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Wine without irrigation: evaluating geographic information systems as a tool to identify potential dryland viticulture sites

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WINE WITHOUT IRRIGATION:
EVALUATING GEOGRAPHIC INFORMATION SYSTEMS AS A TOOL TO IDENTIFY POTENTIAL
DRYLAND VITICULTURE SITES

By

Jennifer Michelle Sorensen

Accepted in Partial Completion

Of the Requirements for the Degree

Master of Science

Kathleen L. Kitto, Dan of the Graduate School

ADVISORY COMMITTEE

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Jennifer Michelle Sorensen
February 21, 2014
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Abstract

This study attempts to assess whether or not geographic information systems (GIS) is an effective tool for identifying potential sites for growing wine grapes without the use of supplemental irrigation water. Using spatial analysis techniques with GIS technology, this study evaluated the Walla Walla Valley American Viticultural Area (AVA) and the immediate region in Washington and Oregon for dryland-farmed viticulture site potential. Cabernet Sauvignon was used as a test variety as an exercise in siting a potential new vineyard planting. The areas where environmental factors were estimated to be both sufficient for vines to survive without irrigation and the best potential for producing quality wine grapes were categorized into a suitability area. This site selection identified approximately 2000 hectares of land suitable for dryfarming Cabernet Sauvignon. Of these 2000 hectares, about 60 hectares are currently planted with vineyards, leaving 1940 hectares of suitable lands in the study area. This area was compared against the rest of the study area in the occurrence of existing dryland vineyards to evaluate the effectiveness of GIS in this application. The majority of known dryland vineyards in the area were found within or immediately adjacent to the suitability area. Results from this study suggest that geographic information systems may be used to identify dryland vineyard site potential.
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Section 1: Introduction

1.1 Research Question and Objectives

This research attempts to answer the question of whether or not geographic information systems (GIS) can be used by viticulturists to find sites for vineyards where no supplemental irrigation water is necessary. Water is being referred to as “the new liquid gold” (WineBusiness.com, 2013). In some parts of California, wells are going dry. For decades water supply has been diminishing there, but a recent boom in new vineyards has coincided with a drastic reduction of ground water (Adams, 2013).

In the area examined in this study, the Walla Walla Valley American Viticultural Area, lack of water rights is the main barrier to development of vineyards (Rudin, 2013); (Fig.1). It follows that there is an increasing interest in dryfarming methods for growing wine grapes here, but also in other areas where fresh water supplies are stressed or limited. Walla Walla AVA serves as a practical location for examining the viability of this tool for identifying dryfarm sites, as there is heightened demand for grapes from the area coinciding with limited supply (Rudin, 2013). In addition to water concerns, vineyards must be sited where they will not only physically survive, but be able to produce quality wine grapes. A vineyard will not survive fiscally without a saleable crop.
This study explores site factors that influence grape health in vineyards in addition to tolerating dryland farming conditions, using Cabernet Sauvignon as a test wine grape variety. Cabernet Sauvignon was selected as an example because it is relatively consistent in marketability and it is already successfully grown in the study area. The study area was selected largely because of interest in dryland farming by local viticulturists.

Figure 1 - Walla Walla American Viticultural Area (AVA) Boundaries

Wine grapes, and in turn the wine made from these grapes, are affected by a wide variety of physical geographic factors including soils, climate, and topography. The term “terroir” encompasses all factors that influence the quality and character of the wine, including vineyard management practices (Swinchatt and Howell, 2004). Terroir is described in more detail within section 1, subsection 1.5. This study attempts to document the basic environmental factors of terroir that can reasonably be scientifically identified, given the broad, imprecise definition of the French concept.

Site characteristics and climatic conditions essential for growing late-ripening grape varietals with dryfarming methods were identified and overlaid on maps to show areas containing all of the key characteristics for growing quality grapes. These results serve as suitability areas. These suitability areas were then compared against the rest of the study area to determine if there is any difference in concentration of dryland vineyards. Surprisingly, no previous research has been performed in regard site selection for dryfarmed vineyards.

1.2 Thesis Overview

The remainder of this section includes the background of this project. It discusses how American Viticultural Areas relate and differ with the concept of terroir in regard to influence of climate and physical geography on the quality and character of wine grapes. Section two outlines the methods used to select for ideal site conditions, the geographic information system data source for each of these site
conditions, and the processes used to isolate the ideal site condition factors to create a suitability area dataset. Section three provides results found in the study and includes discussion on how these relate to previous studies and existing literature. It also includes a comparison of where dryland vineyards occur in the Walla Walla Valley AVA between suitability area and the remainder of the study area. The fourth section discusses the findings of this study, including implications and limitations. It also addresses the research question on whether or not geographic information systems can be used to find sites for dryland vineyards.

1.3 Study Area

The Walla Walla Valley American Viticultural Area (AVA) was established February 6, 1984 (Bureau, Alcohol and Tobacco Tax and Trade, 2001 49 FR 4374). It is part of the Columbia Valley American Viticultural Area\(^1\) (AVA), and straddles the border between Washington and Oregon. As visible in Figure 1, it is bounded at its eastern border by the Blue Mountains and Vansycle Ridge on the southern border. The hills of the Palouse lay to the north, and the Columbia River to the west of its boundaries. There is a significant difference in average annual precipitation within this AVA, increasing from 11 inches in the west, at the bottom of the valley up to 44 inches to the east in the Blue Mountains\(^2\). This pattern is due to orographic lifting

\(^{\text{1}}\) The Walla Walla Valley American Viticultural Area (AVA) is a sub-appellation within the Columbia Valley AVA.

\(^{\text{2}}\) Per PRISM climate data, average yearly precipitation, 1981-2010.
and resulting adiabatic cooling between valley floor to the mountainous eastern boundary of the AVA (Pogue, 2010). Creek drainage generally flows south and east into the Walla Walla River (Bureau, Alcohol and Tobacco Tax and Trade, 2001). Similar to water drainage, colder air drains down in elevation from the Blue Mountains and the Vansycle Ridge toward the west. The airflow slows at a narrowing point that restricts airflow leaving the valley (Rudin, 2010). The result is a formation of nocturnal air pools in low areas of the Valley (Pogue and Dering, 2008).

1.4 American Viticultural Areas

An American Viticultural Area (AVA) is a geographically unique area with defined boundaries approved by the United States of America Alcohol and Tobacco Tax Trade Bureau (TTB). The idea is that an area holds a particular set of characteristics that influence flavor and quality of wine grapes which in turn influences the character of the wine.
According to the U.S. Alcohol and Tobacco Tax and Trade Bureau (2008), appellation of origin is used to designate where the majority (at least 75%) of the grapes in a wine come from. Appellations are defined areas, such as counties, states, countries, or viticultural areas. An American Viticultural Area is a defined, government-recognized region in the United States with “geographic features (such as soil or climate) that set it apart from the surrounding areas” (Bureau, Alcohol and Tobacco Tax and Trade, 2008). An American Viticultural Area (AVA) designation requires at least 85% of the grapes must be grown inside an AVA for a bottle of wine to carry its name. For example, the Smoking Loon label in Figure 2 indicates that at least 75% of the grapes used to make this wine were from somewhere in the state of California. The Ash Hollow label indicates that at least 85% of the grapes are from the Walla Walla Valley because this area is an AVA rather than an appellation (Fig. 2).
In this case, this Cabernet Sauvignon is labeled as estate grown, produced, and bottled by Ash Hollow, which means that this wine (including 100% of the grapes) was made entirely on their sites from vine to corked bottle. Viola’s 2007 Sangiovese, as you can see in Figure 3, shows that at least 85% of the grapes were from the Walla Walla Valley AVA, but the Nicholas Cole Vineyard indication on the label means that 95% of the grapes came from this specific vineyard (Fig. 3).

