	285.41	936.39
49H	6.35	2.57	3.71	6.50	281.74	924.36
50H	0.55	0.22	2.74	4.78	283.62	930.51

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
51H	19.77	8.00	4.29	7.52	283.67	930.68
52H	1.47	0.60	9.77	17.21	275.03	902.34
53H	6.22	2.52	5.14	9.02	277.65	910.94
54H	4.56	1.85	4.48	7.85	278.88	914.96
55H	1.63	0.66	5.37	9.44	275.26	903.08
56H	1.28	0.52	4.21	7.37	274.57	900.82
57H	0.75	0.30	13.77	24.26	258.55	848.26
58H	1.75	0.71	3.87	6.77	275.18	902.82
59H	1.44	0.58	4.74	8.31	171.78	563.59
60H	1.47	0.59	4.62	8.09	168.21	551.86

Appendix B-9. Continued. Hermann AVA and surrounding area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
61H	2.49	1.01	5.32	9.34	161.71	530.55
62H	4.20	1.70	10.43	18.36	192.77	632.44
63H	1.58	0.64	9.63	16.96	182.24	597.89
64H	3.73	1.51	4.10	7.18	279.98	918.57
65H	7.03	2.84	3.06	5.34	278.60	914.04
66H	8.74	3.54	3.18	5.56	277.07	909.03
67H	4.27	1.73	3.78	6.62	275.18	902.82
68H	2.16	0.87	8.34	14.68	213.35	699.97
69H	1.19	0.48	6.26	11.00	203.00	666.01
70H	0.56	0.22	5.95	10.46	207.55	680.92
71H	2.81	1.14	3.06	5.34	230.06	754.79

Appendix B-10. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
1H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
2H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
3H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
4H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
5H	Beemont-Ramsey-Rock outcrop complex	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
6H	Beemont-Ramsey-Rock outcrop complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
7H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
8H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
9H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
10H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
11H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
12H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
13H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
14H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
15H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
16H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
17H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
18H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
19H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
20H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
21H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
22H	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
23H	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
24H	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
25H	Winfield silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
26H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
27H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
28H	Menfro silt loam	Qal	Quaternary alluvium	clay, silt, sand, and gravel
29H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
30H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
31H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
32H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
33H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
34H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
35H	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
36H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
37H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
38H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
39H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
40H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
41H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
42H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
43H	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
44H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
45H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
46H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
47H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
48H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
49H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
50H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
51H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
52H	Beemont-Ramsey-Rock outcrop complex	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
53H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
54H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
55H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
56H	Menfro silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
57H	Beemont-Ramsey-Rock outcrop complex	Ospe	Ordovician, St. Peter and Everton formations	sandstone
58H	Menfro silt loam	Pu	Pennsylvanian System, undifferentiated	shale
59H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
60H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-10. Continued. Hermann AVA and surrounding area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
61H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
62H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
63H	Menfro silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
64H	Wrengart silt loam	Pu	Pennsylvanian System, undifferentiated	shale
65H	Wrengart silt loam	Ospe	Ordovician, St. Peter and Everton formations	sandstone
66H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
67H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
68H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
69H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
70H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones
71H	Wrengart silt loam	Ojc	Ordovician, Jefferson City and Cotter formations	dolomite with oolitic chert & local sandstones

Appendix B-11. Rocheport area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
1R	Les Bourgeois Vineyards	Vignoles	SE	South	Convex
2R	Les Bourgeois Vineyards	Vidal	NE	South	Convex
3R	Les Bourgeois Vineyards	Chardonel	N	South	Convex
4R	Les Bourgeois Vineyards	Norton/Chambourcin	E	South	Convex
5R	Les Bourgeois Vineyards	Norton/Chambourcin	E	North	Convex
6R	Les Bourgeois Vineyards	Norton/Chambourcin	NE	South	Concave

Appendix B-12. Rocheport area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
1R	5.53	2.24	3.18	5.56	229.65	753.44
2R	10.32	4.18	3.54	6.18	231.33	758.96
3R	7.21	2.92	2.46	4.30	233.95	767.56
4R	4.09	1.65	5.13	8.98	240.00	787.40
5R	0.78	0.32	4.03	7.06	239.29	785.08
6R	0.28	0.11	6.90	12.12	240.38	788.66

