

*Geographic Analysis of Viticulture Potential
in Virginia*

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(ABSTRACT)

The state of Virginia was analyzed to establish its suitability for grape culture. This investigation occurred in two phases: a small scale analysis that encompassed the entire state, and a large scale analysis which focused on site selection at the local level. After identifying regions across the state in terms of their viticulture potential, a study area was chosen from within the highest ranking region. This study area was the focus for the local-scale site potential analysis.

First, to delineate regions across Virginia that had greater or lesser viticulture potential from a physical and climatological basis, weather station data were collected for minimum winter temperatures, maximum summer temperatures, precipitation, length of growing season, and day versus night temperature differentials. In addition, elevation and slope models were constructed to complement the climatic variables in identifying areas that contained factors most conducive to grape production. To validate this regional assessment, the history of fruit industries within the state are outlined geographically to display the evolution of the fruit industries, and to establish the factors which have shaped the current fruit landscape.

Secondly, at the local scale, a Geographic Information System (GIS) approach was used to identify sites at the county scale that had greater or lesser viticulture potential from a physical basis. Composite maps, constructed by individual counties in the state, were produced from a series of physical databases. The individual databases (sources and resolution in parentheses) included land-use (Virginia Gap Analysis; 30meter² resolution),

slope, aspect, and elevation (USGS 1:24,000 Digital Elevation Model; 30meter²), and soils data (USGS Digital Line Graph (DLG-3)). Each physical feature layer was given a numerical classification, then all layers were combined to produce a 0 to 100 scale in the final, composite image.

Given this model of potential vineyard suitability, existing fruit operations in select counties were geo-located on each feature layer using a Global Positioning System (GPS: 1-2meter accuracy). Actual data on occurrences of frosts, minimum winter temperatures, and other site variables were collected from these fruit operations and surrounding weather stations as a sample to validate the model. A strong correlation between areas containing characteristics of current fruit acreage--namely apple--and sites high in potential for viticulture according to the model.

Studying the history of geographic distribution of apple and grape industries across the state reinforces the regional assessment of viticulture potential, formulated by the climatic and topographic analysis. Employment of GIS approach at the local site scale was shown to be an effective tool for site selection at the local scale with certain caveats. In addition, the evaluation procedure integrating GIS and GPS technologies allows us to visually assess the distribution pattern of each of the factors employed individually; and, in turn, physically identify and locate areas of viticulture potential created from the combination of those factors.

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Chapter 1. Introduction

This study was undertaken to define a methodology for identifying areas of the state most suited to the growing of the primary wine grape, *Vitis vinifera*, in terms of: 1) the most suitable climatic regions of the state, and 2) the most suitable sites within those regions. *Suitable*, in this analysis, refers to an area or site that possesses the physical characteristics of the environment (climate, topography, soil) that make for successful viticulture--successful meaning high quality of fruit, low maintenance costs, and minimal risks to vine survival. While commercial success depends on physical and cultural factors (i.e. distance to market, competing land uses), cultural considerations do not directly influence success potential of the fruit, and thus are not considered in this work.

Fruit quality can be defined by an infinite number of parameters--based on desired grape varieties, grape content, and the winemaker's style and vision for the final product. An adequate discussion of the infinite and intricate facets of defining fruit or wine quality is beyond the scope of this work. For the purposes of this study, fruit quality will refer to areas containing certain parameters defined by me to be desirable in grape development. These parameters are centered primarily around a cool growing season to maintain acid levels and varietal character; and reduced precipitation during harvest which maintains sugar levels. Again, this definition of fruit quality is specific to this work only.

A major problem in Virginia viticulture is the great diversity of climatic and biological problems that challenge grape growers across the Commonwealth. Youth of the industry, limited acreage, and range of climate extremes have combined to create a lack of well established/time tested viticulture areas from which others can draw inference when planting. Classic vineyards of France and Germany have had at least 3000 years to hone their regional and site selection processes to maximize fruit success; California, at least 200 years; but Virginia has had less than thirty years to develop regional-- much less local-- assessment of viticulture potential.

A geographic analysis of the physical environments of viticulture potential of the state is offered by this work in order to compensate for these limitations. Integration of the apple and other more established tree fruit industries helps complement this analysis by lending their much longer historical record of successes and failures to the review. By

‘borrowing’ their track record within different regions of Virginia, we can better predict the potential for grapes--a fruit of similar physiographic requirements to the apple and peach.

Section 1.1 entails a brief introduction to the status of viticulture in Virginia, proceeded in Section 1.2 by a literature review of the geographic principles involved in this analysis. Section 1.3 outlines the methodology employed, 1.4 addresses the practical implications of the work, followed by a summary in Section 1.5.

1.1 Viticulture in Virginia

Wine making in Virginia began when the Jamestown settlers first fermented the native New World grapes in 1607. Today, the state is gaining national and even international recognition as a source of quality wine and as a promising area for future investment. However, since its historic beginnings to the present, the industry’s evolution has been anything but smooth or continuous. Only the technological advancements of the last fifty years have allowed local viticulturists to perfect their craft to the point of true commercial success, resulting in a rapid growth of the industry. Thus, in a state that can boast the longest history of wine making, the current landscape of Virginia viticulture is a relatively recent phenomenon--and it can be considered still as in an experimental phase.

Viticulture is the term given to the science of growing grapes; it is a science distinct from oenology, which is winemaking. Of the fifty major grape species, the single most important species for premium wine production is *Vitis vinifera* (Figure 1.1).

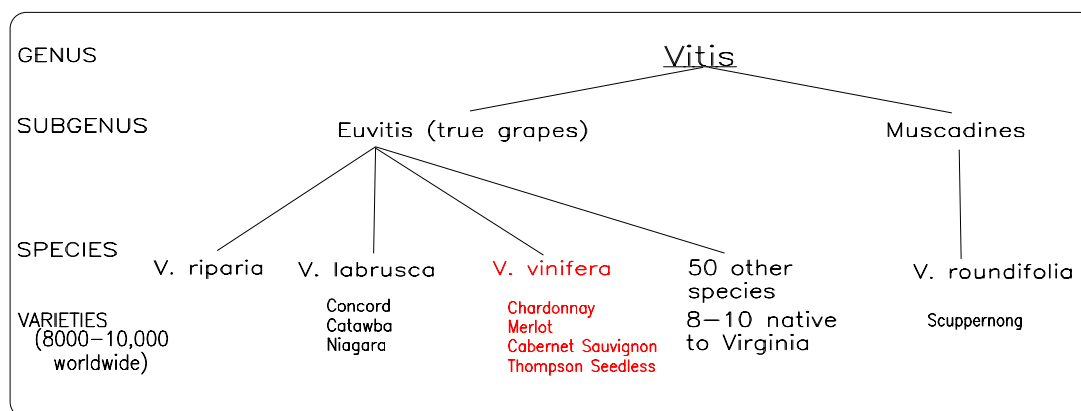


FIGURE 1.1
Grape species

Archaeological evidence indicates that *V. vinifera* probably originated in the Caucasus Mountains between the Black and Caspian Seas--modern day Georgia, Armenia, and Azerbaijan--somewhere around 5000 (BC). With the identification of this species as a superior wine grape, it was propagated across the Middle East, to the Mediterranean, and into western Europe to its more familiar niches of Italy, France, and Germany by the 2nd century AD. Unfortunately for the Jamestown colonists, *vinifera* was unknown to the western hemisphere; the wine they produced was from native North American species *V. labrusca* and others--species which generally produce unpalatable wine, but occur in great proliferation across the eastern United States (Figure 1.2).

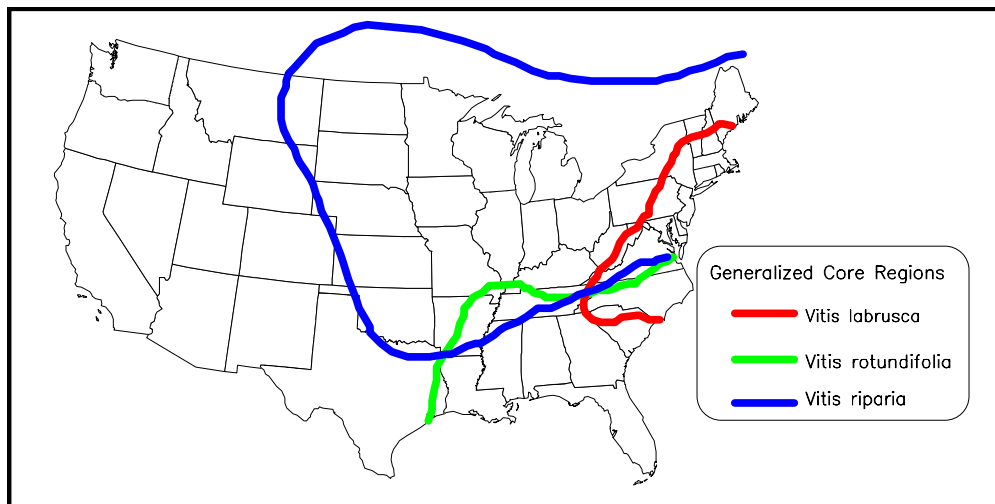


FIGURE 1.2
Core regions of common, native grape species

Numerous attempts were made to establish *vinifera* in Virginia from colonial times to the present, most of which were in vain. *Vinifera* vines were simply not climatically adapted to the humid summers and harsh winters of the eastern US, a situation compounded by a host of fungi and pests to which it had no tolerance. Advances in grafting technologies, pesticide development, and trait selection at the genetic level, however, have made *vinifera* growing in the east a reality. Virginia has come to realize this potential just in the last twenty-five years, which is the approximate age of its wine grape industry.

To date, approximately 1600 acres of grapes are grown in Virginia, of which 95% are used for wine production. (Figure 1.3) This makes grape production the sixteenth largest agricultural commodity in the state (Johnson & Wade, 1993). The passage of the Virginia Farm Wineries Act in 1980 stimulated industry growth by providing financial incentives to growers and by establishing a monetary fund from an alcohol sales tax. The fund is used to finance research, promotion, and information networks of the grape and wine industries. Subsequently, farm wineries have increased from six in 1979 to over fifty today, making the state 7th in the nation for wine production (Zoecklein, 1998).

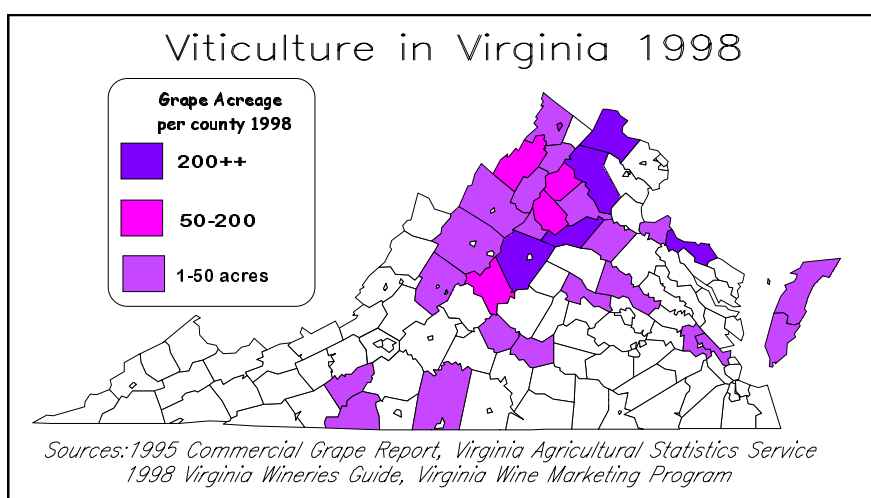


Figure 1.3
Grape acreage in the Commonwealth

Virginia's annual raw grape product value exceeds \$3.5 million, with a wine value in excess of \$12 million. Overall, "...in 1992, the sector[Virginia wine] accounted for almost \$65.4 million in economy wide activity, contributed over \$36.35 million to the gross state product and accounted for about 1,433 full time job equivalents" (Johnson and Wade, 1993). In addition, studies undertaken by the Division of Tourism indicate 3% of visitation to the state is winery oriented, and 5% of total visitors include wineries in their agenda. These are important statistics considering the total tourist trade in the state was estimated at \$8.5 billion in 1992 (Johnson and Wade, 1993).