1.5 Terroir

Terroir can be defined as a “holistic concept that relates to both environmental and cultural factors that together influence the grape growing to wine production continuum” (Jones, et al., 2004). James Wilson describes it as “…the interaction of the elements of the vineyard habitat…” (Wilson J., 1998). A
more basic definition is that terroir is determined by a variety of factors that influence the quality of wine produced from grapes. The term is French in origin and a variety of American translations are offered: some only describe the land characteristics associated with quality wine grape production (Meinert and Busaca, 2000); (Swinchatt and Howell, 2004). Others describe terroir as the nexus of all factors that influence the quality and character of the wine (Haynes, 1999; Jones, et al., 2004; Sommers, 2008; White, 2009; Wilson , 1998). This includes, but is not limited to physical geography, vineyard management, oenology, and the culture of the process and the area. It is an imprecise concept that varies in definition. The common threads between various definitions of terroir include three basic categories: environmental factors, vineyard management practices, and winemaking. Environmental factors include topography, soil composition, and climate. Examples of vineyard management practices include application of irrigation water, trellising methods, pruning techniques, or whether or not grapes are harvested by hand. The winemaking category includes decisions made by the winemaker such as the selection of the grapes, or the judgment on best harvest date, but also the processes and equipment used to craft the wine. The combination of these components is what gives different wines and wine regions individual character. If any of these factors are altered, a difference in wine character will result. Terroir differs from the AVA definition which only considers the physical geography of the vineyard.
1.6 Differences Between American Viticultural Areas and Terroir

Though American Viticultural Areas and terroir appear that they could or should be related, there is very little discussion about how they compare and contrast. An American Viticultural Area requires a formal review process proving geographic uniqueness to an area to be awarded (Alchohol and Tobacco Tax and Trade Bureau, 2012). Terroir, though there is no consensus on an absolute definition, is also at least partly based on uniqueness of place. Suprisingly, these two concepts are kept as separate elements in current literature. An example of this is the book The Winemaker’s Dance: Exploring the Terroir in the Napa Valley (Swinchatt and Howell, 2004). As the name suggests, the book focuses on exploring the concept and physical aspects of terroir, but there is very little in terms of discussing American Viticultural Areas. There is one inset section, which is the only mention of AVAs in this book, kept separate from the rest of the discussion in the “Introduction: The Place and the Notion” chapter. In the inset, they do mention that the AVA designation process is political and by requirement the boundary of these areas must not cross property boundaries and must follow features visible in standard maps, such as USGS topographic survey maps. According to Swinchatt and Howell, “the political nature of defining AVAs has led to some boundaries that do not seem to make much geologic, geographic, or enological sense” (Swinchatt and Howell, 2004). Based on these types of assessment in current literature, it appears that AVAs may be more of a marketing tool than a true reflection of a geographically
distinct wine area. Terroir, on the other hand is a loose concept that describes a region subjectively and also extends to vine-tending and wine making processes, and perhaps local cultural practices (Wilson, 1998; Jones, et al., 2004).

1.7 Influence of Physical Geography on Grape Quality

Exactly how physical geography influences terroir is still being explored. The nature of terroir and wine character is not easily quantified. Reading wine descriptions reveals language including words like aroma, complexity, hints, flavors, and the like. Nefarious Cellars of the Lake Chelan AVA provides one of my favorite descriptions for their 2008 Syrah from Defiance Vineyard: “a rich, brooding monster packed with blackberry, graham, and spice on the nose leading into intense dark fruit and vanilla. It is chewy, layered, and just plain hedonistic.” This language is vivid and highly illustrative marketing and not translatable into measurable units.

In the last decade, grapes are no longer considered just a crop, and qualities of soil and site have taken center-stage (Swinchatt and Howell, 2004). An example of this is off of the back label of a Chateau Ste. Michelle 2008 Riesling from the Columbia Valley AVA, which offers a bit of prose is offered summarizing the appeal of the product: “the magical combination of sun, soil and water – the ‘terroir’ of Washington State’s world-class growing region makes it the North American home of premium Riesling...” Though this is only marketing language and it lacks evidence and true substance, the label description implies the relationship between sun, soil, and water provides ideal conditions for growing wine grapes. It also demonstrates
that selling an idea of a place and an associated terroir may also sell wine, hence geography matters.

Obviously there is a great deal of subjectivity within wine culture. This is not unlike an art or performance competition where there is no concrete formula to achieve success. There may be commonalities, but there is no single ideal or model of perfection and originality may increase appeal. The Waters 2007 Interlude back bottle label from the Walla Walla Valley rejects rigid scientific identification in this red wine blend: “…the natural balance and elegance of this wine is derived not only from utilizing our best vineyard lots, but also through rigorous ‘blind’ blending trials. Making the best blend possible, without knowing the vineyard source or varietal, forces us to make pure sensory evaluations and offer up our most personal and artistic winemaking expression.” This statement does not reject the existence or importance of terroir, but does imply a creative freedom by not factoring it in selecting grapes for the wine.

In the effort of studying how place influences the production of wine grapes, and in turn, the character and quality of wines, is even more difficult to pin down than the concept of terroir. As for literature on specific criteria, there is no information available that describes ideal growing conditions in detail for Cabernet Sauvignon in the Walla Walla Valley. Though details on ideal growing conditions for this variety are generally scant, it is known that it performs best in well-drained soil in warmer locations relative to other varieties (Swinchatt and Howell, 2004).
Additionally, according to Jacques Fanet (2004), Cabernet Sauvignon is easily grown, relatively hardy, and traditionally produces high quality grapes in France grown on gravel terraces. Most literature makes generalizations about all varieties of Vitus vinifera and can easily be summarized. In reality, specific scientific prescription on exact conditions for producing ideal wine grapes does not exist, as there are many ways to achieve this (Jones et al., 2004; Kurtural et al., 2006; Swinchatt, 2004; Wilson, 1998; Vaudour, 2002). Despite the subjectivity, there are a number of facts known about the physical site conditions that typically leads to successful growth for all wine grape vines according to existing documentation.

1.8 Documented Site Conditions Beneficial in Producing Wine Grapes

Summers with little to no rainfall and cool winters are generally best for wine grapevines to reduce occurrence of fungal disease and pest attack (Winkler, et al. 1974). In their research, Jones, et al. included rainfall amount and frequency at key points of grape development in their study of the Umpqua Valley in Oregon (2004). Unfortunately, they did not disclose how they weighted or categorized these data. Winkler, et al. (1974) outline moisture requirements by categories defined by degree days (DD). The Walla Walla Valley AVA ranges between 2700 and 3240 DD Fahrenheit (Meinert and Busaca, 2000); which indicates that moisture
requirements could range between 16 inches\(^3\) for areas closer to the 2700 DD, and 30 inches for higher DD areas (Winkler, et al., 1974).

According to Winkler, et al. (1974) climate is a greater factor over soil in grape development and quality. Most soils, with exception of the very heaviest ones, can successfully support viticulture (Winkler, et al., 1974). Ideally, a vineyard site would have a minimum depth of 30-40 inches of permeable soil and no impeding layers to provide adequate space for vine roots (Jones, et al., 2004). Moderate soil fertility is best, as too much will maximize leaf canopy and minimize fruit productions, and too little will not provide for adequate development of grapes (Jones, et al., 2004). The best mix for wine grape production is composed of twenty-five percent sandy or course material in the mix with some clay to retain moisture (Wilson, 1998). Though, for dryfarming, soil must be deep with a high water-holding capacity for storing the precipitation from winter rains to supply vines with moisture in the summer (Winkler, et al., 1974). Deep sandy loams and deep clay loams have the greatest capacity to hold plant available water (White, 2009).

As for slopes, mid-slope is ideal for good drainage and capturing more sunlight (Wilson, 1998). Slopes between 5-15% are considered most ideal for drainage while maintaining equipment access (Jones, et al., 2004). Generally, southern and western aspects are preferred to darker and colder eastern and northern exposures.

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\(^3\) Units in acre-inches per acre
(Jones, et al., 2004). Also related to temperature influence, areas in lower elevation are best because of a lower risk of freezing and frost (Jones, et al., 2004), but lowest topographic points, such as valley bottoms and lower slopes, are more susceptible to frost in spring (White, 2009). Ideal elevation will vary from location to location because of localized climate conditions.

Exact temperature conditions are not agreed upon, except that extreme winter freezes make a site unsuitable for viticulture. For example, Jones, et al. (2004) removed areas that that experienced temperature values lower than 5 degrees Fahrenheit (~-21F) from their site assessment study, but in a study of viticulture site selection in Illinois, utilized -26 degrees Celsius as their critical temperature value for an extreme low (Kurtural, et al., 2006). In addition to avoiding hard winter freezes, Winkler, et al. (1974) note that vines are particularly vulnerable to frost damage during the growing season. They recommend avoiding planting in any areas that regularly experience temperatures below 30 degrees Fahrenheit in late spring and early fall. As for the production of grapes, in the Geography of Wine (2008), Brian Sommers notes that wine production, though generally possible both below 2,000 and above 4,000 growing degree days (GDD), is most ideal between 2,500 and 4,000 growing degree days (GDD). Because Cabernet Sauvignon ripens

\footnote{Growing degree days are the sum of each degree that exceeds 50 degrees Fahrenheit each day, measured during between April and October (Sommers, 2008).}
late mid-season it is best suited to regions that see between 2,501 to 3,500 degree days\(^5\) (Winkler, et al., 1974).