Appendix B-13. Rocheport area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
1R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone
2R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone
3R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone
4R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone
5R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone
6R	Menfro silt loam	Mo	Early Mississippian-Osagean Series	limestone

Appendix B-14. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
1S	Crown Valley Winery	n/a	N	South	Convex
2S	Crown Valley Winery	n/a	NE	South	Convex
3S	Crown Valley Winery	n/a	NE	South	Convex
4S	Crown Valley Winery	n/a	NW	East	Concave
5S	Crown Valley Winery	n/a	NW	South	Concave
6S	Crown Valley Winery	n/a	NW	South	Convex
7S	Crown Valley Winery	n/a	NW	South	Convex
8S	Crown Valley Winery	n/a	NE	West	Concave
9S	Crown Valley Winery	n/a	E	South	Convex
10S	Crown Valley Winery	n/a	N	South	Convex

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
11S	Crown Valley Winery	n/a	N	South	Convex
12S	Crown Valley Winery	n/a	NW	East	Concave
13S	Crown Valley Winery	n/a	E	South	Convex
14S	Crown Valley Winery	n/a	N	South	Convex
15S	Crown Valley Winery	n/a	NW	South	Concave
16S	Crown Valley Winery	n/a	E	South	Convex
17S	Crown Valley Winery	n/a	E	South	Concave
18S	Crown Valley Winery	n/a	E	South	Convex
19S	Chaumette Vineyards & Winery	Traminette	N	East	Convex
20S	Chaumette Vineyards & Winery	Chardonel	E	East	Convex

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
21S	Chaumette Vineyards & Winery	n/a	E	North	Convex
22S	Chaumette Vineyards & Winery	n/a	N	North	Convex
23S	Chaumette Vineyards & Winery	n/a	N	East	Convex
24S	Chaumette Vineyards & Winery	n/a	E	South	Convex
25S	Chaumette Vineyards & Winery	n/a	NE	South	Convex
26S	Chaumette Vineyards & Winery	n/a	NE	East	Convex
27S	Charleville Vineyard Winery & Microbrewery	n/a	N	South	Convex
28S	Charleville Vineyard Winery & Microbrewery	n/a	N	West	Convex
29S	Charleville Vineyard Winery & Microbrewery	n/a	N	East	Concave
30S	Charleville Vineyard Winery & Microbrewery	n/a	NW	South	Concave

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
31S	Charleville Vineyard Winery & Microbrewery	n/a	NE	East	Convex
32S	Charleville Vineyard Winery & Microbrewery	n/a	NW	South	Convex
33S	Cave Vineyard	n/a	N	South	Convex
34S	St. Francois Winery	Traminette	N	East	Convex
35S	St. Francois Winery	Cynthiana/Norton	N	East	Convex
36S	St. Francois Winery	Traminette	N	East	Convex
37S	St. Francois Winery	Chambourcin	N	East	Convex
38S	St. Francois Winery	Chardonel	N	East	Convex
39S	Twin Oaks Vineyard & Winery	Traminette	E	South	Convex
40S	Twin Oaks Vineyard & Winery	Chambourcin	N	East	Convex

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
41S	Twin Oaks Vineyard & Winery	Traminette	N	South	Convex
42S	Twin Oaks Vineyard & Winery	Chambourcin	E	South	Convex
43S	Sand Creek Vineyard	Norton/Catawba	NE	West	Convex
44S	Sand Creek Vineyard	Chardonel	N	West	Convex
45S	Sand Creek Vineyard	Concord	NE	West	Convex
46S	Twin Oaks Vineyard & Winery	Norton	N	South	Convex
47S	Twin Oaks Vineyard & Winery	Traminette	E	South	Convex
48S	Twin Oaks Vineyard & Winery	Vignoles	E	South	Convex
49S	Marco Vineyard	n/a	E	South	Convex
50S	Marco Vineyard	n/a	E	South	Concave