Wine grapes are a high valued commodity, as indicated by gross receipts per acre currently averaging between \$3000 to \$6000 (Wolf, 1998)--much higher than most other

agricultural products, tobacco being a prominent exception. Investment in viticulture is made even more alluring given that the average productive life of a vineyard, and subsequently the returns, last minimally between 20 to 30 years with routine maintenance. With these extended levels of return and high value per acre, grape production is more competitive with non-agricultural land uses such as residential and commercial activity. The grape and wine sectors are also an asset to the state economy in that they effectively generate employment and income in rural areas due to their high intensity requirements of labor per acre. (Johnson & Wade, 1993)

The future of the grape and wine industries appears promising as well. The Impact of Farm Wineries on Virginia's Economy states it in rather explicit terms:

“Based on the experience of Oregon and Washington, it is not unrealistic to expect Virginia wines to achieve a 20% share of the state's growing premium wine segment, plus a share of the market in Maryland, North Carolina, South Carolina, and other East coast states which make up the state's tourism base. In order to achieve this level of market penetration, the industry would need to produce sufficient quantities to support annual sales of 500,000 to 600,000 cases, a quadrupling of the current production levels...” (Johnson & Wade, 1993)

To be labeled a Virginia wine requires a minimum input of 75% of Virginia grown grapes, 50% of which are from lands owned or leased by the winery (Zoecklein, 1998). To achieve the predicted growth of wine sales, the acreage of grapes will need to increase by roughly 2500 acres--almost double the existing acreage.

With the current and predicted future demand for Virginia wines, future expansion of viticulture in the state is greatly needed. However, three major obstacles impede this growth: 1) the high cost of vineyard establishment, 2) the high cost or lack of skilled vineyard labor, and 3) climatic constraints of the vine (Wolf 1997). While the first two obstacles are well defined and succinct, climatic constraints of viticulture are more indistinct. And, while costs associated with viticulture may be prohibitive to expansion, climatic factors will ultimately determine success of that expansion and quality of the fruit produced, even when costs are overcome.

In Europe, centuries of experience have identified the best locations for growing wine grapes and well known, distinctive wine regions have evolved. Even California has had a couple hundred years of continuous production and experimentation to determine the best locations for vinifera. Virginians, however, do not have a long history of such trial and error to reference when selecting sites for vinifera planting. However, a geographic analysis of the state in terms of its viticulture potential, combined with an assessment of other, more established fruit crops--namely apple--will help us better predict sites for viticulture.

1.2 Literature Review

This research emphasizes the relationship between the location of an agricultural activity and certain aspects of the physical environment, a major theme in agricultural geography. This field is mainly concerned with description and explanation of spatial patterns of an agriculture activity. In the last several decades, the geography of viticulture and wine has emerged, creating its own niche as a sub-discipline within agricultural geography (de Blij, 1981; Dahlberg, 1961; Fisher, 1978; Gruber, 1981; Salt, 1985). Many works within both fields interpret agricultural landscapes in terms of the physical, cultural, economic or political influences which shape them, or combinations of these factors.

My major focus centers on the physical-environmental forces that have contributed to the landscape of viticulture in Virginia. However, my research will go one step further: specifically, it will focus on characteristics of the existing agricultural landscape that can be used to predict future sites of agricultural expansion. In short, I will build a model for identifying viticulture potential based upon desirable physical attributes that have been defined by a combination of literary sources and analysis of the current fruit landscape in Virginia.

1.2.1 Agricultural Geography

The field of agricultural geography began emerging as a separate discipline with the publication of J. Heinrich Von Thunen's The Isolated State in 1826 (Von Thunen,

1826). Von Thunen's urban-rural land use theory identified concentric circle zones of agriculture around an urban area or market. His belief was that the land use which provided the highest economic rent--the return for investment in the land-- would displace all other land uses and be closest to the urban center. Transportation, product perishability and bulk were emphasized as important determinants in the system. Environmental influences were, on the whole, ignored.

Von Thunen's work utilized the market principle to predict land use patterns of agriculture around markets. However, this is not the only approach used to describe and explain the distribution of agriculture activities across the surface of the earth--the essence of agricultural geography. J. R. Tarrant (Tarrant, 1974) outlined three main theoretical approaches in agricultural geography which have shifted from first to last in the post-war period:

1. Environmental, which assumes that the physical environment acts in a deterministic manner and controls agricultural decision-making.
2. Economic, [as exemplified by Von Thunen] assumes that economic factors of market, production, and transportation costs operate on a group of homogeneous producers, who in turn react to them in a rational manner.
3. Social-personal, which assumes that there are further sets of influences which affect agricultural decision-making, such as farmers' values, beliefs and attitudes.

(Tarrant, 1974)

I do not agree that the environmental approach has to possess the degree of determinism suggested by Tarrant, nor that major focus has shifted from it; I am more inclined to view the environmental approach as a study of the *influence* of physical factors on agricultural patterns, and that this influence has become more intensive in the sub-fields of interest (i.e. viticulture). It is this environmental approach that has a long-standing tradition in agricultural geography, and is the theoretical perspective of my work.

This debate between determinism versus possibilism, or man versus nature, has been problematic among geographers since the late nineteenth century. Determinists argue that the environment controls the course of human action--in this case what is

grown where--while possibilism holds that the environment only serves as a provider of multiple possibilities, with humans having the opportunity to choose among them. This heated debate has even found its way into the realm of wine geography: in the 'Jekel-Prats' discussion of the role of *terroir* on wine quality (Jekel, 1982; Prats,1983).

In its most widely accepted sense, *terroir* refers to the coming together of climate, soil, and landscape, including all site aspects such as soil depth, hours of sunshine, slope, etc.--in other words, every single characteristic of a site, making every site on earth unique. To the French, and others, this is the determinant of wine quality, the input of man is secondary or excluded altogether. The idea that limited, uniquely superior sites exist that predetermine a wine's quality is the basis for the intensive *Appellations d'Origine Controlees* system in France and other European countries. By law, these systems preordain the 'best sites' which can produce the 'best wines'(Unwin, 1996).

The 'Jekel-Prats' discussion was based on an article written by a California winemaker, Bill Jekel, who downplayed the role of nutrients in the soil, as compared to other factors like temperature and soil depth. His article was to spark widespread debate about the deterministic beliefs of *terroir* versus the abilities of man to influence grape and wine quality. This debate has often been caricatured as New World versus Old World, or even United States versus France (Dickenson, 1991). To many researchers, especially from America, influences of the environment are paramount--Rankine (Rankine, 1971), Fisher (Fisher,1978), Sichel (Sichel,1971), *et al.*--while other geographers, such as Raymond Christ (Christ, 1960), believe that the positive work of man over time, not the environment, is responsible for even the greatest vineyards of France.

My interpretation of the *terroir* debate is summarized by the work of J. Salt (Salt, 1985) who, in his *Determinism versus possibilism: the case of wine (1985)*, suggests that even though soil and climatic factors influence the production of good grapes, grapes are only the raw material on which the winemaker applies his skills. Whichever side of the debate one is on, most would agree that, "Climate, soil, and slope are the key physiographic factors in viticulture," (de Blij,1983). While not solely responsible for grape success, the environment does contribute significantly to the quality, consistency, and operating cost of a vineyard.

1.2.2 The role of the environment

The role of the environment in agricultural activity has been studied in an array of methodologies, at a variety of scales. Some have concentrated on identifying and delimiting agriculture regions from the global to the local scales, such as D. Whittelsey's Major Agricultural Regions of the Earth (1936), or G. T. Trewartha's The Iwaki Basin: Reconnaissance Field Study of a Specialized Apple District in Northern Honshu (1930). Physical criteria--such as climate, soils, topography-- formed the basis for the resultant regions, in studies at any scale.

Others have worked in different directions, delimiting climates suitable for crops, such as C. W. Thornthwaite's An Approach Toward a Rational Classification of Climate, based on the regional variation of "potential evapotranspiration". Thornthwaite and colleagues developed an index to predict crop suitability based on temperature and precipitation of an area, combined with water requirements of the plants (Thornthwaite, 1948). Still others have specialized in defining the ecological optimum of crops, based on physical crop requirements. The ecological optimum maintains that each crop has minimum moisture and temperature requirements which must be met for growth to occur, and also has maximums above which growth will cease (Grigg, 1982). These optimums have been areally differentiated by numerous authors for numerous crops, including volumes of phenological maps produced by the United States Department of Agriculture (USDA).

Within viticultural geography, Clarence Olmstead's work American Orchard and Vineyard Regions (1956) concentrated on explaining the distributions of vineyards based on various environmental factors, along with the cultural and economic situations of the surrounding areas. The Concord grape industry of the Chautauqua-Erie area is a typical survey-style work which models many environmental themes--terrain, soil--along with grape type, vine training style, and other human controlled factors (Dahlberg, 1961). This type of environmental appraisal more closely resembles the format I am following.

1.2.3 Agriculture adjusting to 'best' physical environment

The framework for my particular research is grounded in "...the increasingly closer adjustment of agriculture to areas with the best physical environment," (Gregor, 1970).

This subject has been thoroughly covered from as early as the 1920's, when O.E. Baker published The Increasing Importance of the Physical Conditions in Determining the Utilization of Land for Agricultural and Forest Production in the United States (1921). In the article, Baker elaborated in great detail on how the agricultural land use patterns could increasingly be linked to variations in terrain, soils, temperature and moisture. Baker's main theme is outlined succinctly in the opening paragraph of the article:

“The physical factors or conditions determine in large degree the utilization of the land in a region; and these physical factors become more important as the population increases, the knowledge and practice of agriculture advances, transportation facilities are improved, and the supply of capital and labor is increased and better distributed,—in brief, as agriculture and forestry become more highly organized and commercialized,”

(Baker, 1929).

In essence, as societies and agricultural activities become more organized and advanced, economic/transportation factors cease to be the *dominant* shapers of the agriculture landscape. For example, the advent of refrigeration eliminated the requirement to have perishable items--i.e. milk--located juxtapose the market. As conditions favoring closer adjustment to physical differences reach an optimum, greater selectivity will occur to match each type of agricultural land use to the area containing the most favored environmental conditions. Eventually, crops will be located in areas most environmentally suited to them--'unburdened' by the demands of proximity to economic centers.

This line of thought can almost be considered the antithesis of Von Thunen's work, as it completely disposes of the idea of market proximity as the decisive link in agricultural patterning. Of course, competing land uses can potentially displace agriculture from a higher to a lower physically suited area, or displace it altogether; such as expanding suburbs pushing cropland to less fertile mountains. Usually, whatever economic activity pays the highest rent will ultimately prevail--but not always (e.g. horse pastures). Baker was not averse to the possibility that the reversal of any of his outlined conditions--particularly rise in transportation costs--could result in a return to Von Thunen prescribed patterns. For example, a drastic rise in fuel prices might force

agriculture activity back to market proximity; the economic forces of the agriculture activity would overpower the benefits of locating in an environment more suited to the crop.

Baker's thesis has been strengthened and built upon in many ways since its initial publication. One of the more prominent works has been M. Prunty Jr.'s Recent Quantitative Changes in the Cotton Regions of the Southeastern States (1951). Prunty outlined the retreat of cotton to the 'best' lands and how this retreat has redefined the boundaries of the Cotton Belt into a series of small cotton regions. "At the same time, intensification of production on better soils has not only increased total American cotton production, but has also fostered a shift in the median center of production precisely opposite the historic westward movement..." (Prunty, 1951).

Delimiting the optimum areas for valuable crops is a theme in agricultural geography which is receiving increasing attention in the modern era as well. The spatial structure of agriculture is being influenced more and more by environmental factors, due in part to, "...a reflection of economic recession and price-cost squeeze in agriculture. As a consequence, yields and intensity of production have become very important, encouraging farmers to seek the 'best' physically endowed area for their enterprises..." (Pacione, 1986). In a study of forty years of census data, M. Winsberg concluded that reduced transportation costs had induced agricultural commodities to become more concentrated and regionally specialized, regardless of reduced comparative advantage or population distribution (Winsberg, 1980). Some examples of this phenomenon are the concentration of dairy products in Wisconsin, massive concentration of the apple industry in Washington, and the large American market share of table grapes from Chile.

Perhaps the most pertinent methodology which my research is modeled after comes from a line of very crop specific studies comparing physical factors influence on crop yields. A perfect example of this type study is D.J. Briggs' Environmental Influences on the Yield of Spring Barley in England and Wales (1981). Incorporating multiple regression analysis, Briggs established correlations between barley yield and four climatic/soil factors. Once the correlation was identified, Briggs asserted that the findings should be incorporated into soil surveys and land use classifications to help close the

discontinuity between *actual* yields and *potential* yields. It is exactly this type of discrepancy between actual and potential viticulture suitability in Virginia that my research will address.

1.2.4 Focusing on the physical

As B. W. Ilbery so aptly points out, "...it is the interaction of physical and human factors that determines patterns of agricultural land-use," (Ilbery, 1985). By concentrating on the physical aspects of the environment as influencers of the agricultural landscape, I am not suggesting that there are no human or economic inputs present. On the contrary, I realize that agricultural decisions depend highly on the individual and on the economics of the area. This research is being conducted to facilitate agricultural decision-making by increasing the physical knowledge base. Thus, when other economic and human factors favor agricultural growth, this work will be in place to provide data on the physical-environmental aspects of that growth.