As for specifically how these factors affect character and quality, there is little documentation from scientific studies up to this point. This is likely due to the difficulty in setting up a controlled situation to isolate individual factors. Swinchatt and Howell (2004) describe this in greater detail:

“...winegrowing and winemaking involve numerous processes and decisions, any (or all) of which might influence the character of the product. To test the effect of any one variable – substrate (soil and sediment), for example – you must hold all the others constant while varying only the one under examination. This, of course, is extraordinarily difficult. It means using the same rootstock, the same grape, variety, [and] the same clone. The vine must be planted the same way, pruned the same way, trellised the same way, [and] irrigated the same way. This is all possible, but you must also consider the human factor, recognizing that the experiment will be influenced by the people who undertake it. Then you must also duplicate the aspects of place other than substrate – solar exposure, rainfall, slope angle, aspect, [and] temperature. The problem is obvious” (Swinchatt and Howell, 2004).

This is not to say that simply due to the difficulty to prove scientifically how elements of the environment influence vines does not mean that there is not knowledge about how these factors may influence wine grapes. Winemakers in

\(^5\) Crop yield affects timing of ripening in Cabernet Sauvignon in dry-farmed vineyards (Nuzzo and Mathews, 2006). “Carefully managing crop load is essential in a Washington State climate, where timing of harvest is critical, where Cabernet Sauvignon ripens late and the harvest is therefore threatened by frosts, cool weather, and late rains.” (Rudin, 2010).
Napa Valley generally accept that vines growing on lean, sharply drained soils typically produce a more robust, but tannic wine grape than vines on greater on a gentler, more fertile soil, which are known to produce a “softer character” (Swinchatt and Howell, 2004). According to James Wilson (1999), “a moist (not wet) soil absorbs heat about 15 percent more efficiently than a perfectly dry soil. This is important in vine terms because the rate at which soils warm up has a bearing on the rate of ripening: long, slow maturation tends to mean more concentrated fruit flavors.” Wilson (1999) also notes that northern slopes and higher elevations tend to delay ripening times. Moving from generalizations on a larger scale, adjacent vineyards are not necessarily starting from the same point. Microclimates, on a smaller geographic scale, have a big impact on terroir; side-by-side vineyards may see differences due to different aspects, slopes, elevations, and prevailing wind direction (Meinert and Busacca, 2000).

Terroir and geography are linked, but there is no concrete formula to achieve success in producing wine (Meinert and Busacca, 2000). “Different places can produce equally classy wine...whatever specific effects terroir might have on wine character, the range of terroir that can produce great wine is broad” (Swinchatt and Howell, 2004). The influence of geography may influence the character of a wine, as there are a number of environmental factors that provide ideal conditions for growing quality wine grapes, but it is but one component in the holistic concept of terroir.
Soil, slope, aspect, and climate are consistently identified as critical environmental factors in grape production quality in current literature (Wilson, 1998; Vaudour, 2002; Jones et al., 2004; Kurtural et al., 2006; Swinchatt, 2004). Within these critical factors, there are more ideal and less ideal conditions for growing wine grapes.

1.9 Related Research

No documentation was available on GIS site selections for dryland-farmed vineyards at the time this research was performed. However, a number of existing studies evaluate grape growing conditions through spatial analysis and propose regional site suitability. Jones, et al. (2004) use class rankings for the presence of ideal conditions to produce a composite viticulture suitability map for the Umpqua Valley AVA in Oregon. Kurtural, et al. (2006) use a point system that provides the highest scores in areas with the most beneficial ranges of environmental and geographic influences on ideal grape-growing conditions. Rather than evaluating an AVA, they explore overall suitability in all of Illinois and further dissect two counties. Irimia and Patriche (2010) also assign points, but for the presence of the best range of each ideal condition. Imre and Mauk (2009) have a different approach in their study of New Zealand terroir. Instead of assigning points or rankings to determine best sites for growing wine, they identify existing vineyard legal land parcels and compile the conditions associated with the property. They create a ratio by comparing awards won by the wines produced by region to percent of plantings.
the region holds in the study area. The characteristics associated with the highest ratios of awards to planting area are determined to be most ideal for New Zealand.

Aside from Imre and Mauk’s focus on existing vineyards, there is little effort in current studies describing how study results compared outside of the conceptions of the study to the actual sites. Ian-Huei Yau developed a GIS database for the Columbia Valley AVA (Yau, 2011). In his study, existing vineyard sites were evaluated individually in GIS for microclimate conditions. Instead of a local-scale site selection, his approach utilized GIS to determine the sources of various problems experienced in selected blocks in subject vineyards.
Section 2: Methods

2.1 Introduction

This section describes the steps taken to evaluate whether or not geographic information systems can be used to find sites for dryland vineyards. Subsection 2.2 describes the criteria selection process for a dryfarmed vineyard, with Cabernet Sauvignon as the example variety. It also describes the results of literature review. This literature review identified the geographic and climatic site factors that influence the survival of grapevines or level of quality in the production of wine grapes. Subsection 2.2 also outlines unique study area conditions identified by local experts based in the Walla Walla Valley. All selected geographic and climatic site factors are then broken down individually at the end of this subsection. It includes detailed discussion on the criteria selection process, including adjustments made to the selection criteria and how it evolved through this study. Subsection 2.3 outlines the data and sources for the geographic information system (GIS) data that were used to perform this site selection. Strengths and limitations of the data are also discussed in this subsection. Subsection 2.4 describes the details of the GIS site selection model developed for this study, including individual tools, processing steps for GIS output products. And finally, subsection 2.5 compares the occurrence of dryfarmed vineyards within the identified suitability area against the rest of the Walla Walla Valley AVA.
2.2 Criteria Selection for Suitability

Generally speaking, the criteria were selected based on information derived from a literature review and from local expert knowledge. Specific details of criteria selection are spelled out in the latter half of this subsection. As for the literature review, I reviewed all relevant viticulture studies related to the influence of geography and climate. I looked for characteristics important in influencing the survival of grapevines, especially when using dryfarming cultivation practices, the characteristics that influenced the quality of wine grapes produced in a vineyard, and what is needed by Cabernet Sauvignon in relation to other wine grape varieties for ripening and fruit quality. See subsection 1.8 for full discussion of information found in the literature review. In addition, a summary of these influential characteristics and their literature source can be found in Appendix A.

From my research conducting the literature review, I determined that there is little written documentation on specific site criteria that are influential or effective for viticulture for the Walla Walla Valley region. To find more specific information, I also performed informal interviews with four local experts in the Walla Walla Valley viticultural industry to learn about local region conditions and climate patterns. These experts are: Dr. Kevin Pogue; Professor of Geology, independent consultant; Brian Rudin, Winemaker; Ken Hart, independent consultant, multiple-site vineyard manager; LeaAnn Hughes, dryland vineyard owner and viticulturalist. Figure 4 summarizes key points of information derived
from these interviews, as well as other details from research specific to viticulture in the Walla Walla Valley AVA area. Appendix B includes full interview notes.

<table>
<thead>
<tr>
<th>Environmental Influence</th>
<th>Influence Type</th>
<th>Influence Details</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Depth</td>
<td>Positive</td>
<td>Deep till loam allows storage of precipitation to sustain the vine through the growing season.</td>
<td>Pogue (2011)</td>
</tr>
<tr>
<td>Soil Type</td>
<td>Positive</td>
<td>Athena, Palouse, and Walla Walla soils are composed of well-drained deep silt, formed in deep loess.</td>
<td>Meneer and Busacca (2000)</td>
</tr>
<tr>
<td>Aspect</td>
<td>Positive</td>
<td>Southern and western exposure maximize ripening potential for late ripening varieties.</td>
<td>Rudin (2011)</td>
</tr>
<tr>
<td>Climate</td>
<td>Positive</td>
<td>13 to 17 inches of average annual precipitation may provide necessary moisture for vine survival.</td>
<td>Hart (2011)</td>
</tr>
<tr>
<td>Climate</td>
<td>Positive</td>
<td>18 inches of average annual precipitation provides necessary moisture for vine survival.</td>
<td>Rudin (2011)</td>
</tr>
<tr>
<td>Climate</td>
<td>Positive</td>
<td>Increased precipitation in the eastern portion of the Walla Walla Valley AVA (20 inches of average annual precipitation and above) conservatively provides necessary moisture for vine survival.</td>
<td>Pogue (2011)</td>
</tr>
<tr>
<td>Climate</td>
<td>Positive</td>
<td>Above 300m avoids frost damage in the Walla Walla Valley.</td>
<td>Pogue (2010)</td>
</tr>
<tr>
<td>Climate</td>
<td>Negative</td>
<td>Grapes do not ripen above 3,000 feet in the Columbia Valley.</td>
<td>Pogue (2010)</td>
</tr>
<tr>
<td>Climate</td>
<td>Positive</td>
<td>Above 3500m to 4500m has the best temperatures for ripening grapes in the Walla Walla Valley.</td>
<td>Pogue (2011)</td>
</tr>
<tr>
<td>Slope</td>
<td>Positive</td>
<td>25% slope provides adequate drainage for quality grape production.</td>
<td>Rudin (2011)</td>
</tr>
<tr>
<td>Streams</td>
<td>Negative</td>
<td>Areas within 500m of streams are cooler, warmer air helps to ripen grapes.</td>
<td>Pogue and Exner (2004)</td>
</tr>
</tbody>
</table>

**Figure 4 – Documented Environmental Influences for the Walla Walla Valley American Viticultural Area**

Influencing factors include slope, precipitation, soil type and depth, aspect, elevation, and proximity to major streams. Individual factors are identified as having either a positive or a negative influence on the process of growing particular wine grape variety (Cabernet Sauvignon) using dryland farming. I identified these factors through a literature review (see subsection 2.2) and through feedback from local experts in the Walla Walla AVA viticulture industry (see subsection 2.3). A suitability area dataset was produced which shows the spatial extent of where all
positive environmental factors occur and excludes any areas where negative environmental factors occur. The remainder of this section describes my criteria selection process specific to each of these factors.