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
51S	Chaumette Vineyards & Winery	Norton	E	North	Convex
52S	Chaumette Vineyards & Winery	n/a	NW	South	Convex
53S	Chaumette Vineyards & Winery	n/a	NW	East	Convex
54S	Chaumette Vineyards & Winery	n/a	NW	South	Convex
55S	Charleville Vineyard Winery & Microbrewery	n/a	N	South	Convex
56S	Charleville Vineyard Winery & Microbrewery	n/a	NW	West	Concave
57S	Cave Vineyard	n/a	E	South	Convex
58S	Cave Vineyard	n/a	E	South	Convex
59S	Cave Vineyard	n/a	E	South	Convex
60S	Cave Vineyard	n/a	E	North	Convex

Appendix B-14. Continued. St. Francois and Ste. Genevieve area data for each vineyard.

Vineyard ID	Winery	Varietal	Row Orientation	Aspect	Curvature
61S	Crown Valley Winery	n/a	E	South	Convex
62S	Crown Valley Winery	n/a	NE	South	Convex
63S	Crown Valley Winery	n/a	E	South	Convex
64S	Crown Valley Winery	n/a	E	South	Concave

Appendix B-15. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
1S	7.99	3.23	3.19	5.58	223.35	732.79
2S	2.07	0.84	3.54	6.19	222.79	730.95
3S	13.74	5.56	2.93	5.13	216.90	711.63
4S	5.59	2.26	3.76	6.57	214.92	705.13
5S	9.33	3.78	3.18	5.55	213.90	701.77
6S	3.04	1.23	2.78	4.86	216.86	711.49
7S	5.87	2.38	2.01	3.50	219.39	719.78
8S	1.86	0.75	3.90	6.82	208.79	685.01
9S	24.42	9.88	1.98	3.46	206.81	678.52
10S	17.16	6.94	3.49	6.10	208.46	683.91

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
11S	8.51	3.44	2.18	3.80	203.77	668.54
12S	0.79	0.32	4.33	7.57	205.42	673.95
13S	5.55	2.25	4.87	8.53	212.33	696.61
14S	4.73	1.91	1.86	3.25	201.50	661.10
15S	8.05	3.26	1.96	3.43	196.96	646.20
16S	18.74	7.59	3.38	5.90	204.82	671.97
17S	10.19	4.13	3.79	6.63	205.71	674.91
18S	23.91	9.68	3.12	5.46	213.63	700.90
19S	1.07	0.43	3.73	6.52	226.98	744.68
20S	4.59	1.86	4.12	7.20	233.20	765.08

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
21S	2.17	0.88	1.71	2.99	226.83	744.20
22S	2.19	0.88	2.81	4.91	226.17	742.02
23S	2.09	0.85	4.04	7.06	218.37	716.43
24S	1.21	0.49	8.80	15.49	215.71	707.72
25S	0.43	0.17	9.05	15.94	216.56	710.49
26S	0.52	0.21	7.94	13.97	212.22	696.27
27S	2.08	0.84	7.01	12.31	245.77	806.34
28S	1.49	0.60	4.70	8.27	238.24	781.61
29S	1.03	0.42	9.80	17.29	214.63	704.17
30S	2.89	1.17	7.43	13.06	209.06	685.89

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
31S	2.46	1.00	6.87	12.05	218.49	716.82
32S	1.60	0.65	6.68	11.72	188.39	618.08
33S	14.18	5.74	3.39	5.94	228.31	749.06
34S	0.73	0.29	3.52	6.16	281.10	922.25
35S	2.06	0.83	3.62	6.33	280.13	919.08
36S	0.85	0.34	2.85	4.97	286.00	938.33
37S	0.81	0.33	4.37	7.65	277.88	911.67
38S	1.28	0.52	2.58	4.51	285.89	937.98
39S	4.80	1.94	0.92	1.60	287.85	944.40
40S	1.19	0.48	4.83	8.45	283.03	928.58

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
41S	1.62	0.65	3.27	5.71	283.34	929.59
42S	5.21	2.11	3.98	6.96	273.21	896.37
43S	2.32	0.94	3.78	6.60	264.52	867.83
44S	2.02	0.82	3.31	5.78	268.93	882.32
45S	1.05	0.42	4.18	7.32	274.36	900.14
46S	3.58	1.45	3.44	6.02	284.17	932.33
47S	4.71	1.90	0.73	1.28	287.98	944.82
48S	4.07	1.65	1.49	2.60	286.77	940.86
49S	1.04	0.42	3.22	5.62	273.33	896.76
50S	1.13	0.46	2.85	4.98	269.23	883.30