Physical constraints or hindrances to agriculture have a long history of being dispelled by modern technology and innovations of man. For example, viticulture is now possible in the East due to innovations such as resistant rootstock breeding and pesticide developments and in many California locales due mostly to innovations of irrigation.

However, there are currently several factors which create a situation that emphasizes the importance of focusing on the physical environment for viticulture:

1. The Virginia wine industry needs grapes from inside the state. To be labeled as a Virginia wine, composition of wine requires a minimum of 75% Virginia grown grapes. Thus, we are looking for the best sites *within a finite area*.
2. Supply is low, demand is high. Economic limitations are at a minimum, except the high cost of capitalization.
3. Eighty-five percent of wineries own or rent acreage not attached to the winery facility. Transportation of grapes to winery is not a significant factor, since it is already common practice and transportation costs are low.
4. Vineyards are a long term investment. Site selection is critical to quality and longevity of vineyard life (and therefore length of profit return). The best physical

sites bring about short-term profit due to higher quality fruit, and long-term profits in extended vineyard life.

Thus, currently, the physical attributes of the landscape are of prime importance to the expansion of this agricultural activity. Identifying the optimum areas of the landscape in terms of their physical attributes is the priority of the industry at this time.

Dr. John Dickenson, University of Liverpool wine geographer, summarizes this framework:

“Identification of ideal sites for wine growing are matters of active research for the industry, ...there are geographical contributions to be made in the field, both in seeking correlation between the various environmental factors and wine production ...and between the physical properties of site and wine quality,” (Dickenson, 1991).

The linkage of physical properties of site to wine quality is the basis for this thesis. However, my work focuses more on site factors and their role on quality of grapes, rather than wine. Specifically, identifying regions and sites in terms of viticulture potential is the format for integrating this theme, since the identification is based on factors from the physical environment.

1.3 Methodology

Most studies in the agricultural geography field can be classed into one of two major approaches, either empirical (inductive) or normative (deductive) (Ilbery, 1985). Empirical approaches describe what actually exists in the agricultural landscape, while normative approaches are more concerned with describing or identifying what the agricultural landscape *should* look like. Although Ilbery insists that, “These two approaches have never really merged,” my research intends to do just that: integrating the existing agricultural landscape attributes [empirical] to aid in establishing a model to predict other suitable agricultural sites [normative].

The central theme of this thesis advocates the significance of the environment in influencing spatial patterns of agriculture. Modeling viticulture potential based upon physical factors in the environment is a purely environmental approach which adheres to

the theory that agricultural activities are ‘adjusting’ to areas that contain the optimum physical characteristics for that crop (Baker, 1929). Variations in the physical environment--namely topography, climate, and soils-- not only define the current fruit landscape but will be used to identify areas of future suitability for viticulture (as well as other fruit crops). Through analysis of the physical characteristics of an agricultural pattern, this research will contribute to a more complete understanding and future development of the Virginia fruit industry as a whole.

I will begin at the **state scale**. The first step of this study is to analyze the climatic and topographic features of Virginia in terms of their regional potential for viticulture. From this analysis, I will then qualitatively identify and rank regions of this homogeneous viticulture potential. In order to more thoroughly understand these climatic and topographic requirements, the research also includes a historic assessment of the apple industry. The historic evolution of these more established fruit crops in the state, crops which nearly parallel grapes in their physiographic and climatic requirements, will be compared in order to support or correct the regional ranking. Disparities and similarities between the landscapes of the grape and apple will complete the state overview.

Next comes site analysis at the **local level**. After selecting a study area for focus, I will build a Geographic Information Systems (GIS) model which will delineate sites within the study area as having greater or lesser viticulture potential from a physical and climatological basis. Factor layers, constructed at the county scale, will be produced from a series of physical databases, representing viticulturally desirable features of the landscape. A ranking system will be developed for each layer and, in turn, all layers will be combined to create a single image displaying suitability score (0 to 100, 100 as perfect score) for every 90 ft² cell in the study area.

The final step in the thesis entails validation of this model. All existing fruit operations in the study area were geo-located on each feature layer using a Global Positioning System (GPS: 1-2meter accuracy). Scores from the model were evaluated within the actual fruit acreages, and compared to data from the sites. Actual data on occurrences of frosts, minimum winter temperatures, and other site variables have been collected from fruit operators and surrounding weather stations by questionnaire, personal

interview, and historical records analysis. These data reinforce continuity or explain disparity between the model and reality. Concluding remarks on the utility and effectiveness of this approach will complete the thesis.

Specific objectives were developed in order to outline and focus the research procedure:

1. Identify viticulture potential at the state scale using climatologic and topographic data associated with quality fruit growth, minimized risks, and low maintenance costs. Delineate and describe regions based upon their viticulture potential.
2. Trace the evolution of the apple and grape histories within the state to support or dispute the regional assessment of viticulture potential as outlined in Objective #1. Assess similarities and disparities of apple landscape versus the grape.
3. Build a viticulture suitability ranking system that evaluates each factor (or layer) in a selected study area, combining viticulture requirements of topography and soils into a single point system (i.e. 4 factors, each factor worth a possible 25 points, for a best possible aggregate score of 100).
4. Validate the model by collection of field data. 1) Locate all existing acreage of fruit crops in the study area using a Global Positioning System (GPS). 2) Conduct on-site evaluation of vineyards and/or orchards, personal interviews with growers to determine history and potential of site, and questionnaire mailing.
5. Draw conclusions on viticulture potential in Virginia and on the utility of this methodology for determining site selection.

Figure 1.4 is offered as a graphic representation of the methodology.

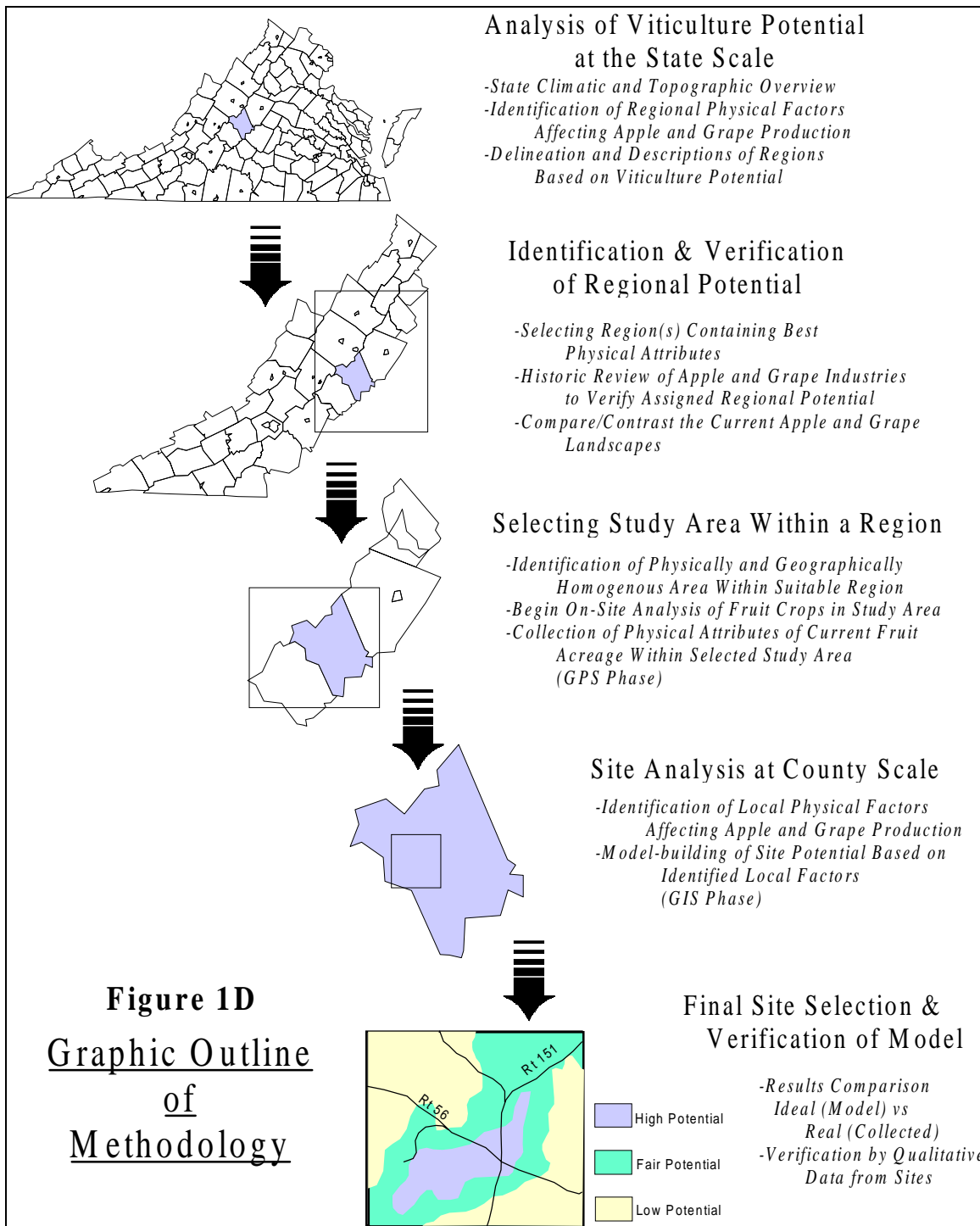


FIGURE 1.4
Methodology

1.4 Practical Implications of Viticulture Site Suitability Study

The major task of this study will be to compare the actual viticulture areas against the best potential viticulture areas, as identified by my model. If the model is valid and successful, discrepancies between the actual and the potential would need to be addressed by the grape industry. When such information is made available to farmers, agriculture extension agents, real estate agents, and others, the spatial pattern of viticulture acreage in the state could in time be fundamentally changed. Also, successful validation of the model with current fruit acreage will serve to support Baker's approach to utilization of land for agriculture.

This initial implication to the industry will be supplemented by increased awareness and interest in viticulture. Identification of promising viticulture areas could stimulate interest in local economic growth, both from internal and external potential investors. "Expansion of the wine industry is a viable, and sustainable economic development strategy for rural areas, since total income and employment opportunities may be increased without damaging the rural character and environmental quality of the region," (Johnson & Wade, 1993). Investment and expansion of viticulture equates to more jobs, more money invested in local economies, and presents a viable supplementary income to rural landowners.

The study also will present a possible diversification alternative to current fruit orchardists or other agriculturists. This in turn may increase value of these rural lands which will more effectively compete with non-agricultural uses like industrial and residential development. As diversification occurs at the local level, it is simultaneously occurring at the state level, thus strengthening the state economy as well.

In addition, another positive implication of this work will be to help minimize unnecessary and unexpected expenses associated with high maintenance costs of poorly located vineyards. The study will be a valuable tool for risk assessment in general, and will expedite the federal crop insurance programs to enlist grape production as an insurable commodity--an important step that the industry has been awaiting.

Classification into an insurable crop category would mean that growers, and future

potential growers, could protect their investment against damaging climatic events--drought or hail, for example. Currently, because of the industry's youth, this type of insurance, accessible to most other agricultural commodities, is unavailable to grape growers. This situation is largely the result of the inexperience of the insurers--they [the USDA] simply do not have a reference base to refer to when assessing vineyards in Virginia. A 'sound' site has not sufficiently been distinguished from a poor one, from an insurance point of view. This study could provide just such a base.

Analysis of the spatial patterns of fruit industries will, for the first time, give a systematic inventory of site characteristics of the state's fruit acreage, and graphically outline areas of future expansion based on desirable site features. This database will become a reference for future research of the Virginia fruit industries. Some level of quality control may be established by ascertaining the characteristics of particular high production/high quality sites. Homogeneous regions of fruit quality or distinctive traits in fruit may be established as well. This is an important factor in establishing a 'nationally recognized viticulture area': a title granted by the Bureau of Alcohol, Tobacco, And Firearms (USBATF) to designate an area of unique wine growing conditions.

Theoretically, the analysis of the current fruit industries, particularly apple, will support the theoretical work of O.E. Baker, *et al*, concerning the increasing importance of physical factors influencing the spatial distribution of agricultural activities. The work will join the ever increasing literature base that specializes in analysis of a particular agricultural activity--in this case grapes and apples--in regard to how they are influenced by the environment, and therefore where they should be located within it. In addition, my work will stand as an example of a successful integration of inductive and deductive approaches to achieve a common goal. It will add to the growing literature on the importance of detailed examination of the physical environment as agricultural landscapes adjust to their optimal locations. This thesis represents an integration of high resolution digital data, field collected location data, and qualitative grower data into one database. An unique attribute of this database will be the ability to identify viticulture potential not just at a regional scale as most studies, but also at the local 'site' level. The multiple scale

approach may serve as a valuable tool to the grape industry here in Virginia, and also to future studies of this kind in and across the field of agricultural geography.