Slope is an important factor in two ways. The first is that it promotes cold air runoff, thus warming the site (Sommers, 2008; White, 2009; Jones, et al., 2004). The second is that it allows excess precipitation to drain away (Sommers, 2008). A general guideline noted in literature is at least 5 percent slope is needed to produce a quality grape, and if machinery will be used, a 15 percent slope or less is best (Jones, et al., 2004; Winkler, et al., 1974). My initial research included only areas with at least 5 percent slopes and up, with everything over 15 percent given a discounted value. After an initial review with Winemaker Brian Rudin, I discovered that at least two sites with highly reputable vineyards were excluded with this criterion. In the Walla Walla Valley AVA, a site with well-drained soil and an elevation above cold air pooling, vineyard quality will not be reduced as long as the site is not flat (Rudin, 2012). This lead to the revision of the criteria to include all areas that were not flat, 2 percent slope or greater. Slopes over 15 percent were also included, partly to reduce fragmentation of resulting areas, but primarily because local practice shows that machinery is not necessary for a profitable vineyard. (Pogue, 2010; Rudin, 2012). Figure 5 shows the classification of all slopes, from under 2 percent to areas over 15 percent.
Estimates for the minimum average annual precipitation necessary ranged from a low of 15.5 inches (Hart, 2011), to 18 inches (Rudin, 2012), up to 20 inches (Pogue, 2011). Twenty inches was used to be conservative in the effort of finding sites with adequate precipitation year over year.
Deep silt loam soil is needed to provide the best precipitation storage capabilities to sustain vines through the dry Walla Walla Valley growing season without supplemental irrigation (Pogue, 2010; Hart, 2011). Deep soils are at least one meter in depth (White, 2009, p. 45). In my original criteria, I had intended on selecting all silt loam soils one meter or greater in depth. Because soil depth data (Gridded Soil Survey Geographic (gSSURGO) Database) do not include measurement values of surface to bedrock in this area, another selection method was needed. In a Geological study of terroirs of the Walla Walla Valley appellation, Ritzville, Walla Walla, Athena, and Palouse series soils were all specifically noted to be formed in deep loess (Meinert and Busaca, 2000). With the exception of a few soils with in these series with hardpan layers, or other obstructions that would limit root growth noted within the map unit description, these soils were added to the criteria for this site selection.

Southern and western aspect exposures to the sun typically produce the greatest amount of solar radiation. The warmest sites are needed in this location due to late season fruit maturation of Cabernet Sauvignon and a dramatic temperature drop at the end of the growing season (Rudin, 2010). To be consistent with previous research by Jones et al. 2004, aspect values of 89 to 270 degrees were used to exclude the darkest northern and eastern aspects.

Average growing season temperatures increase with elevation in the Walla Walla Valley up to 450m (Pogue, 2011; Pogue and Dering, 2008). Specific to the
study area, nocturnal cold air pooling is a major influence for all vines in this area (Pogue and Dering, 2008). As temperatures drop at night and the cooler air drains (Sommers, 2008), it is slowed by a dramatic narrowing at the outlet of the Walla Walla Valley drainage. This causes the backup, holding the coldest air at the lower elevations of the study area (Pogue, 2011; Pogue and Dering, 2008; Hart, 2011; Rudin, 2011). As a result, year over year, the greatest frost damage to vines is sustained below 300m elevation (Pogue, 2011; Pogue and Dering, 2008). Elevation between 350m and 450m tends to provide best ripening with lowest occurrence of frost damage in the study area (Pogue, 2010). In preliminary iterations, 350m to 450m formed the elevation criterion, but preliminary results showed that the 350m lower limit removed sites where established dryland vineyards are currently sited (Rudin, 2012). 300m to 450m is a more realistic range.

According to a study by Kevin R. Pogue and Gregory M. Dering (2008), when comparing sites within 500 meters of streams to other sites at similar elevations, the major stream sites were found to be 0.5C to 2.0C colder on average due to cool air draining. Areas meeting all other site selection criteria were removed if near major streams (within 500m). Major streams were defined by consulting sites in Pogue and Dering study specifically classified as near major streams, as well as consulting the drainage section of the Soil Survey for Walla Walla County, WA (Harrison, et al., 1964). The following streams were classified as major streams for
this study: Mill Creek, Blue Creek, Cottonwood Creek, Dry Creek, Pine Creek, Russell, Creek, Touchet River, Walla Walla River, and Yellowhawk Creek.

Figure 6 - Source Dataset Overview – All Data Inputs for Site Selection (see text for additional information)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Data Resource</th>
<th>Originator</th>
<th>Publication/Downloaded</th>
<th>Resolution</th>
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</thead>
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<tr>
<td>Major Streams</td>
<td>National Hydrography Dataset</td>
<td>United States Geologic Survey</td>
<td>20110404</td>
<td>1:24,000</td>
</tr>
<tr>
<td>Major Streams</td>
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<td>USDA/USDA - Aerial Photography Field Office</td>
<td>20120405</td>
<td>6 Meters or better</td>
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<tr>
<td>Elevation</td>
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<td>United States Geologic Survey, EROS Data Center</td>
<td>20120403</td>
<td>10 Meters or better</td>
</tr>
<tr>
<td>Precipitation (Washington)</td>
<td>Annual Average Precipitation by State</td>
<td>Oregon State University and the Oregon Climate Service at Oregon State University</td>
<td>20110404</td>
<td>Approximately 800 Meters</td>
</tr>
<tr>
<td>Precipitation (Oregon)</td>
<td>Annual Average Precipitation by State</td>
<td>Oregon State University and the Oregon Climate Service at Oregon State University</td>
<td>20110404</td>
<td>Approximately 800 Meters</td>
</tr>
<tr>
<td>Slope</td>
<td>National Elevation Dataset</td>
<td>United States Geologic Survey, EROS Data Center</td>
<td>20110408</td>
<td>10 Meters or better</td>
</tr>
<tr>
<td>Aspect (Solar Radiation)</td>
<td>National Elevation Dataset</td>
<td>United States Geologic Survey, EROS Data Center</td>
<td>20120408</td>
<td>10 Meters or better</td>
</tr>
<tr>
<td>Soil (WA)</td>
<td>Soil Survey Geographic (SSURGO) database for Walla Walla</td>
<td>United States Department of Agriculture - Natural Resources Conservation Service</td>
<td>20120825</td>
<td>The information was collected at scales ranging from 1:12,000 to 1:16,000</td>
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<tr>
<td>Soil (OR)</td>
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<td>The information was collected at scales ranging from 1:12,000 to 1:16,000</td>
</tr>
<tr>
<td>A/VA Boundary</td>
<td>USGS-NRCS-NCGC Digital Raster Graphics County Mosaics</td>
<td>USGS - Natural Resources Conservation Service</td>
<td>20110104</td>
<td>Constructed from legal description with use of data</td>
</tr>
</tbody>
</table>

2.3 Data

This subsection provides information about the source data used in the site selection for this study. Figure 6 provides an overview of the source datasets used in this study. Detail is provided for each factor of influence in the site selection, including: slope, precipitation, soil type, aspect, elevation, and proximity to major streams.

**Slope**

Slope was derived from the National Elevation Dataset from the United States Geologic Survey EROS Data Center utilizing the ESRI ArcGIS Spatial Analyst slope
tool. Percent rise output was selected, which produced a raster polygon containing percent slope values.

**Precipitation**

Average annual precipitation data were compiled from PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Raster Average Yearly Precipitation 1981-2010 datasets from Oregon State University, the Oregon Climate Service at Oregon State University and United States Department of Agriculture Natural Resources Conservation Service.

**Soil Type**

For soil type and depth, Gridded Soil Survey Geographic Soil Survey Geographic (SSURGO) databases from the United States Department of Agriculture Natural Resources Conservation Service were used. Umatilla County, Oregon dataset OR667 was combined with Walla Walla County dataset WA071. “Depth to bedrock” values associated with each soil unit were largely unpopulated. As a result, soil depth estimates were not available and could not be obtained for the study area within the scope of this project. For discussion about how and what soil types were selected see section 2.2.