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
51S	5.99	2.42	4.72	8.26	229.25	752.14
52S	1.96	0.79	7.50	13.19	214.53	703.85
53S	1.56	0.63	7.52	13.23	234.29	768.68
54S	4.39	1.78	6.23	10.92	199.98	656.11
55S	1.62	0.66	8.66	15.25	204.26	670.15
56S	1.20	0.49	5.97	10.47	191.31	627.66
57S	3.85	1.56	10.04	17.76	216.28	709.58
58S	0.77	0.31	10.56	18.67	215.19	706.01
59S	1.40	0.57	8.79	15.50	214.15	702.59
60S	1.15	0.46	7.79	13.73	217.81	714.60

Appendix B-15. Continued. St. Francois and Ste. Genevieve area numerical data for each vineyard calculated using USGS DEMs.

Vineyard ID	Acreage	Hectares	Mean Slope (degrees)	Mean Percent Rise	Mean Elevation (ft)	Mean Elevation (m)
61S	10.68	4.32	5.09	8.92	247.30	811.36
62S	5.70	2.31	3.69	6.45	248.87	816.50
63S	10.82	4.38	4.38	7.67	233.94	767.53
64S	12.80	5.18	4.14	7.24	227.16	745.28

Appendix B-16. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
1S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
2S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
3S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
4S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
5S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
6S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
7S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
8S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
9S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
10S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
11S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
12S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
13S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
14S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
15S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
16S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
17S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
18S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
19S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
20S	Fourche silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
21S	Fourche silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
22S	Fourche silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
23S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
24S	Gasconade-Rock outcrop complex	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
25S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
26S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
27S	Goss very cobbly silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
28S	Goss very cobbly silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
29S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
30S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
31S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
32S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
33S	Wrengart silt loam	Og	Ordovician, Gasconade Dolomite	dolostone (dolomite)
34S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
35S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
36S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
37S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
38S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
39S	Jonca silt loam	Clm	Lamotte Sandstone	sandstone
40S	Lamotte silt loam	Clm	Lamotte Sandstone	sandstone

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
41S	Jonca silt loam	Clm	Lamotte Sandstone	sandstone
42S	Lamotte silt loam	Clm	Lamotte Sandstone	sandstone
43S	Haymond silt loam	Clm	Lamotte Sandstone	sandstone
44S	Lamotte silt loam	Clm	Lamotte Sandstone	sandstone
45S	Lamotte silt loam	Clm	Lamotte Sandstone	sandstone
46S	Jonca silt loam	Clm	Lamotte Sandstone	sandstone
47S	Jonca silt loam	Clm	Lamotte Sandstone	sandstone
48S	Lamotte silt loam	Clm	Lamotte Sandstone	sandstone
49S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
50S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
51S	Fourche silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
52S	Goss very cobbly silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
53S	Goss very cobbly silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
54S	Goss very cobbly silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
55S	Caneyville silt loam	Cep	Cambrian, Eminence and Potosi formations	dolostone (dolomite)
56S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
57S	Wrengart silt loam	Og	Gasconade Dolomite	dolostone (dolomite)
58S	Wrengart silt loam	Og	Gasconade Dolomite	dolostone (dolomite)
59S	Wrengart silt loam	Og	Gasconade Dolomite	dolostone (dolomite)
60S	Goss very cobbly silt loam	Og	Gasconade Dolomite	dolostone (dolomite)

Appendix B-16. Continued. St. Francois and Ste. Genevieve area soil and geology data for each vineyard.

Vineyard ID	Major Soil Type	Major Map Unit	Geologic Name	General Rock Type
61S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
62S	Caneyville silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
63S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)
64S	Fourche silt loam	Ceb	Cambrian, Elvins and Bonneterre formations	dolostone (dolomite)

Appendix C – Wine Region Statistics

Appendix C-1. Statistics for 65 vineyards inside the Augusta AVA.