1.5 Summary

The models of Baker and many others--Thornthwaite, Whittelsey, Prunty--are the frameworks for studies of agricultural spatial patterns as explained by influences of the physical environment. This type of methodology within the environmental approach to agricultural geography has been prevalent since Baker's initial publication of The Increasing Importance of the Physical Conditions in Determining the Utilization of Land for Agricultural and Forest Production in the United States in 1929. Since then, studies have increasingly focused on individual crops in local environments in supporting the methodology.

As Baker outlined, the advancement of technology, decrease in transportation costs, and dominance of commercial economies have combined to push agricultural activity to the *physical* areas most conducive for their success. Identification of these physically 'best' areas for individual crops are increasingly important in an age where intensive agriculture and high yield per acre are a predominant theme for agriculturists to maximize profit margins.

Using Baker's methodology and concentrating on physical factors of the environment is particularly relevant to the tree fruit and wine grape industries. This is due to the 'permanence' of the agricultural activity: once a site is planted to trees or vines, an agriculturist is locked into his/her initial decision for thirty to sixty years--the average longevity of these fruit crops. Economic and human factors in decision-making can fluctuate widely in this time frame, but the physical factors affecting the activity generally do not. Therefore, it seems that more importance would be attributed to the proper physical placement of this type of agricultural activity, with much less emphasis on the other factors.

Using the methods of Baker, and more closely the structure of Briggs and others, I will examine the wine grape industry in the state of Virginia. My objective is to build a model to identify physical areas of highest potential for viticulture, based upon a variety of

physical factors--namely topography, climate, and soil. Since the industry is itself in what can still be considered an experimental phase, I will incorporate other fruit crops into my analysis. The apple is a commodity with physiographic requirements similar to the grape, but it possesses a better established core growth area.

As the wine grape industry is posed for rapid growth, this work is in the unique position of having great potential to be verified with actual field testing of the results. The validity of Baker's work, as well as the viticulture potential model I will construct, will be manifested on the future landscape of Virginia viticulture. Close observance of these future trends in Virginia wine should authenticate this type of environment-based approach and my methodology for its engagement. In one of his nine canons of viticultural geography, de Blij asserts that "...the diffusion of the species *Vitis* has produced ampelographic questions which require geographic answers," (de Blij, 1987). This thesis attempts to answer some of these questions for Virginia.

Chapter 2 Analysis of Grape Potential at the State Scale

The objective of this chapter is to identify broad regions of the state most suited for grape and apple production. This identification will produce by examining individual facets of the climate and topography. To understand the mechanics of successful site selection at the local scale, it is important to first understand the nature of the climate and topography at the state scale so one can then better interpret and predict the role of climate at a potential vineyard site.

Climate refers to the long-term weather conditions of a region: “..a synthesis of the succession of weather events we have learned to expect at any given location,”(de Blij & Muller, 1993). Region, and therefore climate, is a very scale dependent term. There exists a region and climate of a single vineyard; regions and climates of the state; and regions and climates of the world. This chapter divides the state into homogenous regions based upon climate features desirable to the grape.

Section 2.1 offers a concise overview of the Virginia climate--its major descriptors and influences. This provides a prelude to the climate and topographic variables analyzed independently in 2.2. Finally, in 2.3, viticulture potential for the state will be identified on a regional basis, formed from the factor analysis of the previous sections.

2.1 Virginia Climatic and Topographic Overview

In the modified Koppen world climate classification system (de Blij & Muller, 1993), Virginia is categorized as humid subtropical, a mesothermal climate with no dry season and hot summers. Humid is defined as having enough precipitation to support forest growth; subtropical denotes both the latitudinal position poleward of the Tropics and temperature regimes with hot summers and relatively mild winters (Woodward and Hoffman, 1991). Average summer temperatures range from 70° to 80°; winter temperatures from 32° to 42°. Precipitation across the Commonwealth is between 35 to 45 inches on average. On the whole, Virginia maintains a mild, moderate climate.

However these statewide averages do not accurately reflect the true nature of the diverse climate regimes across the state. This diversity is the product of two distinguishable forces: continental versus maritime influences, and the relationship between elevation and temperature. These forces work together to affect temperatures and

precipitation patterns which can be linked to the relief features of the terrain. Thus, the final focus will concentrate on identifying desirable climate regions physically defined by physiographic areas.

Continentality refers to climatic factors (temperature and precipitation) which are modified by large land masses, while maritime climates are influenced by their proximity to large bodies of water. In Virginia, most high-pressure frontal systems which affect climate--especially in winter--come from northwestern Canada, sweeping across the US midwest before arriving in the East. Since land heats and cools rapidly, it tends to take on the characteristics of the surrounding air mass. The land does not measurably affect air temperatures, and air masses that come from across the continent maintain their characteristics through the entire frontal movement. Thus, in winter, very cold temperatures are 'brought' to Virginia from the Canadian high pressure cells.

Inversely, maritime effect influences temperatures in the opposite direction. Water, in contrast to land, heats and cools slowly. Large bodies of water, particularly the oceans, retain and disseminate heat even in the winter months. Air masses moving over the water toward land are affected positively by this heat exchange, as is the land that the air mass then passes over. The reverse happens in summer, as the water bodies are cooler due to their slow warm up time; air passing over them now will be cooled as the water absorbs heat. Some examples of this effect: large regions of fruit plantings on the leeward sides of the Great Lakes, narrow bands of vineyards along the Finger Lakes, and vineyards of Germany which are modified by the North Sea--all areas much further north than would be possible in the absence of large bodies of water.

Together the influences of continentality and maritime effect divide the state into two regimes: the maritime areas of Tidewater and Eastern Shore, and lands west of them which are best described as more continentally influenced, with a small transition strip between the two (Gottman, 1969). (Figure 2.1)

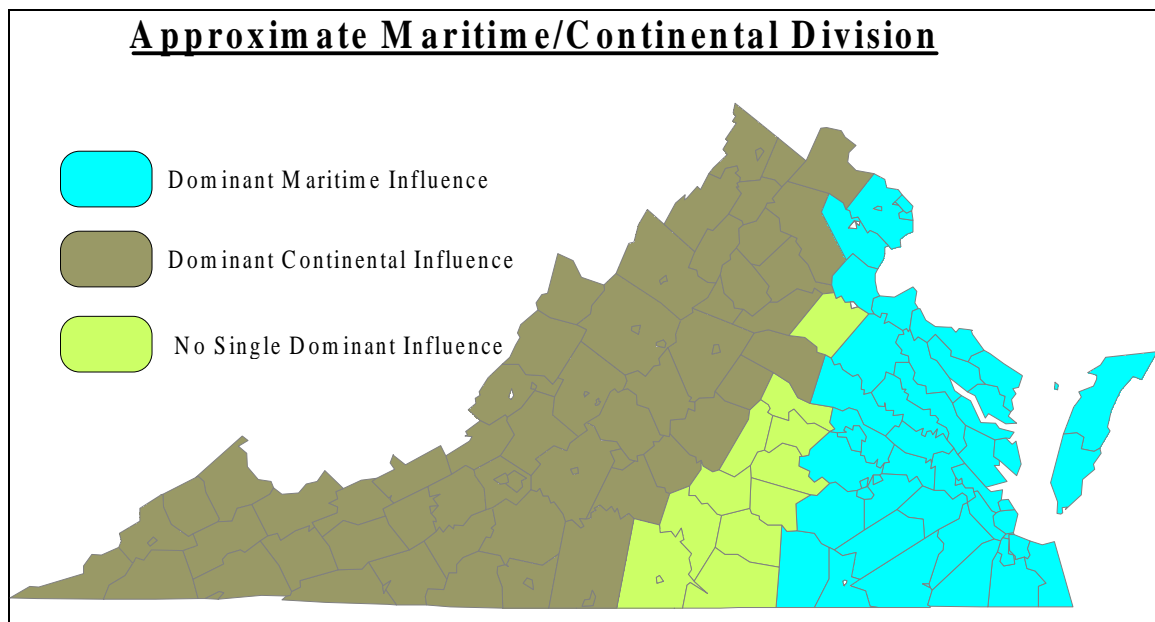


FIGURE 2.1
Maritime versus continental influences
(from Gottman, 1969)

Most significant, according to Jean Gottman (Gottman, 1969) is that: “..such continental influences make for greater ranges in the variation of temperature *both within the year and within the day.* (my italics) Maritime influences, predominating in the east owing to both the Chesapeake Bay and the proximity of the ocean, have on the contrary a moderating effect on the ranges of temperature,” (Gottman, 1969). Rapid temperature fluctuation is a characteristic of continental climates which can serve as a detriment or asset to fruit growing, as will be addressed later.

The important roles continentality and maritime forces play are not solitary ones in this production. The topography of Virginia also contributes greatly to the temperature and precipitation patterns observed in her climate. Increasing elevation equates to decreasing temperature, on the order of 3.5°F per every 1000 feet (5.5°C/km), otherwise known as the troposphere lapse rate (de Blij & Muller, 1993). Elevation in Virginia ranges from zero at sea level to almost 5730 feet asl (above sea level) at Mount Rogers, the highest point in the state. Discounting all other climate factors, this equates to a possible 20° difference between the highest and lowest parts of the state in any given hour, on any given day.

This diversification of topography creates a variety of sub-climates within the continental/maritime division. Traveling east to west (and maritime to continental), the lowland elevations combine with the maritime influences to give the Tidewater area consistently warmer temperatures during all seasons (Woodward & Hoffman, 1991); the upper Piedmont slightly cooler with the increased elevations of the rolling hills; and the mountainous areas of the state reaching much cooler temperatures on average, especially when reaching altitudes above 3000 feet asl.

Topography also significantly affects precipitation. “The general north-south orientation of the mountains interrupts the westerly flow of air and forces it to rise over the ridges. On the windward side of the mountains, orographic precipitation is a significant component of annual rainfall totals,” (Woodward & Hoffman, 1991). Orographic precipitation refers to rainfall produced by moist air parcels that are forced to rise over a mountain range; such air parcels move in this way being forced by steering winds and the push of other air parcels behind them (de Blij & Muller, 1993).

Many leeward flanks of the Allegheny Mountains are located in the shadow of this effect, and can be exceptionally dry, resulting in a wide range of precipitation variability (Hayden, 1979). While typical flow of air is west to east across Virginia, many storm systems track up the coast from the south and, “..are responsible for the heaviest storms and over half the total annual precipitation,” (Woodward & Hoffman, 1991). When these systems reach the Blue Ridge and are subsequently pushed upward, it creates another high precipitation orographic effect on the eastern mountain flank in the central part of the state.

“Continentality and altitude increase the amplitude of the range between recorded extremes for rainfall as well as temperature, stressing one more contrast between the Tidewater and the western mountainous section,” (Gottman, 1969).

Although pure geologic description of the landscape does not allude to climate, the divisions attributed by geologic formations are inherently tied to topography. It seems a natural extension to employ topographic divisions (outlined in Figure 2.2) as descriptors of homogeneous climate regions. For example, the Blue Ridge--by means of its

topographic difference-- has a homogeneous temperature and precipitation regime which is radically different than that of the Tidewater, another homogenous region.

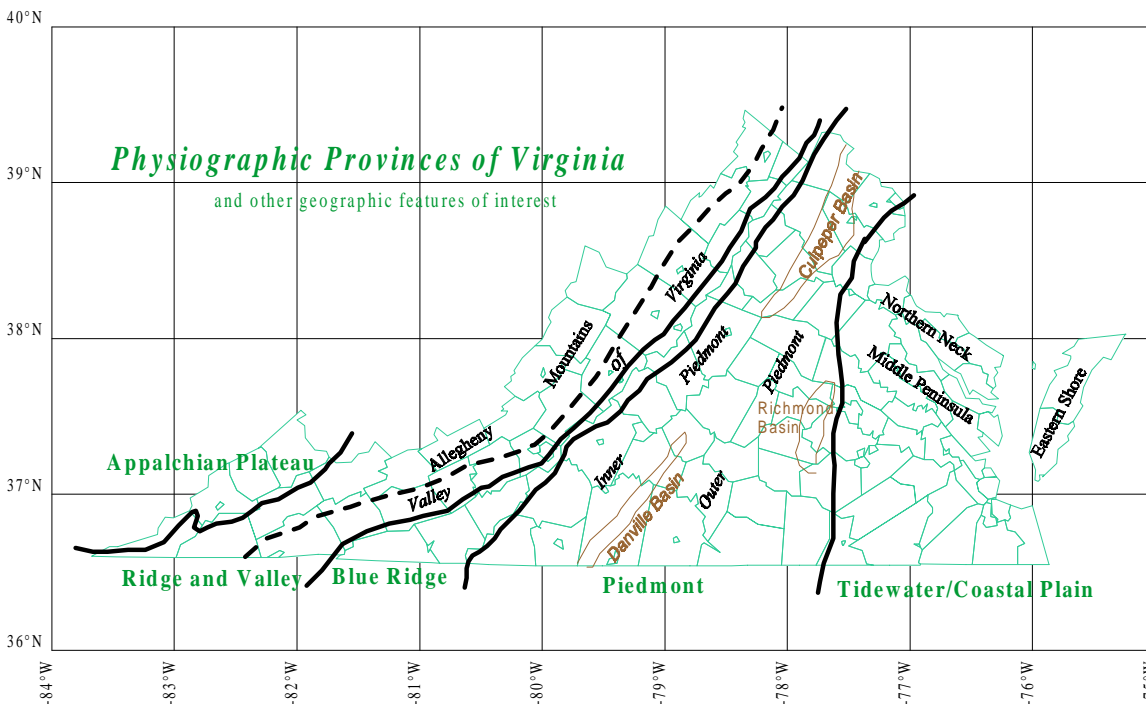


FIGURE 2.2
Physiographic Regions of Virginia
(adapted from Woodward & Hoffman, 1991)

For this reason, the five physiographic region classification system (in Figure 2.2) will be employed for the rest of this discussion. The Appalachian Plateau, the Ridge and Valley, the Blue Ridge, the Piedmont and the Tidewater or Coastal Plain will be the regions referred to as the climatic units for analysis. In reality, many sub-regions of precipitation and/or temperature occur within and among the generalizations presented here. Departures of particular interest will be addressed on an independent basis when appropriate.