**Aspect or Solar Radiation**

Aspect was derived from the National Elevation Dataset from the United States Geologic Survey EROS Data Center utilizing the ESRI ArcGIS Spatial Analyst aspect tool. Solar radiation values were also generated for the growing season (May 27
1 through October 31) using the ESRI ArcGIS Spatial Analyst solar radiation tool. Aspect was selected over solar radiation values for two reasons. The first is for simplicity of classification of values and the second is for consistency with past site selection studies, including work by Jones, et al. (2004) in the Umpqua Valley.

**Elevation**

Ten meter resolution National Elevation Dataset elevation data were obtained from the United States Geologic Survey EROS Data Center in the form of numerous raster tiles. These were merged into a single elevation dataset for the study area and nearby region.

**Proximity to Major Streams**

A major stream dataset was generated manually through heads up digitizing using the 1:24,000 National Hydrography Dataset and 2011 aerial ortho photography from the United States Department of Agriculture Farm Service Agency Aerial Photography Field Office National Agriculture Imagery Program as guides. The manual digitization was preferred to avoid high costs associated with the purchase of stream data of unspecified accuracy from Walla Walla County and Umatilla County. Using the ESRI ArcGIS buffer tool, a new dataset was created to form the boundary of areas within 500 meters of a stream.

**2.4 Site Selection**

This subsection outlines specific details of the site selection developed for this study using geographic information systems (GIS). Overall, the site selection
identifies areas where all favorable conditions intersect, then removes the areas within 500m of major streams. The end result is a suitability area polygon showing the spatial extents that meet all criteria for ideal growing conditions for Cabernet Sauvignon in dryland farming conditions in the Walla Walla Valley AVA. The remainder of this subsection includes the specific details of individual tools and processing steps in the site selection. This begins with 2.4.1, which includes a discussion of steps necessary to determine the spatial extent of individual positive environmental factors as discussed in subsection 2.2. 2.4.2 includes the steps necessary to find the locations where all positive factor conditions occur. It also describes that an output dataset is produced that shows the spatial extent of where all of the positive factors are present. Subsection 2.4.3 discusses the processing step for removing negative factor conditions. Finally, subsection 2.4.4 discusses the final step in the site selection that removes the negative factor spatial extents from the positive factor spatial extents to produce a final suitability extent dataset. Note that all tools described are included in the ESRI ArcGIS 10.1 geographic information systems software suite. See Appendix C for model diagram.

2.4.1 Processing Favorable Conditions

Slope Processing

Slopes greater than two percent were extracted using the Extract by Attributes tool. See subsection 2.2 for information regarding criteria selection. Then the Raster Calculator was used to multiply all values by zero to form a uniform single value of zero. This left only acceptable values left which share a zero value. This
uniform value allows for a conversion from a raster to a single polygon file geodatabase. Then the Int tool was used to convert the raster from a floating point format to integer values. This allowed for the conversion using the Raster to Polygon tool. Then the Project tool was used to convert the data from North American 1983 UTM Zone 11N to NAD 1983 UTM Zone 11N.

Precipitation Processing
Washington and Oregon average annual precipitation datasets were combined into a single dataset using the Merge tool. Then values of 20 inches (approximately 508mm) or greater was derived using the Select tool. (See subsection 2.2 for information regarding criteria selection.)

Soil Type Processing
Walla Walla County and Umatilla County area data were combined using the Merge tool. Then a table listing deep silt loam map units was joined using the Join tool. This manually created table contains each individual map unit with a soil series identified by Lawrence Meinert and Alan Busacca in their research on the terroirs of the Walla Walla Valley appellation as deep silt loams. See subsection 2.2 for information regarding criteria selection. Units noted as hardpan variant or lacustrine substratum were excluded. The Select tool was used to extract only those map units matching the deep silt loam map unit table.


Aspect Processing

South to western aspects, 89 to 270 degrees were extracted with the Extract by Attributes tool. See subsection 2.2 for information regarding criteria selection. The Int tool was used to convert the raster from floating point format to integer values. Then the Raster to Polygon tool was used to convert the data to vector format. Then the Project tool was used to convert the data from North American 1983 UTM Zone 11N to NAD 1983 UTM Zone 11N to be consistent with other datasets used in this study.

Elevation Processing

Elevation values from 300 to 450 meters in elevation were extracted with the Extract by Attributes tool. See subsection 2.2 for information regarding criteria selection. Then the Int tool was used to convert the raster from floating point format to integer value format. The data were converted to vector format using the Raster to Polygon tool. Then the Project tool was used to convert from North American 1983 UTM Zone 11N to NAD 1983 UTM Zone 11N for consistency with the other datasets.

2.4.2 Identifying Areas Where All Favorable Conditions Spatially Coincide

Ideally, the Intersect tool could have been used to identify where all favorable conditions intersect (where they all spatially coincide), and this output dataset would have retained all of the attributes of the input data. Unfortunately, the data necessary for identifying these favorable conditions were too complex to be
successfully executed by this tool. To allow for successful processing of multiple complex features, a simple polygon mask was created. This mask was then used with the Clip tool to simplify and strip complex individual records and attributes into a single simple feature for each favorable condition. The Clip tool was then used in succession to pare down to a single dataset that contains only areas where all favorable conditions intersect.

2.4.3 Processing Unfavorable Conditions

Processing Areas Near Major Streams

Areas near major streams were the only unfavorable conditions in this site selection. To find areas near major streams, the Buffer tool was used on the major streams dataset with an input value of 500 meters. See subsection 2.2 for information regarding criteria selection. This produced a dataset that identifies areas within 500 meters of a major stream.

2.4.4 Removal of Unfavorable Conditions and Final Suitability Area Output

The Erase tool was used to remove areas of unfavorable conditions from the areas where all favorable conditions intersect. Then the Clip tool was used to remove all areas outside of the study area. This produced a final suitability output dataset that shows where Cabernet Sauvignon may be successfully grown through dryland farming methods in the Walla Walla Valley AVA.
2.5 Dryfarmed Vineyard Locations in Comparison to Suitability Area

Vineyards identified as using dryland farming techniques in the Walla Walla AVA were overlaid on the mapped extents of the suitability area (see subsection 3.4). Occurrence of these vineyards that fell within the suitability area was visually compared between those that fell elsewhere in the study area. Effectiveness of this suitability area and the use of GIS for finding dryfarming sites for wine grape varieties are documented in subsection 4.1.
Section 3: Results

3.1 Suitability Results

Section three provides suitability results found in this study. The remainder of this section is composed of two subsections. Subsection 3.2 includes mapping that displays results of this study on where Cabernet Sauvignon may likely be grown without supplemental irrigation in the Walla Walla Valley AVA. It also includes an evaluation of spatial patterns found in review of these results, along with the total land area deemed to be suitable. Subsection 3.3 breaks down each input factor used in determining final suitability. The spatial patterns of these factors their impact on final suitability results are discussed in detail. Subsection 3.4 includes discussion on how the results of this study related back to existing literature.

3.2 Results for Individual Factors in Determining Dryland Cabernet Sauvignon Suitability

This subsection provides maps showing the spatial extent of individual criteria factors identified in subsection 2.2. It also provides discussion on how these factors influenced the overall site selection for ideal sites for Cabernet Sauvignon grown without supplemental irrigation.

3.2.1 Factors

Slope

Slope was not much of a limiting factor in the site selection. As shown in Figure 7, the majority of the study area meets slope criterion. A two percent or greater slope is acceptable for viticulture with adequate soil drainage in the study
area (Rudin, 2012).

Figure 7 - Spatial Extent of Suitable Slope – Slopes Over Two Percent (see section 2.2 for suitability criteria).

Figure 8 - Walla Walla AVA Average Annual Precipitation (in inches) – Values Range From a low of 11in in the eastern-most portion of the AVA, up to high of 44in in the outermost in the western-most reaches (see text for additional information).

Precipitation Patterns

Due to orographic lift, there is variation in average annual precipitation between the lower portion of the Walla Walla Valley (Meinert and Busaca, 2000) and the eastern-most portion in the foothills of the Blue Mountains. As displayed in Figure 8, PRISM data show average annual precipitation ranges from 11 inches at the lowest in the west rising to 44 inches at the outermost eastern edge of the AVA.

The criterion used in this study of 20 inches and above includes 277 square kilometers (107 square miles) (Fig. 9). As expected, it is concentrated largely in the foothills of the Blue Mountains. Precipitation held the smallest area of all of the positive environmental factors of influence. Because the presence of all positive environmental factors was a requirement for the site selection, average annual precipitation was the single most limiting factor. This means it was one of the largest influences in the resulting pattern. An average annual precipitation value of 20 inches or higher limited the suitability area to roughly the eastern-most quarter of the study area (Figure 15).