65 in Augusta AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.2	9.9	168.2	2.6	2.0
Hectares	0.1	4.0	68.1	1.1	0.8
Elevation (m)	165.9	204.2		182.3	9.6
Elevation (ft)	544.1	670.0		598.2	31.4
Slope	1.1	14.3		6.9	2.8
Percent Rise	0.0	25.5		11.9	5.0
Curvature	69% convex	31% concave			
Aspect	52% south	26% east	14 % west	8% north	
Soil Type	75% Menfro silt loam	9% Gatewood-Gasconade-Crider complex	6% Holstein loam	6% Winfield silt loam	2% Westerville silt loam, 2% Gasconade Rock outcrop
Bedrock Geology Type	57% Jefferson City and Cotter	43% St. Peter Sandstone			

Appendix C-2. Statistics for 26 vineyards outside the Augusta AVA.

26 out Augusta AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.1	3.7	29.6	1.1	0.8
Hectares	0.1	1.5	12.0	0.5	0.3
Elevation (m)	148.6	195.1		171.5	11.2
Elevation (ft)	487.5	640.2		562.6	36.8
Slope	4.6	24.0		8.0	3.9
Percent Rise	8.0	46.4		14.3	7.6
Curvature	77% convex	23% concave			
Aspect	58% east	19% north	15% west	8% east	
Soil Type	100% Menfro silt loam				
Bedrock Geology Type	69% Jefferson City and Cotter	27% Ordovician System, undifferentiated	4% Quaternary alluvium		

Appendix C-3. Statistics for all vineyards in the Augusta AVA and surrounding area.

All Augusta AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.1	9.9	197.9	2.2	1.9
Hectares	0.1	4.0	80.1	0.9	0.8
Elevation (m)	148.6	204.2		179.2	1.7
Elevation (ft)	487.5	670.0		588.0	6.0
Slope	1.1	24.0		7.3	11.2
Percent Rise	0.0	46.4		12.6	36.7
Curvature	71% convex	29% concave			
Aspect	40% south	35% east	14% west	11% north	
Soil Type	83% Menfro silt loam	7% Gatewood-Gasconade-Crider complex	4% Holstein loam, 4% Winfield silt loam	1% Westerville silt loam, 1% Gasconade Rock outcrop complex	
Bedrock Geology Type	60% Jefferson City and Cotter	31% St. Peter Sandstone	8% Ordovician System, undifferentiated	1% Quaternary alluvium	

Appendix C-4. Statistics for 54 vineyards inside the Hermann AVA.

54 in Hermann AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.5	19.8	186.5	3.5	3.2
Hectares	0.2	8.0	75.5	1.4	1.3
Elevation (m)	161.3	284.4		250.2	40.7
Elevation (ft)	530.6	936.4		820.8	133.4
Slope	1.3	13.8		5.7	2.7
Percent Rise	2.5	22.1		10.6	5.4
Curvature	70% convex	5% concave	24% flat		
Aspect	35% east	30% south	20% north	19% west	
Soil Type	65% Menfro silt loam	28% Wrengart silt loam	7% Beemont gravelly silt loam		
Bedrock Geology Type	74% Jefferson City and Cotter	20% St. Peter Sandstone and Everton	4% Pennsylvanian System, undifferentiated	2% Quaternary alluvium	

Appendix C-5. Statistics for 17 vineyards outside the Hermann AVA.

17 out Hermann AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.2	5.1	34.4	2.0	1.2
Hectares	0.1	2.1	13.9	0.8	0.5
Elevation (m)	171.7	205.8		190.1	7.9
Elevation (ft)	563.2	675.1		623.6	26.0
Slope	3.8	9.9		6.1	1.5
Percent Rise	7.0	16.8		108	2.7
Curvature	82% convex	11% concave	6% flat		
Aspect	47% south	24% east	18% north	12% west	
Soil Type	71% Menfro silt loam	29% Wrengart silt loam			
Bedrock Geology Type	100% Jefferson City and Cotter				

Appendix C-6. Statistics for all vineyards in the Hermann AVA and surrounding area.