2.2 Climatic and Topographic Variables Affecting Grape Production

The focus will now be on individual components which affect fruit production, highlighting the areas most desirable for minimizing risks and obtaining high fruit quality. The traits of the apple and grape will be explained on a factor to factor basis. As with all climate attributes, it is the combination of factors which produce each unique climate: in

reality all of these factors are intertwined and do not lend themselves to easy separation. The variables enlisted in this analysis include: minimum winter temperatures, maximum summer temperatures, precipitation, daytime versus night-time temperatures, length of growing season, and the topographic variables of slope and absolute elevation.

2.2.1 Minimum Winter Temperatures

“Probably the most important factor influencing the distribution of the fruit industry is minimum winter temperatures,” (Childers, 1976). This is a sentiment echoed throughout all temperate zone fruit literature, whether it be apple, grape, peach or cherry. Occurrences of certain minimum temperatures actually define where certain fruits--or any plant for that matter--can be grown. However, even within established fruit areas, temperatures can sometimes get low enough to cause significant damage. Because *vinifera* is not the hardiest of fruits, or even of grapes, this is of increased importance.

Freezing injury, or winterkill, occurs as a result of permanent parts of the vine or tree being damaged by low temperatures. This is distinct from frost damage which usually results in bud loss, and therefore the season’s fruit. Thus, winterkill can be much more costly, as entire plants can be destroyed, not just the crop. Common injuries include winter sunscald, frost-splitting of trunks, death of dormant buds, stem blackening, and death of tissue in twigs, branches and trunks, (Westwood, 1993).

However, the injuries listed do not occur indiscriminately; many factors of plant hardiness and health determine the probability and extent of such injuries. Levels of damage from minimum temperature exposure have been linked to tissue type (Stergios and Howell, 1977); level of plant dormancy and season (Fuchigami, 1971); fluctuating mid-winter temperatures (Proebsting, 1970); and plant size, wood maturity, and variety hardiness (Amberg, 1985; Howell and Shaulis, 1980; Wolpert and Howell, 1985). This analysis assumes that vines are of suitable hardiness, possess good wood maturity and health, and are in full dormancy during the winter period.

Hardiness is a product of not only the lowest temperatures that a plant can withstand, but also how well the plant acclimatizes to the winter conditions of an area (Burke *et al.*, 1979). This can become problematic:

The protection of cultivated plants against winter injury may present problems not found in natural environments. Many of these species were either bred for specific fruit quality factors or have been moved from the climate in which they evolved. Thus, many domestic forms are not completely adapted to the environment in which they are cultivated. (Westwood, 1993)

Vinifera have been subjected to this exact circumstance for hundreds of years, but there exist many cultural practices which have augmented the ability of fruit species to survive outside of their indigenous range.

In general, the hardiness of the major temperate fruits, from strongest to weakest is best summarized by: apple>pear>plum>cherry>peach/grape (Barden, 1998). This means that most apple and pear species can withstand lower temperatures than can the peach or grape, and possess superior acclimation processes. However, great variation occurs within and among each fruit type, with native varieties and hybrids being naturally more hardy than introduced ones.

As an example, consider the hardiness within the subset of grape:

V. riparia>V. labrusca>'hybrids'>V. vinifera>V. rotundifolia

(Mullins, Bouquet and Williams, 1992).

Thus, we see that the native species are much hardier than the hybrids, which in turn are hardier than *vinifera*--one of the reasons hybrids became established in the East before *vinifera*. The object of this section is to identify areas within the state that are most conducive to minimizing the winter injury risk. Since *vinifera* are one of the most cold-tender fruits grown in Virginia, assignment of areas best suited to their hardiness, by default, identifies areas well suited to many other temperate fruits.

A prerequisite for understanding minimum temperature occurrence is an understanding of the two main types of freezes: advective versus radiational. Radiational freeze events usually occur during calm, clear weather as the ground naturally cools--or 'radiates' heat-- after sunset (Geiger, 1966). As the ground heat dissipates into the atmosphere, the ground becomes cooler, and begins to cool the air directly above it. Since the earth, and air, are naturally cooler at higher elevations--a product of the atmospheric

lapse rate--they become cooler faster. Cold air is much denser than warm air, and will actually begin to flow in a viscous manner, from high to low areas, when these radiational conditions prevail. The flowing cold air 'fills' lower lying areas, displacing warmer air upwards; thus creating a temperature inversion, as temperature increases with altitude--the inverse of normal air behavior (Geiger, 1966).

Advectional freezes are usually attributed to much grander atmospheric phenomenon, most likely the movement of an entire frontal system of cold air across the landscape (Geiger, 1966). These polar-derived cold air masses tend to be turbulent, and arrive rapidly, allowing little or no temperature stratification of the air. They are also termed 'top-down' freezes because the standard atmospheric lapse rate, or decreasing temperature with increasing altitude, usually holds true (Geiger, 1966). Both types of freezes can occur at any time; however, radiational freezes are mostly associated with spring and fall frosts, while advectional freezes are predominant in the winter season. Frost will be a topic of focus in the next chapter during site analysis. Advectional freezes, or more appropriately the avoidance of them, is the focus of identifying regions of minimum temperatures.

Topography is another player in the minimum temperatures equation. Given the loss of 3.5°F per 1000 feet described by the air lapse rate, absolute elevation, or height above sea level, becomes crucial when assessing cold potential; this becomes further complicated by the downhill flow of cold air described in radiational situations. Thus, the *absolute* highest surfaces possess more advectional freeze potential, but the *relative* lowest sites are most prone to radiational freezes. Landforms within the landscape also affect these freezes, influencing air direction, drainage, and permeability (Cox, 1923). As with all aspects of climate, the dependent variables are too numerous and inter-related to include, but will be alluded to when appropriate to complement my analysis.

So what temperature is the critical point below which damage or death is expected? Dependent on variety, apple hardiness may range to as low as -30° or -40°F while some peach and grape varieties will display trunk damage as the temperature dips just below zero; most temperate fruits and most varieties are somewhere between these extremes. All *Vitis vinifera* are cold hardy in the sense that they seasonally develop the

ability to withstand sub-freezing temperatures (Pool *et al.*, 1992) However, this cold hardiness varies greatly within the *Vitis* genus: *V. riparia* and *V. amurensis* can survive -40°F at full acclimation (Pierquet *et al.*, 1980), while some cultivars of *vinifera* may exhibit severe damage at only -4°F (Pool *et al.*, 1990).

Many studies have been conducted to determine hardiness of specific *vinifera* varieties. Particular to Virginia, Wolf and Cook (Wolf & Cook, 1991) demonstrated a one to two degree difference in hardiness between Cabernet Sauvignon and Cabernet franc--franc being the hardier of the two. In addition, Wolf and Cook (Wolf & Cook, 1994) demonstrated that thermal analysis accurately estimated dormant bud cold hardiness of many *Vitis* species. In doing so, they established a useful range of mean low-temperature exotherm temperatures for nine cultivars in Virginia; ranging from -8°F in Cabernet Sauvignon #6 to -14.6°F in Concord. Other important factors determining hardiness--in these studies and in the field--include day length during acclimation and growing season (Pool *et al.*, 1992); transitory cold or warm spells during acclimation (Pool *et al.*, 1992); and deacclimation during dormant season (Wolf & Cook, 1992).

Utilizing these studies and discussion with Dr. Tony Wolf, the state viticulturist--a very conservative -8°F was chosen as the threshold temperature below which extensive winter damage to *vinifera* can be expected. But this is not a static variable. Vineyards can be expected to withstand a low temperature event of that magnitude about once every ten years without causing irreparable damage. Two occurrences within a decade turns a site into a risky venture; three or more occurrences make it essentially unsuitable, as damaging temperatures will never allow the vineyard to become fully established. Therefore, the potential for viticulture suitability will be based on the frequency of an occurrence of -8°F.

Now to determine where these minimum temperatures occur in the state.

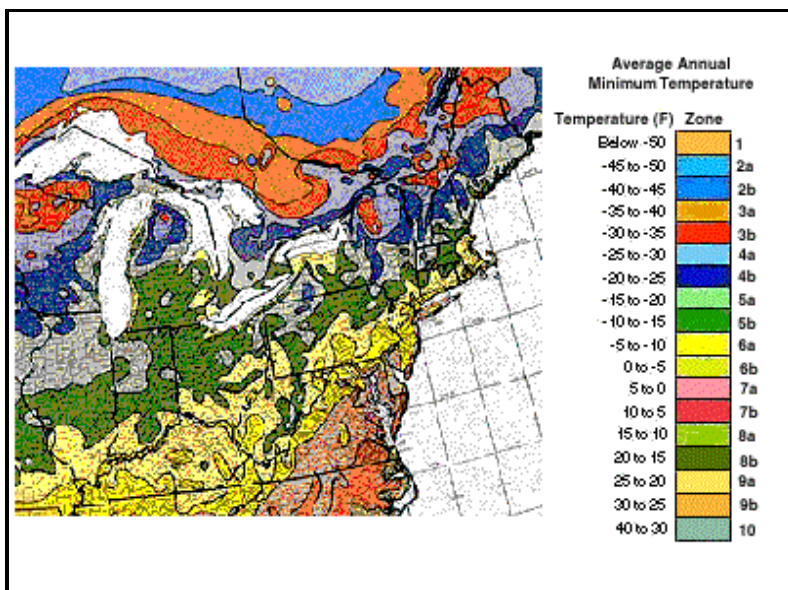


FIGURE 2.3
 USDA Plant Hardiness Zones
 Planting zones established by the United States Department of
 Agriculture, defined by minimum winter temperatures.

There are probably hundreds if not thousands of mesoclimates just within the state of Virginia. With the limited meteorological data available, it becomes impossible to identify and categorize them all, so we start with the general. Figure 2.3 is the United States Department of Agriculture's (USDA) plant hardiness map, based on average minimum temperatures. Virginia lies predominantly in Zones 7a and 7b (in pink and red), areas characterized by the USDA as having annual minimum temperatures from 0 to 10°F. The coastal areas reach Zone 8a (10 to 15°F), and west of the Blue Ridge are characterized by Zones 6a and 6b (0 to -10°F). Notice also that pockets of Zone 5b (-10 to -15°F) occur in the southwest part of the state. Based on the -8°F target temperature for determining *vinifera* suitability, all lands west of the Blue Ridge--zones 6a and lower--are susceptible to extremes that may be detrimental to grape growth.