With the presence of deep silt loam soils (as described in subsection 2.2), it may be possible to use dryland farming techniques in areas below the 20 inch average annual precipitation criteria used in this study. Fifteen and a half inches was the lowest threshold suggested (Hart, 2011), up to a more conservative estimate of 18 inches (Rudin, 2010). The difference between 18 inches and 20
inches removes a total of over 170 square kilometers (nearly 66 square miles) from consideration in this study.

Figure 9 - Spatial Extent of Suitable Average Annual Precipitation - Areas estimated at 20 inches and above met average annual precipitation suitability criteria (see section 2.2 for more information about suitability criteria).

Figure 10 - Spatial Extent of Average Annual Precipitation Margin – Areas estimated between 18 and up to 20 inches were removed from precipitation suitability criteria (see section 2.2 for more information about suitability criteria).


The entire study area encompasses 1291 square kilometers and about 498 square miles. The difference between 18 and 19 inches equals about 13 percent of
the Walla Walla Valley AVA. Figure 10 displays PRISM data for this margin area broken into precipitation categories of 18 inches, 19 inches, and more than 19 inches for average annual precipitation.

Figure 11 - Spatial Extent of Selected Deep Silt Loams – Deep Silt Loams of Ritzville, Walla Walla, Athena, and Palouse Soil Series (see section 2.2 for selection criteria).

Data Source: United States Department of Agriculture, Natural Resources Conservation Service, Soil Survey, Geographic (SSURGO) database for Walla Walla. AVA boundary interpreted from description in U.S. Federal Register. (http://federalregister.gov/a/00-14162)
Soil Patterns

The majority of the Walla Walla Valley is composed of an accumulation of wind-blown loess from the Touchet beds and the Pasco Basin (Carson and Pogue, 1996). It has formed the deep, silty soils ideal for precipitation storage to sustain vines through the growing season (Pogue, 2011). The spatial extent of deep silt loams from the Ritzville, Walla Walla, Athena, and Palouse Soil Series are shown in Figure 11. See section 2.2 for details on criteria selection.

Aspect

Greater topographic variation in the Blue Mountain foothills creates a greater variation of suitability due to more pronounced southern and western exposures. The western-most portion of the study area with the lowest elevations shows the greatest suitable aspect areas. A consistent pattern is also visible on the hills near the north bank of Dry Creek6. Figure 12 shows the spatial extent of aspect criterion for southern and western exposures.

Elevation Band

Elevation generally increases from west to east in the AVA. As visible in Figure 13, the 300m to 450m band includes the foothills of the Blue Mountains, the northern

6 Two streams named Dry Creek exist within the AVA boundary. This reference is to the larger Dry Creek in Walla Walla County, in Washington State.
slope of the Vansycle Ridge, and extends past the AVA boundary into the hills of the Palouse.

Figure 12 – Spatial Extent of Suitable Aspects - To be consistent with previous research by Jones et al. 2004, aspect values of 89 to 270 degrees were used to exclude the darkest northern and eastern aspects (for more information on criteria selection, see section 2.2).

Figure 13 – Spatial Extent of Suitable Elevations

Proximity to Major Streams

The two largest streams flow down from the Blue Mountains to the floor of the valley. The Walla Walla River and its major tributary, the Touchet River, combine and flow west to the Columbia River, just north of the Wallula Gap. (Harrison, et al., 1964, p. 4). Figure 14 shows the streams classified as major for the purposes of this study: Mill Creek, Blue Creek, Cottonwood Creek, Dry Creek\(^7\), Pine Creek, Russell Creek, Touchet River, Walla Walla River, and Yellowhawk Creek.

\(^7\) Two streams named Dry Creek exist within the AVA boundary. This reference is to the larger Dry Creek in Walla Walla County, in Washington State.
Figure 14 – Areas within 500m of Major Streams in the Walla Walla Valley AVA

3.3 Dryland Cabernet Sauvignon Suitability Results

Results show the foothills of the Blue Mountains as most viable for dryland viticulture and ripening of Cabernet Sauvignon, as this area holds the greatest concentration of area identified as meeting suitability requirements. As displayed in Figure 15, this area extends to the northern boundary of the AVA. Overall suitability results include an approximate area of 20 square kilometers, or about 7.8 square miles. Existing vineyards are visible in and near identified suitability areas in five different areas, identified as areas 1 through 5 (Fig. 16). Area one includes the area around the intersection of Clodious Road and Corkrum Road, including Couvillon Vineyard, as visible in Figure 17. The second area includes the area near the intersection of Sapolil Road and Highway 12 shown in Figure 18, including Golden Ridge Vineyard.

Area three includes the area near the intersection of Vineyard Lane and Mill Creek Road shown in Figure 19. Suitability results in this area include large portions of Kenny Hill Vineyard, Walla Walla Vintner's estate vineyard, and smaller portions of Yellow Bird Vineyard and àMaurice Vineyard. Leonetti Upland Vineyard is just out of the area but immediately adjacent to Yellow Bird and àMaurice. The fourth area includes Dwelly Vineyard between Bennington Lake (reservoir) and Russell Creek Road off of an unnamed dirt road shown in Figure 20. Area five includes Les Collines Vineyard, an area directly to the east of a portion of Hood Road as shown in Figure 21.
Figure 15 - Cabernet Sauvignon Dryland Suitability Area Results

Figure 16 - Vineyard Areas Located within Suitability Results

Figure 17 – Area 1 – Includes Couvillion and Chateau St. Michelle Vineyards.

Figure 18 - Area 2 - Includes Golden Ridge Vineyard and Two Other Unknown Vineyards.

Figure 19 - Area 3 - Includes Yellow Bird, Chan, Walla Walla Vitners, A’Maurice, and Leonetti Upland Vineyards.

Figure 20 - Area 4 – Includes Dwellly Vineyards.

Figure 21 - Area 5 – Includes Les Collines Vineyard.

3.4 Dryfarm Vineyard Locations Inside and Outside Suitability Area

There are few dryland vineyards in the Walla Walla Valley. These are concentrated in two areas of the AVA (Fig. 22). Only five are confirmed as unirrigated at this time. Three of these five fall partially within the suitability results. These vineyards are Kenny Hill, Yellow Bird and Walla Walla Vintner’s Estate Vineyard. Tokar Vineyard is around 800m outside of the suitability area. As for Patina Vineyard, it is the furthest away from the suitability results at over 3500 meters away. Patina is the only vineyard in dryland area 2 (Fig. 24), the rest are concentrated in dryland area 1 (Fig. 23). This area is believed to be subirrigated from Cottonwood Creek (Hart, 2013; Pogue, 2011). Finally, Patina is the only known dryland vineyard that does not grow Cabernet Sauvignon for commercial purposes.

Overall, vineyards compose around three percent of the suitability area results. Known dryland vineyards compose around a half of a percent of all suitability area results. The vast remainder of the suitability area is still available for future dryland vineyard development.
Figure 22 – Dryland Vineyard Areas Located within Suitability Results

Figure 23 – Dryland Area 1 – Includes Kenny Hill Vineyard, Yellow Bird Vineyard, Walla Walla Vintners Estate Vineyard, and Tokar Vineyard.

Figure 24 – Dryland Area 2 – Includes Patina Vineyard

Section 4: Discussion and Conclusion

4.1 Conclusions

This study attempted to answer the question of whether or not geographic information systems (GIS) can be used to identify sites for dryfarmed vineyards. Results suggest that GIS can be effectively used for this application. Four out of five known dryland vineyards were included within or near this study's site selection. Of these dryland vineyards, four of them are Cabernet Sauvignon vineyards. Three of the four of these dryland Cabernet Sauvignon vineyards were included within the study's site selection, with the fourth nearby. See subsection 3.4 for additional discussion and figures on dryfarmed vineyard locations in the Walla Walla Valley American Viticultural Area (AVA).

Results produced from this study provide a general guide for viticultural experts interested in planting Cabernet Sauvignon in the Walla Walla Valley AVA on sites without irrigation water rights. Viticulturalists can use these maps to identify new grape growing sites containing suitable aspect, slope, elevation, average annual precipitation, and proximity away from major streams. As Cabernet Sauvignon is a late-ripening variety, this study is applicable to other late varieties grown in the study area.

Overall suitability results include an approximate area of 20 square kilometers, or about 7.8 square miles. Land near the suitability results should be
viable for dryland viticulture and support ripening of Cabernet Sauvignon. The pattern that emerged from this study shows that the foothills of the Blue Mountains, including the northern portion past the AVA boundary as most ideal (Fig 15). See subsection 3.3 for figures and more information result extents. Of this area, the actual amount of suitable land is lower in reality because building sites and roads have not been included. Some vineyards already exist in the suitability area. See subsection 3.3 for figures showing where these existing vineyards are located. Subsection 3.4 provides figures and discussion of known dryfarmed vineyard sites and how they related to the suitability area.