All Hermann AVA	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.2	19.8	220.9	3.1	2.9
Hectares	0.1	8.0	89.4	1.3	1.2
Elevation (m)	161.7	285.4		235.8	43.9
Elevation (ft)	530.6	936.4		773.6	144.1
Slope	1.3	13.8		5.8	2.5
Percent Rise	2.5	22.1		10.7	4.8
Curvature	73% convex	20% flat	7% concave		
Aspect	34% south	32% east	20% north	17% west	
Soil Type	66% Menfro silt loam	28% Wrengart silt loam	6% Beemont gravelly silt loam		
Bedrock Geology Type	80% Jefferson City and Cotter	15% St. Peter Sandstone and Everton	3% Pennsylvanian System, undifferentiated	2% Quaternary alluvium	

Appendix C-7. Statistics for the vineyards in the Rocheport area.

Les Bourgeois Vineyards	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.3	10.3	28.2	4.7	3.5
Hectares	0.1	4.2	11.4	1.9	1.4
Elevation (m)	229.7	140.4		235.8	4.3
Elevation (ft)	753.4	788.7		773.5	14.2
Slope	2.5	6.9		4.2	1.5
Percent Rise	4.3	12.1		7.4	2.6
Curvature	100% convex				
Aspect	83% north	17% south			
Soil Type	100% Menfro silt loam				
Bedrock Geology Type	100% Osagean Series				

Appendix C-8. Statistics for 17 vineyards in St. Francois County.

17 Vineyards	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.2	5.2	38.5	2.3	1.5
Hectares	0.3	2.1	15.6	0.9	0.6
Elevation (m)	264.5	288.0		279.3	7.2
Elevation (ft)	867.8	944.8		916.3	23.6
Slope	0.7	4.8		3.1	1.1
Percent Rise	1.3	8.5		5.4	2.0
Curvature	94% convex	6% concave			
Aspect	47% south	35% east	18% west	0% north	
Soil Type	65% Caneyville silt loam	29% Lamotte silt loam	6% Haymond silt loam		
Bedrock Geology Type	59% Lamotte Sandstone	41% Elvins and Bonneterre			

Appendix C-9. Statistics for 47 vineyards in St. Genevieve County.

47 Vineyards	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.4	24.4	275.4	5.9	6.0
Hectares	0.2	9.9	111.5	2.4	2.4
Elevation (m)	188.4	248.9		217.2	13.3
Elevation (ft)	618.1	816.5		712.7	43.8
Slope	1.7	10.6		5.1	2.5
Percent Rise	3.0	18.7		8.9	4.4
Curvature	79% convex	21% concave			
Aspect	66% south	19% east	9% north	6% west	
Soil Type	43% Fourche silt loam	34% Caneyville silt loam	13% Goss very cobbly silt loam	9% Wrengart silt loam	1% Gasconade – Rock outcrop complex
Bedrock Geology Type	57% Elvins and Bonneterre	32% Eminence and Potosi	11% Gasconade Dolomite		

Appendix C-10. Statistics for 64 vineyards in St. Francois and Ste. Genevieve counties.

64 Vineyards	Minimum	Maximum	Sum	Mean	St. Dev.
Acres	0.4	24.4	313.9	4.9	5.4
Hectares	0.2	9.9	111.5	2.0	2.2
Elevation (m)	188.4	288.0		233.7	29.9
Elevation (ft)	618.1	944.8		233.7	30.0
Slope	0.7	10.6		4.6	2.4
Percent Rise	1.3	18.7		8.0	4.2
Curvature	83% convex	17% concave			
Aspect	61% south	24% east	9% west	6% north	
Soil Type	36% Caneyville silt loam	31% Fourche silt loam	9% Goss very cobbly silt loam, 8% Lamotte silt loam	6% Jonca silt loam, 6% Wrengart silt loam	2% Haymond silt loam, 2% Gasconade-Rock complex
Bedrock Geology Type	51% Elvins and Bonneterre	25% Eminence and Potosi formations	16% Lamotte Sandstone	8% Gasconade Dolomite	

Appendix D – Map Algebra for Suitability Maps

Appendix D-1. Map algebra used to create the suitability map for the Augusta AVA area.