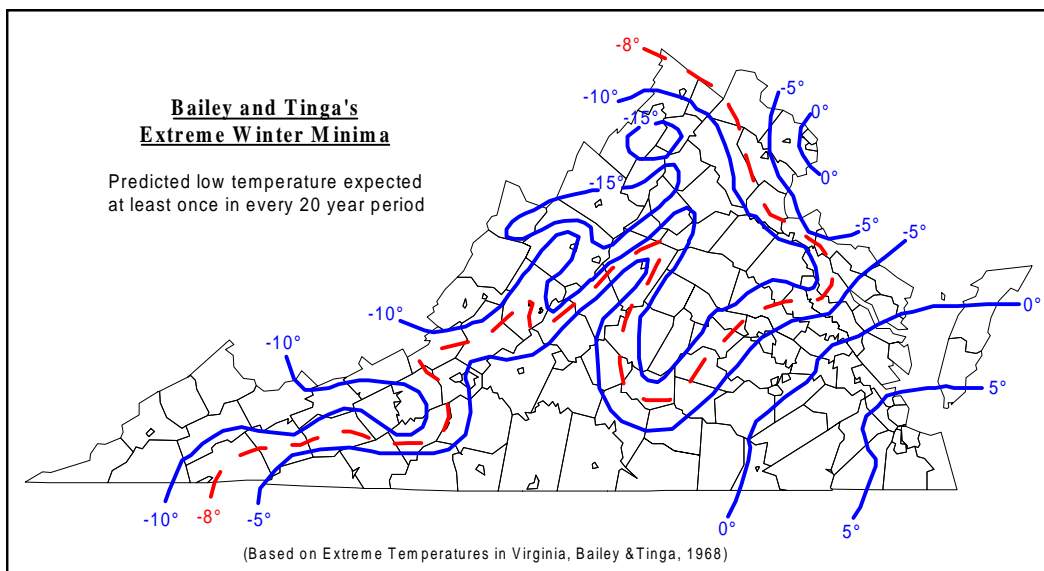


FIGURE 2.4
Minimum temperature probability map
(Based on Bailey and Tinga, 1968)

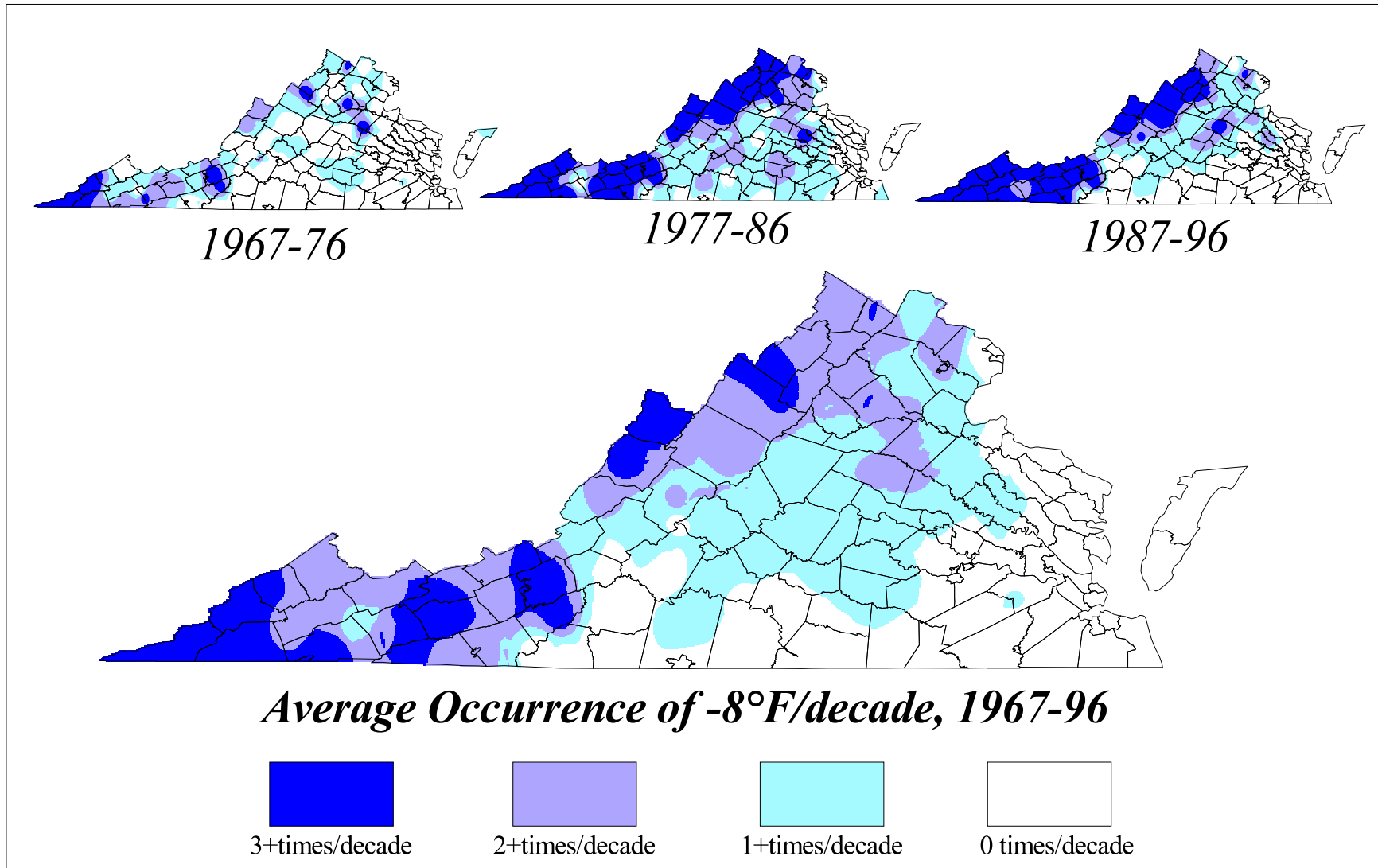
Figure 2.4 represents an analysis of 57 National Weather Service stations to determine probabilities of extremely low and extremely high temperatures throughout the state. It was produced by M. H. Bailey, State Climatologist, and J.H. Tinga, VPI Horticulturist, in 1968 (Bailey and Tinga, 1968). The report used statistical and probability functions to calculate expected minimums, and the probability of it happening. Thus, in the figure above, the actual degree numbers represent the expected low with a 5% probability: meaning not that it happens every twenty years, but that it has a 5% chance of happening every year--leaving a real possibility of multiple occurrences of the minimum.

“...the next largest factor influencing temperature extremes locally is the moderating effect of the Atlantic Ocean,” (Bailey and Tinga, 1968). Immediately identifiable is the maritime influence on the coastal areas, as indicated by the predicted minimum as positive in the southeast part of the state. Of particular interest is just how far inland the maritime influence extends--examine the pattern of the -5° line encompassing Charlottesville and stretching to Roanoke and southward. This influence is marked throughout many other variables in this study.

Bailey and Tinga cite elevation as having “the greatest effect on temperature extremes,” (ibid.). However, notice the massive dip of the -8°F predicted line (indicated by dashed red line) into the upper Piedmont and down into the central part of the state, an area of limited elevation. Referring back to Figure 2.3, the USDA map also has an isolated island of zone 6b (0 to -5°) in this vicinity. Apparently some sort of phenomenon is occurring in this part of the state to make it differ markedly from the surrounding area. If elevation has the greatest effect, then why doesn't this map conform to the elevation contours of the state? Elevation certainly does not explain the anomaly in the Piedmont, nor does this map reflect extreme lows in the highest parts of the state (Mount Rogers and southwest). Elevation is a very important factor in temperature distribution, however, it may not be the only decisive factor shaping the distribution of minimum temperatures.

To adequately determine the best areas for minimum temperature avoidance, I next turned to the history of recorded occurrences of the target temperature--not a prediction, but a known. Figure 2.5 is an interpolation of the number of times -8°F actually occurred at up to sixty-six recording stations, depending upon availability, across the state. The interpolation does not account for elevation or any other variables. As previously alluded to, many *vinifera* cultivars can recover from such minimum when they occur only once a decade. Thus, the three smaller images represent occurrences in ten-year increments, between 1967 and 1996. The large image is an average of the three smaller, constituting, on average, how often the minimum temperature is reached or exceeded across the state.

Some important patterns on this image are complementary to the previous maps. First, the influence of the ocean is again witnessed by the lack of target temperature occurrence as far inland as Danville and into the Roanoke vicinity. Second, the same temperature anomaly in the upper Piedmont identified by the previous maps is given credence by the occurrence rates averaging two or more a decade--in direct contrast to the more stable surrounding area. Third, the occurrence of -8°F three or more times per decade occurred almost exclusively at higher elevations.



Average Occurrence of -8°F/decade, 1967-96

3+times/decade 2+times/decade 1+times/decade 0 times/decade

Figure 2.5
Occurrence of Minimum Winter Temperatures

This image, more so than the USDA or Bailey/Tinga maps, reflects the adverse minimum temperature/elevation relationship. A definitive break between the east and west sides of the Blue Ridge Mountain chain can be seen--the east characterized by less frequent occurrences of the target temperature; the west with generally higher occurrence rate, but punctuated with concentrated areas of consistent high occurrences. This is much more consistent with the role of elevation, as the occurrence rate becomes higher in a more linear fashion as one progresses west into higher territory. The areas rating as three or more occurrences per decade are characterized by having stations at high elevations (i.e. Monterey), or stations located on valley floors (i.e. Luray) which are affected by cold air ponding.

However, the lack of consistency among the elevation/minimum occurrence relationship needed further elaboration. Why didn't all the stations at high elevations exhibit high -8°F occurrence rates? The following figure displays how the high elevations stations compared to ones lower.

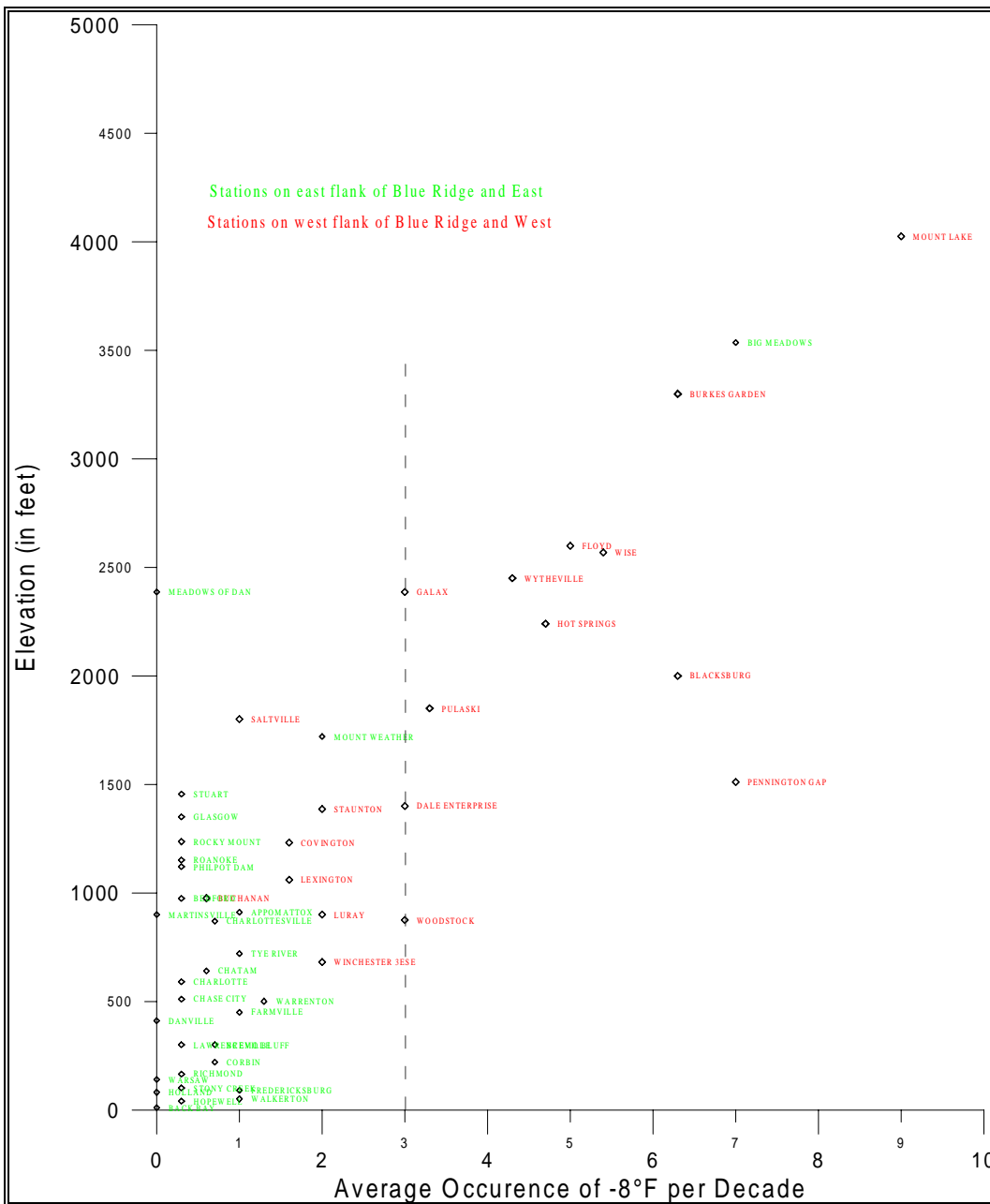


FIGURE 2.6
Occurrences plotted against elevation

Figure 2.6 plots elevation by average occurrence of -8°F , for the stations used in the interpolation of Figure 2.5. The Tidewater stations were omitted for clarity, and all stations were split into one of two groups; east of Blue Ridge or west of Blue Ridge. Immediately one can identify a major trend: almost all the eastern flank stations fall within one or less occurrence and form a relatively tight distribution. Alternatively, the western

flank stations are more randomly distributed, most falling outside the three or more occurrence range deemed unsuitable.