At this time, existing vineyards compose only around three percent of the suitability area results. The vast remainder of the suitability area is still available for future dryland vineyard development for late season varieties. This area totals around 19.4 square kilometers, or around 7.5 square miles. As irrigation rights become more limited, dryfarming may be the only viable option. As interest in dryfarming wine grapes grows, properties in the suitability area should become more desirable.

4.2 Comparison of Study Results with Existing Research

Results from this study cannot easily be compared to previous research results. No other GIS site selection studies consider dryland farming methods. No other study evaluates the effectiveness of using GIS as a tool for more specialized
viticultural site selection. This study is also specific to the Walla Walla Valley AVA. Only one other study has used GIS to evaluate vineyard sites in this geographic area, but its study area extends across the entire Columbia Basin American Viticultural Area\(^8\) (Yao, 2011). In the Columbia Basin AVA study, existing vineyard sites were evaluated individually in GIS for microclimate conditions. This information was used to determine the sources of various problems experienced in the selected vineyards. This Walla Walla Valley AVA study is different in that uses GIS to identify an area where dryfarming may be possible using Cabernet Sauvignon as an example variety.

There are other studies in North America outside of the study area that use site selection techniques similar to this study, as described in subsection 1.9. These studies produce growing feasibility for an entire study area. Each of them categorizes results by a measure of relative feasibility or divided by climate group suitability. In contrast, this study produced a single suitability category only falling in locations thought to be best suited for a particular variety. Beside dryfarming method focus, this study also differs from previous research because it does not consider zoning in selecting for potential vineyard sites. Zoning was intentionally left out of selection criteria for this study because it is a barrier that can be removed

through policy change. Soil, climate, precipitation, and terrain cannot be so easily changed.

4.3 Model Limitations, Sources of Error, and Further Work

A challenge with this project was determining appropriate classification and development of exacting criteria. Geographic information systems (GIS) serve as a practical tool to evaluate multiple variables and the sites on which they converge, but it requires precisely defined limits on each variable, as described in section 2. As discussed in subsections 1.7 and 1.8, there are no precise formulas to apply to site conditions that guarantee healthy, vibrant vineyards and high quality wine grapes.

This study is intentionally generalized due to data resolution constraints and due to the limited size of the study area. Because the suitability criteria are somewhat conservative and data resolutions are plus or minus 20 meters, adjacent areas may also produce quality Cabernet Sauvignon grapes. Obtaining or collecting more precise data would yield more precise results. The majority of land use in the suitability area appears to be farmland dedicated to wheat. To convert wheat fields to dryland vineyard requires substantial investment in soil preparation (Hart, 2011). For that reason pasture or undisturbed land is preferred for new vineyards because soil is not as compacted and nutrient-poor as wheat fields (Hart, 2011). With better data it would be practical to consider land use (such as wheat fields). Proximity to
road access, favorable zoning, private land ownership, and level of development would also be useful. With more precise data, future study could identify developable tax property parcels with the highest potential for dryland vineyards.
Works Cited


Pogue, K. (2010, September 27). Informal email correspondence on vine growth limitations for dryland conditions in the Walla Walla Valley region. (J. Sears, Interviewer)


Rudin, B. (2012, September). Informal interview. (J. Sears, Interviewer)


Appendix A – Noteworthy Literature on Specific Environmental Influence on Viticulture and Terroir Related to Site Selection (in order by author)


[In reference to the Western Snake River Plain, Idaho]

“Risk of frost damage is minimized by locating vineyards on slopes with good air drainage towards river or valley bottoms.” (p.44)

“Vineyards tend to be located on hillsides with a southern or southwestern aspect to maximize heat unit accumulation and to avoid direct exposure to prevailing northwesterly winds. Vines are generally planted in north-south rows to facilitate cold air drainage and to provide equal sunlight exposure on both sides of the vine canopy.” (p.44)


“To me, the very essence of the concept of terroir is that the specific quality of the wine produced from a particular grape variety a the micro-level of a vineyard is a fundament of the complex interrelationships of all the factors, above and below the ground, that affect the grape during growth, excluding pests, diseases, herbicides,
mutations, etc. Generally, these factors may be divided into five main groups: meteorological, physiographic, pedological, geological and viticultural. Examples of these factors include, but are not restricted to:

1. Meteorological: temperature maxima and minima, hours of sunlight, wind conditions, and rainfall;

2. Physiographic: type of landform, elevation, slope aspect and gradient, and slope drainage;

3. Pedological: composition and porosity of overlying soils, soil mineralogy and chemistry, solid grain size and texture, and clay mineralogy;

4. Geological: geology of the subsoil and the geochemistry, petrology and the texture of individual strata, surface water and ground water flow rates and chemistry, and;

5. Viticultural: trellising method, row spacing, grape-bunch thinning and allowable production, fertilizing, mechanical addition of soils or rock material, systematic tile-draining, and irrigation.” (p.191)

“...I believe that the subsoil geology is the determining factor controlling the taste and bouquet of a wine (the very essence or ‘soul’ of a wine). I consider that the soil primarily affects young vines in their early growth stages, but once the vine is established it is affected mainly by the geological conditions of the subsoil. Evidence for this is that it is well known from areas of old-growth vines that the
wine from old vines tastes different than young vines (often better but sometimes worse). Grapes are exceptionally deep-rooted plants that dislike wetlands and grow best on well-drained soils.” (p.193)


[This article provides an excellent example of previous modeling work.]

"The physical factors that influence the [grape growing to wine production continuum] process include matching a given grape variety to its ideal climate along with optimum site characteristics of elevation, slope, aspect, and soil." (p. 167)

"of all site factors, climate exerts the most profound effect on the ability of a region or site to produce quality grapes." (p. 168)

"Topographic factors that exert the greatest influence on a site’s climate include elevation, slope, aspect, hill isolation and how it affects air drainage, and proximity to bodies of water. A marginal climate can be mitigated to some degree by locating the vineyard on an ideal site... Grapevines will tolerate a wide range of soils, with nutrient imbalances and moisture issues being the principal factors to consider. Soil drainage is the most important physical property." (p. 168) (Jones G. V., Climate and Terroir: Impacts of Change Variability and Change on Wine, 2003)

“Of all of the site factors, climate arguably exerts the most profound effect on the ability of a region or site to produce quality grapes.” (p.2)

“Cabernet Sauvignon is grown in regions that span intermediate to hot climates with growing season averages that range from roughly 16.5-19.5°C (e.g., Bordeaux or Napa).” (p. 7)

Climate change will affect and change suitability for grape varieties. (p. 7)


Deep, consistent loam is ideal for dryfarming [wheat]. (p.39, p. 74)

Blue Mountains have more precipitation than the rest of the Columbia Plateau. (p.199)

Soil in Walla Walla Valley AVA region not considered different enough to form a distinctive terroir (p. 158).

Multiple factors influence grape quality (p. 157).

Microclimates have a profound impact on site suitability between different wine grape varieties. (p.165)

"...it is very clear that there is a direct correlation between the terroir and the grape varieties and the wine styles that do best in a particular location." (p. 165)

Seven Hills Vineyard is acclaimed for Cabernet Sauvignon. (p.165)


Cropload is essential in a Washington State Climate, where timing of harvest is critical, where Cabernet Sauvignon ripens late and the harvest is therefore threatened by frosts, cool weather, late rains, etc.

Precip. Zone Classification: low = less than 300mm; intermediate = 300-450mm; high = 450-600mm


"Rocky soils absorb and hold heat." (p. 37)

"Increased density of vines without irrigation increases the need for more spacing between vine rows in situations with limited water." (p. 41)

“Combat weeds and grasses in between rows to reduce competition for water for vines.” (p. 42)

“The best production area is in the middle of steep south-facing slopes just above rivers.” (p. 48)

There are differences in how surfaces reflect heat. (p. 49)

Cold air sinks. (p. 52)

“Soil is a pivotal consideration in the production of wine. The physical and chemical properties of soil affect the heath of grapevines and the properties of the grapes they produce.” (p. 60)

“Grapevines can easily root to depths exceeding five feet.” (p. 60)
“...the importance of soil texture for grapes and other plants lies in its impact on the ability of the soil to hold water. The reason soil texture is important is that it influences the infiltration rate, percolation rate, and porosity of the soil.” (p.70)

“From sand to silt to clay, the [water] tension levels that hold moisture in the soil increase.” (p.73)

“In general, soils that are good for agriculture are those that are deep, well drained, loams to loamy. Loams are composed of roughly equal parts of sand, silt, and clay.” (p. 75)