Intention	Parameter	Map Algebra
Best elevation:	meters	(a_dem >= 148.59) and (a_dem >=204.22)
Best slope:	degrees	(a_sloped >= 1.09) and (a_sloped >=23.98)
Best aspect:	East or south	(a_aspect_r == 2) or (a_aspect_r ==3)
Best curvature:	Convex	(a_curva_r==1)
Best soil types:	Menfro and Winfield silt loams, Holstein loam, and Gatewood-Gasconade-Crider	(a_soil_r1 ==5) or (a_soil_r2==48) or (a_soil_r2==6) or (a_soil_r2==32)
Best geology:	Ojc, Ospe, Ou	(a_geology_r ==1) or (a_geology_r ==11) or (a_geology_r ==14)
Suitability map:	All attributes except curvature	(a_all_geology ==1) and (a_all_soils==1) and (a_best_asp_se==1) and (a_best_sloper==0) and (a_best_elev_r==1)

Appendix D-2. Map algebra used to create the suitability map for the Hermann AVA area.

Intention	Parameter	Map Algebra
Best elevation:	meters	(h_elev >= 161.71) and (h_elev <= 285.41)
Best slope:	degrees	(h_sloper >= 1.32) and (h_sloper <= 13.77)
Best aspect:	East or south	(h_aspect_r == 2) or (h_aspect_r == 3)
Best curvature:	Flat or convex	(h_curva_r ==0) or (h_curva_r == 1)
Best soil types:	Menfro, Wrengart, Beemont silt loams	(h_soils_raster == 5) or (h_soils_raster == 44) or(h_soils_raster == 64)
Best geology:	Ojc or Ospe	(h_bedrock_ras == 3) or (h_bedrock_ras == 5)
Suitability map:	All attributes	(h_best_elev2 ==1) and (h_Best_sloper==1)and(h_best_curva==1)and (h_best_soil ==1) and (h_best_geol2==1)

Appendix D-3. Map algebra used to create the suitability map for Les Bourgeois Vineyards.

Intention	Parameter	Map Algebra
Best elevation:	meters	(roch_dem >= 229.65) and (roch_dem <= 240.38)
Best slope:	degrees	(Slope >= 2.46) and Slope <= 6.91)
Best aspect:	South or north	(r_aspect_r == 1) or (r_aspect_r == 3)
Best curvature:	convex	(r_curva_r == 1)
Best soil types:	Menfro silt loam	(r_soils_r == 6)
Best geology:	Mo	(r_geology_r2 == 1)
Suitability map:	All attributes except curvature	(r_best_geo == 1) and (r_best_soil == 1) and (r_best_asp_ns == 1) and (r_best_elev ==1) and (r_best_sloper == 1)

Appendix D-4. Map algebra used to create the suitability map for the St. Francois and Ste. Genevieve Counties.

Intention	Parameter	Map Algebra
Best elevation:	meters	(Gen_Fran_DEM >=188.39) and (Gen_Fran_DEM <=287.98)
Best slope:	degrees	(G_F_Slope_deg >= 0.73) and (G_F_Slope_deg <= 10.56)
Best aspect:	East or south	(G_F_Aspect >= 45) and (G_F_Aspect <= 225)
Best curvature:	Flat or convex	(g_f_curvat_r == 0) or (g_f_curvat_r == 1)
Best soil types:	Caneyville, Fourche, Jonca, Lamotte, Wrengart, and Goss very cobbly silt loams	(g_f_soil_ras2 == 36) or (g_f_soil_ras2 == 40) or (g_f_soil_ras2 == 8) or (g_f_soil_ras2 == 45) or (g_f_soil_ras2 == 50) or (g_f_soil_ras2 == 44)
Best geology:	Og, Clm, Ceb, and Cep	(g_f_geo_ras == 10) or (g_f_geo_ras == 11) or (g_f_geo_ras == 9) or (g_f_geo_ras == 7)
Suitability map:	All attributes except curvature	(g_f_best_soil == 1) and (g_f_best_geo3 == 1) and (g_f_best_el_r == 1) and (g_f_best_slo2_r == 1) and (g_f_best_a_ES == 1)