Low occurrence rates for the eastern flank can be observed from zero elevation all the way to 2400 feet asl at the Meadows of Dan station. Acceptable occurrence rates for western flank range from 700 feet asl at Winchester to under 1800 feet at Saltville. What is of even more interest is the variability of elevation versus occurrence rate: Staunton, Dale Enterprise and Pennington Gap are all roughly the same elevation, but possess a difference of five average occurrences among themselves. Saltville, Pulaski and Blacksburg share this same variability attribute.

Given this variability among stations at the same elevations, it appears that the pivotal factor in occurrences of minimum temperatures may be **topography**. The ridgeline division of the Blue Ridge Mountains acts as a huge dam to the cold air masses that come with the prevailing westerlies during winter. When these systems reach the Blue Ridge, they are somehow blocked or impeded from their standard flow. Thus, topographic divisions explain the distribution of minimum winter temperatures much better than elevation differences alone.

On the days of February 5th and 6th, 1996, an extreme low temperature system affected the entire state. The minimum temperature for the night of the fifth/morning of the sixth is plotted graphically for observation in Figure 2.7.

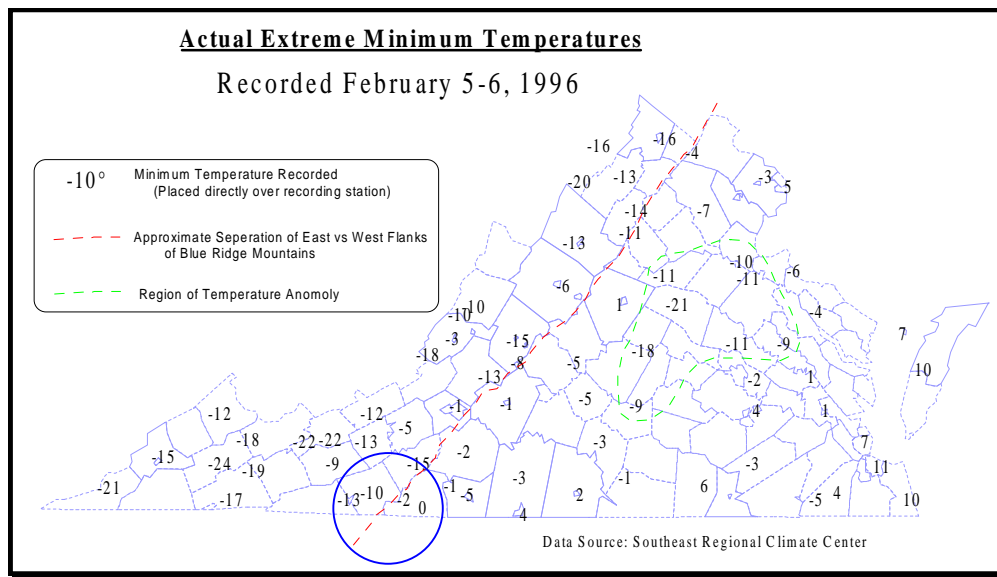


FIGURE 2.7 Extreme cold weather event

Figure 2.7 depicts a classic advective freeze occurrence. Again, the Blue Ridge appears to have a radical effect on the minimum temperature distribution as observed in these readings. What at first appears as random temperature distribution becomes at once a very clear and concise pattern as the ridge line of the mountains is introduced (indicated by red dashed line). Almost every station on the western flank exceeds the -8°F target; very few on the eastern. In fact, the only stations east of the ridge recording below -8°F are all within the same area of anomaly described in previous figures.

To reinforce this observation, notice the area inside the purple circle. Galax, Hillsville, Meadows of Dan and Stuart are the stations depicted by -13 , -10 , -2 , and 0 , respectively. The stations are within 45 miles of each other, yet the temperature difference ranges from an eight to thirteen-degree difference. Of greatest significance, the Galax (-13°) and Meadows of Dan (-2°) stations are at the exact same elevation, just on opposite sides of the ridge. This phenomenon suggests that topography must be considered of vital significance in the distribution of these temperatures.

However, elevation does play an important role; a role with ever increasing importance as one travels west past the Blue Ridge. As indicated in graph 2.6, high target temperature occurrences are tied to higher elevations--just not in a standardized pattern across the state. Big Meadows, at 3585 feet on the eastern flank, does exhibit a high frequency of -8°F , as would be expected for its altitude. But, western flank stations exhibiting high occurrences range from 900 feet asl and upwards, some with moderate elevation (<2000 feet) but very excessive occurrence rates (i.e. Blacksburg, Pennington Gap).

Figure 2.8 below is a revised station plot with the same data as Figure 2.6, but with some hypothetical linear lines drawn on it. Let us make the assumption that, following the standard atmospheric lapse rate, temperatures will decrease with increasing elevation in a roughly linear fashion; then we can also assume that minimum temperatures will occur at a higher frequency with increasing elevation in a linear fashion as well.

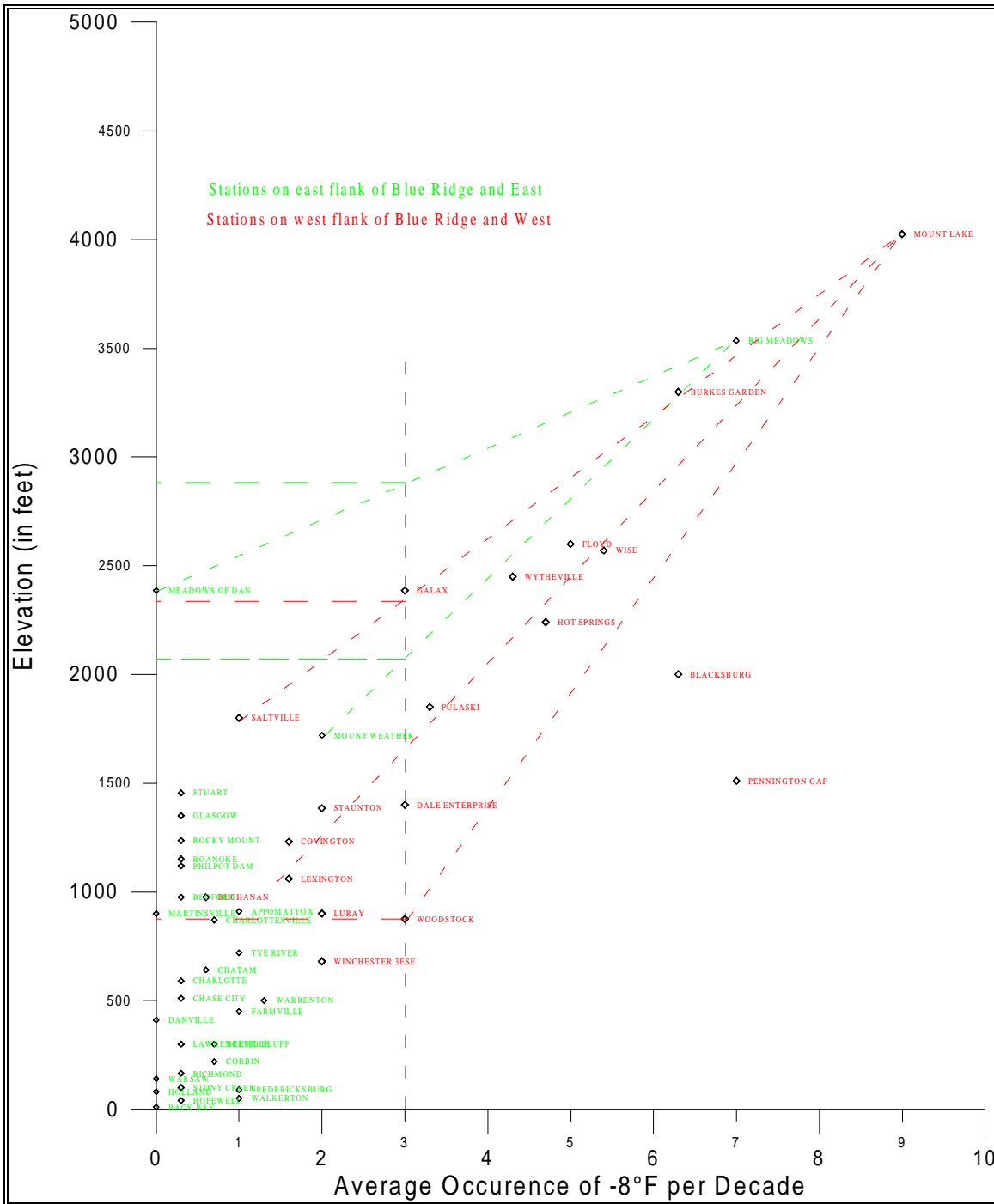


FIGURE 2.8
Linear pattern of occurrences

The manifestation of these hypothetical linear lines are traced for the eastern (green lines) and western (red lines) topographic divisions. For the eastern flank, lines are drawn from the two highest stations still within the accepted occurrence range to the

highest outside the range, which is the Big Meadows station. Where these lines cross the average occurrence of three times per decade line is meant to represent the elevation at which the occurrence rate would exceed tolerance, assuming the linear model holds true. Thus, for eastern flank, maximum elevations maintaining three or less occurrences range from 2100 to 2900 feet asl. However, applying the same principles to the western flank, the range becomes 900 to 2300 feet asl. Even with this wide swath, outliers are present (i.e. Blacksburg).

Therefore, western flank minimum temperature occurrence is more difficult to predict than eastward to the sea. The range of elevation at which the damaging temperatures occur is much wider and reaches its acceptable limit lower than its east flank counterpart. Generally speaking, the eastern side of the Blue Ridge may have acceptable areas as high as 2100 to 3000 feet; western flank being more continentally influenced and more heavily affected by elevation effects, probably only to 2000 feet--and that only in prime areas that have low occurrence rates established.

In summary, the figures presented in this section lead to the conclusion that the 'safest' areas for planting of *vinifera*--solely in terms of minimum winter temperature avoidance--lie from the eastern shore of Virginia up to the eastern flank of the Blue Ridge Mountains. The positive attributes of this area are due mainly to the strong maritime influence and the very important blocking role of topography. West of the Blue Ridge, higher occurrences of -8°F associated with more continental forces and higher elevations serve to make it a riskier area, although certainly many sites exist that do not exhibit high occurrence rates.

2.2.2 Maximum Summer Temperatures

“Grape and wine quality are greatly affected by heat, particularly after the onset of fruit ripening. In general, wines produced from grapes that are grown in a hot climate can lack some of the fruitiness and complexity characteristics of the same variety grown in a cooler climate,” (Wolf, 1989). This statement is supported again and again throughout grape and wine literature, and merits an analysis for locating the prime viticulture areas in Virginia.

Heat, as opposed to minimum winter temperatures, affects quality of the fruit not the survivability of the vine. Many systems of quantifying heat and classifying regions based on heat have been developed in viticulture studies: the growing degree day (GDD) classification from University of California, Davis (Winkler *et al.*, 1974) and the Mean Temperature of the Warmest Month classification (Smart and Dry, 1980) are two of the most widely referred to and used. However, these indexing systems are a product of the regions from which they were developed, and do not necessarily reflect true regionality based on heat in the eastern US. As an example, the Dry and Smart classification categorizes almost all of Virginia in its 'hot' or 'very hot' divisions; only radical extremes of elevation escape this classification, making it somewhat useless for analysis within the state.

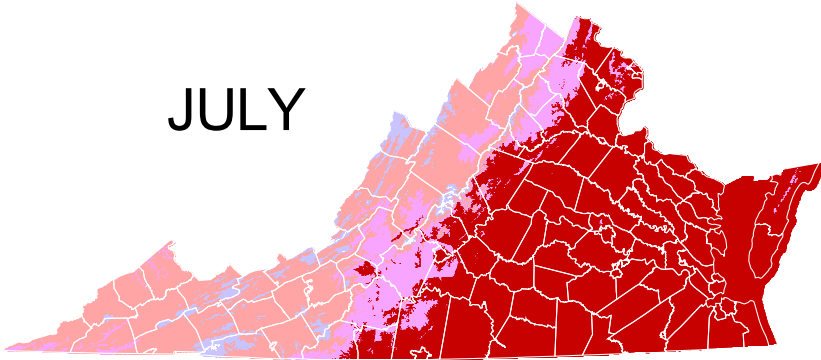
The reason that a lot of emphasis and research is put into heat indices is primarily aimed at grape maturity; that is, ensuring that there is enough heat to ripen a particular variety. However, since most areas of Virginia receive adequate heat to mature most *vinifera* varieties (Wolf, 1998), heat will be examined in its detrimental affects on grape quality. Temperatures during grape development and maturation significantly affect the composition, and therefore quality, of the fruit. High quality grapes retain balanced acidity and sugar, as well as exhibit varietal flavors and aroma. Wines made from grapes of high sugar but low acid concentrations are considered inferior: sweet and unbalanced.