"In Napa Valley, areas with thin sediment cover over bedrock - with sparsely developed soils and extreme drainage with little nutrients with naturally stressed vines coincide with 'mountain vineyards know for intense, highly concentrated wines that tend to be tight and tannic. These wines are sometimes tough in their youth, but the best of them transform with age into marvelously balanced, even elegant, wines." (p. 98-99)

"Wines from the western fans are said to have berrylike fruit, rounded tannins, and a generally softer character than their mountain cousins." (p. 100)

"In general, wines from [valley floor soils] tend to have prominent herbal characteristics." (p. 100)
Experts can distinguish between two areas by tasting the wine. (p.102)

"... two such different places can produce equally classy wine suggest that, whatever specific effects terroir might have on wine character, the range of terroir that can produce great wine is broad." (p. 105)

"Topography strongly influences terroir through its connections with sediment distribution, soil character, temperature, rainfall, fog, and drainage." (p.50)


“The highly significant effects of these three parameters [soil, cultivar, and climate] on vine development and berry constitution are shown. The effect of climate was greatest on most parameters, followed by soil and cultivar. Vine mineral uptake did not appear to have a critical effect on fruit quality. Sunshine hours and temperatures did not have a determining impact on the quality of the vintage.” (p.216)


Plant available water (PAW) "is greatest in deep sand clay loams and deep clay loams." (p.189)

Need “particular root stock for dryland.” (p. 177)
Cabernet Sauvignon considered "intermediate" for water stress sensitivity. (p.128)

Deep soil is greater than one meter. (p.45)

Valley bottoms and lower slopes are more susceptible to frost damage in the spring. (p. 44)

Vines are most sensitive to water stress between flowering and fruiting period. (p.197)

"Slopes also induce drainage of cold air, which helps to avoid damage to vines from low temperatures in winter and frost in spring. Most grape cultivars require at least 180 frost-free days, and frosts after bud burst can cause serious crop losses." (p.44)


Mid-slope provides most idea site by providing good drainage and being an ideal location for collecting solar radiation. (p. 22)

"The climate invites distribution of the vine, the selection of the variety, and its cultivation by man." (p. 5)

"Whatever the parent material, the quality of life for the vine largely depends upon texture and structure of the soil. Granular structure which is best for vine plants, develops most easily where there is about 25 percent sandy or course material in
the mix. Pebbles or rock fragments help break up the tendency of the soils to compact." (p.24)

"It is fairly obvious that ideal for the vineyard is a pebbly, sandy-clayey soil with considerable organic matter. Good soil structure is influenced by limy waters and the type of clay materials. (p.25)

"...plants are better served when the pH is neutral or on the alkaline side." (p. 26)

Stony soil is extolled as being ideal for vineyards. What rocky surfaces often indicate is a texture and structure of soils that are well drained. Stones themselves on the surface serve particular functions. Here's how. The rock surfaces reflect and diffuse sunlight to the lower leaves shaded by the canopy. Also, the tocks absorb heat during the day, then act as miniature radiators to give back during the cooler evening hours." (p.35)

"The further north of the 45 degree parallel, the lower the angle of the sun and more critical the orientation of the vineyard." (p.36)


Deep soil and moisture retention is needed for dryfarming. (p.71)

"For example, in climatic region I of California, about 16 inches of water is required by the average vineyard of wine grapes each year. Each foot in depth of a loam soil will hold about 3 inches of available water. Thus, such a soil must be 5 feet or more
in depth, or the vines will lack water before the crop is mature. Sandy soils hold less water, and must be correspondingly deeper." (p.239)

"The hotter the climate and the shallower the soil, the greater the water requirement." (p.239)

"...regardless of total rainfall, only the water held by the soil and available to plants is useful." (p. 393)

"Grapes of good to excellent quality are produced by numerous varieties on practically all of the soil types, except those of the very heaviest texture. Premium quality wines are produced on most of the soils when the climate is favorable." (p.74)

"Even in the renowned wine-producing areas of Europe, with their varied soils, heat summation must be accepted as the principal factor in the control of quality: their vintage years always coincide with abundance of heat, and such years occur uniformly across all the soil types. The variety, with proper vinification and aging and through such inherent characteristics as aroma and flavor constituents, determines the type of wine to be produced, but climate (primarily heat summation), by influencing the sugar-acid ration, total acidity, tannin content, and minor constituents, determines the quality within the type." (p.75)
Appendix B - Interview Notes

Dr. Kevin Pogue, 3/11/2011 at Whitman College

a) Best ripening season temperatures are between 350 and 450 meters in elevation.
b) Cooling/cooler temperatures will occur near a major stream.
c) About ½ dozen vineyards are growing without irrigation water in the area.
d) Patina has some subirrigation. (Only one portion to get established initially – lines are still in, but not used per LeAnn Hughes)
e) Walla Walla Vintners have no additional irrigation, which is an anomaly in the AVA.
f) Les Collines planted chicory cover crop because of excess water.
g) Spring Valley has to irrigate.
h) Chan Vineyard has always been dry (Dr. Gregory Chan).
i) Described a basalt/soil interface that brings moisture down from the Blue Mountains.
j) 20 inches in precipitation are a good bet for dry-farming vineyards.
k) There is a higher risk of early season freezes at higher elevation.
l) Salinity is not a problem in this area... alkaline soil and PH issues only occur in low rainfall areas.
m) Talking to people on ground will lend credibility to project.
n) Steep, southwest-facing slopes are progressively thinner starting at 25 to 30 degree slopes.
o) Kevin currently working on 30-57% slope project.
p) Study area boundary
   • could extend to Waitsburg, below 2,000 ft.
   • proximity to mountains
   • eastside of precip line with soils deep enough to keep water until August
   • 2 categories – everything machine farmable and up to 20 degree slope and everything else?

Ken Hart, 3/11/2011 at Yellow Bird Vineyard

a) 15.5 to 17 inches of precipitation at Yellow Bird Vineyard (contradicts website info)
b) At 12 brix the vines themselves/chlorophyll resists pests – little use for pesticides
c) Carbon holds eight times the weight of water
d) Soil management involves the soil surface being composed of “crumbs” or clumps to reduce erosion,
e) Topsoil = how deeply oxygen can penetrate the topsoil. Yellow bird has 6-8" past 10 ft. root spread

f) Our vineyards, even unirrigated are less stressed than those irrigated (nearby).

g) Challenges involve conditioning the soil to retain moisture, for Yellow Bird, reconditioning from previous wheat farming on the site to create a living soil. (pesticide and other chemicals previously applied killed beneficial life living in soil)

h) Went tighter with planting so the vines would go further to seek moisture with roots.

i) Control weeds right away to keep them under control with mechanical means

j) Grape plants can pull moisture from fruit to survive and will do that when stressed enough

k) Vineyard land peaked at $21,000 an acre

l) Water rights: $300,000 for 200 gallons per minute

m) Gates foundation is interested in farming research (Ken turned them down)

n) Undisturbed land (such as pasture) requires way less work in soil preparation (anhydrous ammonia from fertilizing wheat -> toxic – kills microbes)

o) Calcium is gravity specific – some vineyards are calcium deprived – leave rolling hills on vineyard to preserve calcium

p) Wind machines are sometimes needed

q) Chen’s vineyard is a 425M in elevation

LeAnn Hughes, 3/11/2011 at Patina Vineyard

a) Vineyard is 5 acres, at 988 ft. in elevation (planted in 1994 with a deep freeze April 1996), all Syrah

b) Recommended Scott Henry system (controls vine vigor)

c) Because of the high nitrogen content the vineyard struggled with fertility

d) End rows near neighbors that irrigate, vigor is a problem

e) Uses foliar spray with kelp to the vegetation but not to the soil

f) Most of the vineyard is on deep loess, but some is on gravel/cobble and has sharper drainage. They had to give the cobble blocks some irrigation to get them started. (Stony soil needed some additional irrigation water)

g) They chose dryfarming because it worked in the Mediterranean.

h) Thought there might be one other person doing dryland, not sure

i) Crop insurance was higher because there is no irrigation
j) Since planting, Patina has never had a failed crop (2 really dry years in a row in ’05-’06, 1999 cold end of season,’04 deep freeze – vines were established and larger and able to survive)
k) More water was available closer to mountains
l) Spacing between vine rows has changed over time.
m) Use fescue as a cover crop – when installing wind machine, 10, 12, 15 feet roots can be seen and there is no problem with competition with vines
n) Lots of rainfall in this location
o) Davey Jones having problems because of adding too much water
p) Cab Sauv – takes too long – takes an additional 2 to 3 weeks to ripen over Syrah. (you need longer sun/heat) Syrah is typically harvested the 5th to the 12th of September in the Walla Walla Valley AVA. (CROP MANAGEMENT WILL BE VERY IMPORTANT WITH CAB SAUV HERE) need more heat units, more slope, more elevation
Appendix C - Site Selection GIS Process Detail

See attached 11x17 Page