Studies have been conducted showing that acids in grapes, prior to veraison, are broken down at higher temperatures, while inversely are synthesized at lower temperatures (Peynaud and Maurie, 1956). Incorporation of particular carbon compounds necessary for acid creation occurs at more than a doubled rate in berries at lower temperatures ($<77^{\circ}$) than in berries at higher temperatures ($>86^{\circ}$) (Kliewer, 1964). Kliewer, Lider and others have shown that lower temperatures (59° - 68°) increase levels of anthocyananins, total titratable acids, and malic acids relative to higher ones (86° - 95°) (Kliewer, 1965)(Kliewer and Lider, 1967). Cooler versus warmer seasons have also been recognized as positively affecting acid retention (Hennig and Burkehardt, 1951). Condensed from a variety of sources, Kliewer summarizes, "low temperatures during the ripening period are generally associated with grapes high in total acidity," (Kliewer, 1971).

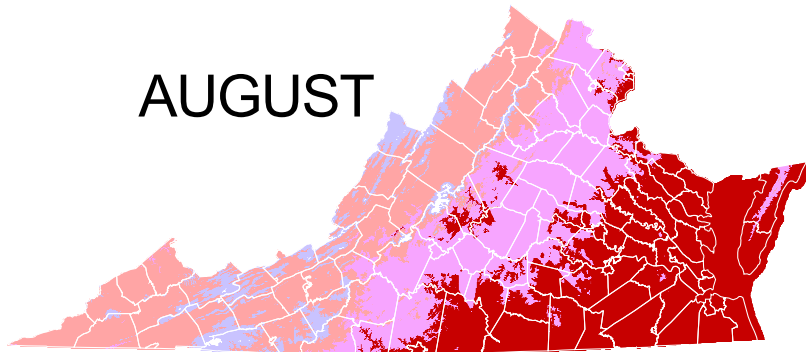
So where are the best regions in the state to avoid maximum temperatures thus facilitating acid retention? As alluded to earlier, reference to other viticulture areas' classification schemes might discourage a potential grower from planting anywhere in the state. A more practical start would be to examine the average temperatures for the period of fruit ripening in the months of July, August and September.

Average Monthly Temperatures Grape Maturation Period

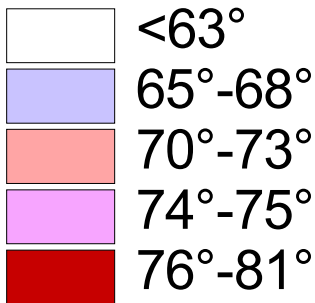
JULY



AUGUST



Average Temperature



SEPTEMBER

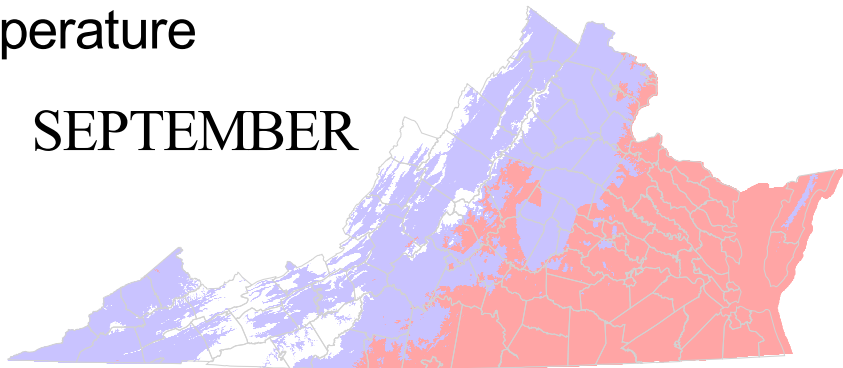


FIGURE 2.9
Monthly averages temperatures,
July - September

Atmospheric lapse rate or decreasing temperature with increasing elevation (3.5° per 1000 feet) will play a vital role in this selection. The images presented in Figure 2.9 come from the thesis work of Scott Klopfer of the Fisheries and Wildlife Department of VPI&SU(Klopfer, 1997). His work used an inverse-distance algorithm, incorporating elevation and adiabatic cooling rates, in a statewide interpolation for monthly average temperatures, based on 87 weather stations in Virginia, North Carolina, West Virginia, Maryland, and Kentucky. Thus, changing terrain is taken into account.

As in minimum temperature occurrence rates, a combination of maritime influences and terrain seem to delineate regions of temperature distribution. Higher temperatures, greater than 79°, dominate the Tidewater region, and even stretch inland as far as Danville. However, instead of the Blue Ridge performing a blocking effect on western fronts, it now is a barrier to eastward progression of high temperatures. The major modifier appears to be the absolute elevation increase, not the topography itself.

The Blue Ridge is an outstanding delineation line, as seen in July--the hottest month of the year. Traveling westward from the coast, temperatures decline in a linear fashion, markedly quicker with increasing elevation. Temperatures east of the mountains range from 77° to 81°, west of the ridgeline average under 75°--a full two degree difference just on either side of the ridge. Further increases in elevation bring temperatures down to under 63°--a full eighteen-degree difference from coast to mountain top. The same type of distribution holds in August, just with the temperatures shifted towards the coast, as the whole state naturally cools with the changing season. Only in September do cooling temperatures begin to equal on both sides of the ridge, with the Tidewater area still being the warmest all phases of the year.

It is evident that increasing elevation naturally brings about a desirable decrease in temperature during the ripening period of the fruit, however, the images presented do not exactly conform to the rule. The highest averages of July temperature do not proceed in a perfect linear fashion across the Tidewater and Piedmont. For example, why does the arm of high temperatures extend inward to Danville? To facilitate a better regional division understanding, recorded occurrences of extreme summer temperatures were looked at.

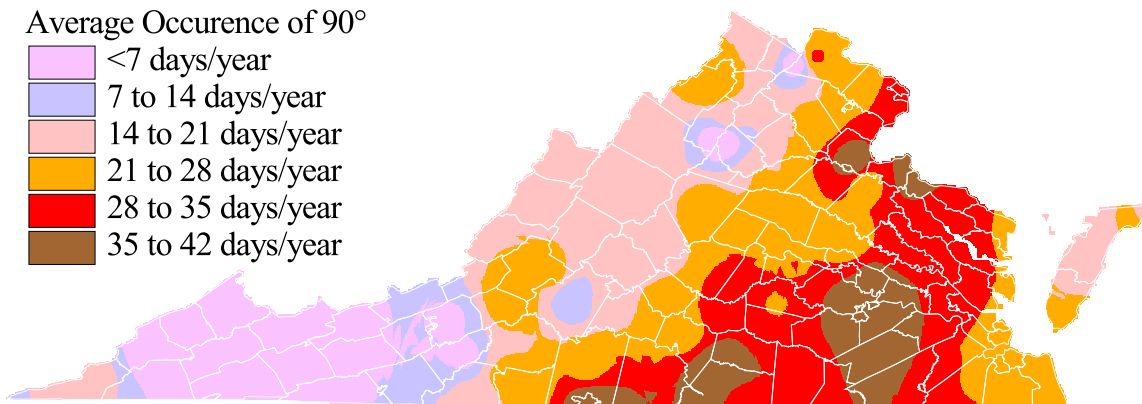
Average Annual Occurrence Rate of Maximum Temperatures

1966-1996

78 weather stations reporting

Daily Maximum of 90° or Higher

Average Occurrence of 90°



Daily Maximum of 95° or Higher

Average Occurrence of 95°

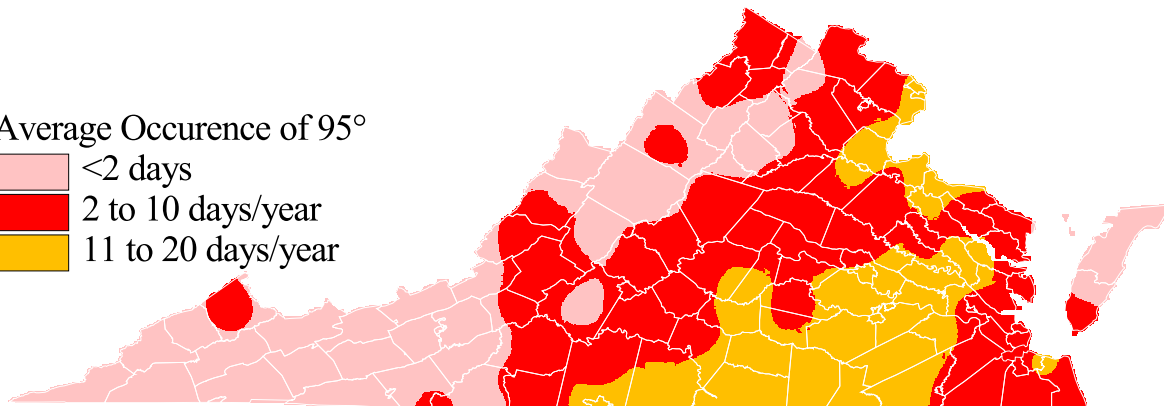
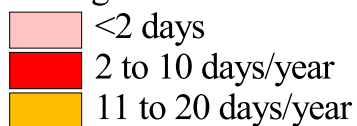


FIGURE 2.10
Occurrence of Extreme Temperatures

The Figure 2.10 represents an interpolation of average annual occurrence of maximum temperatures, namely 90° and 95°. These extremes are not chosen at random, but represent temperatures which can cause significant damage to vine health and grape composition. “...Temperatures higher than 86°F can cause internal water deficiencies, sunburn damage, dehydration of fruit, and reduced growth rates,”(Weaver, 1976). In addition , temperature extremes initiate catabolization of acids and inhibit color formation in the grape: “...anthocyanin concentration was greatest at an intermediate temperature (70° to 79°)...and at the highest (90° to 100°) the berries were almost devoid of pigment,” (Tomana *et al.*, 1979).

As temperatures exceed the mid-eighties, photosynthesis can decline and berry ripening becomes seriously impaired in the upper nineties and above (Kliewer, 1971). In summary: “As temperature rises acid levels may become disproportionately low, sugar production stalls, and the danger of sunburned fruit increases (Morton, 1985). This effect is not limited to grapes. “[At] lower elevations in eastern Virginia, high temperatures are not conducive to apple coloration and cause pre-harvest problems such as fruit softening and early drop,” (Marini, 1988).

In both images in Figure 2.10, it is important to note that the highest occurrences of these extremes occur not on the coast, but in an area that encompasses the inland portions of the Tidewater and extending well into the south central part of the Piedmont. Apparently, the maritime influence is now serving to modify the coastal regions by lowering the daily maximums, providing some relief to potential sites on the Eastern Shore and continental bayside. However, it appears that the south side areas of the state, from Richmond to Danville, may be at greatest risk to summer high temperatures. The occurrences of 95° range from two to three weeks--meaning on average, *every year*, these areas experience ten to twenty days where the maximum temperature reaches 95° *or hotter*.

Mountainous areas of the state, on the other hand, are relatively free from summer extremes. West of the Blue Ridge is typified by the Valley and Ridge province receiving less than three weeks where temperatures reach 90°, and most receive less than two. Into the Appalachian Plateau, less than a week on average above 90°. As elevation of site

increases, so do chances of reaching these extremes. Only around the Roanoke Gap area do temperatures exceeding 95° penetrate in any significant area capacity, and then only in the 1 to 10 day category.

In summary, the coolest regions of the state are located at the higher elevations of the Blue Ridge and westward. However, the hot regions in the south central Piedmont and Tidewater areas merit particular attention as sites to avoid. The ameliorating effects of the Atlantic Ocean and Chesapeake Bay give limited possibility to cooler sites in parts of the Tidewater, particularly the Eastern Shore. If one considers only high temperature avoidance, forsaking all other factors, then the higher the elevation, the better. This temperature/elevation effect is highlighted well in this abridged list of extreme maximum temperatures recorded on July eighth of 1996. (Table 2.1)

TABLE 2.1
Elevation/Temperature listing for select weather stations
July 8th, 1996

Station	Elevation	Maximum Temperature July 8, 1996
BACK BAY	10	92
NORFOLK	22	95
HOPEWELL	40	94
WILLIAMSBURG	70	93
HOLLAND	80	93
RICHMOND	165	93
ASHLAND	220	92
JOHN H KERR	250	95
BREMO BLUFF	300	96
DANVILLE	410	96
LOUISA	420	93
FARMVILLE	450	97
LINCOLN	500	91
PIEDMONT STTN	515	91
CHARLOTTE	590	95
CHATAM	640	91
WOODSTOCK	875	89
MARTINSVILLE	900	88
LURAY	900	90
LEXINGTON	1060	87
STAUNTON	1385	86
MOUNT WEATHER	1720	83
BLACKSBURG	2000	85
HOT SPRINGS	2240	85
GALAX	2385	82

WISE	2570	80
FLOYD	2600	82
BIG MEADOWS	3535	78
MOUNT LAKE	4025	73

2.2.3 Precipitation and Humidity

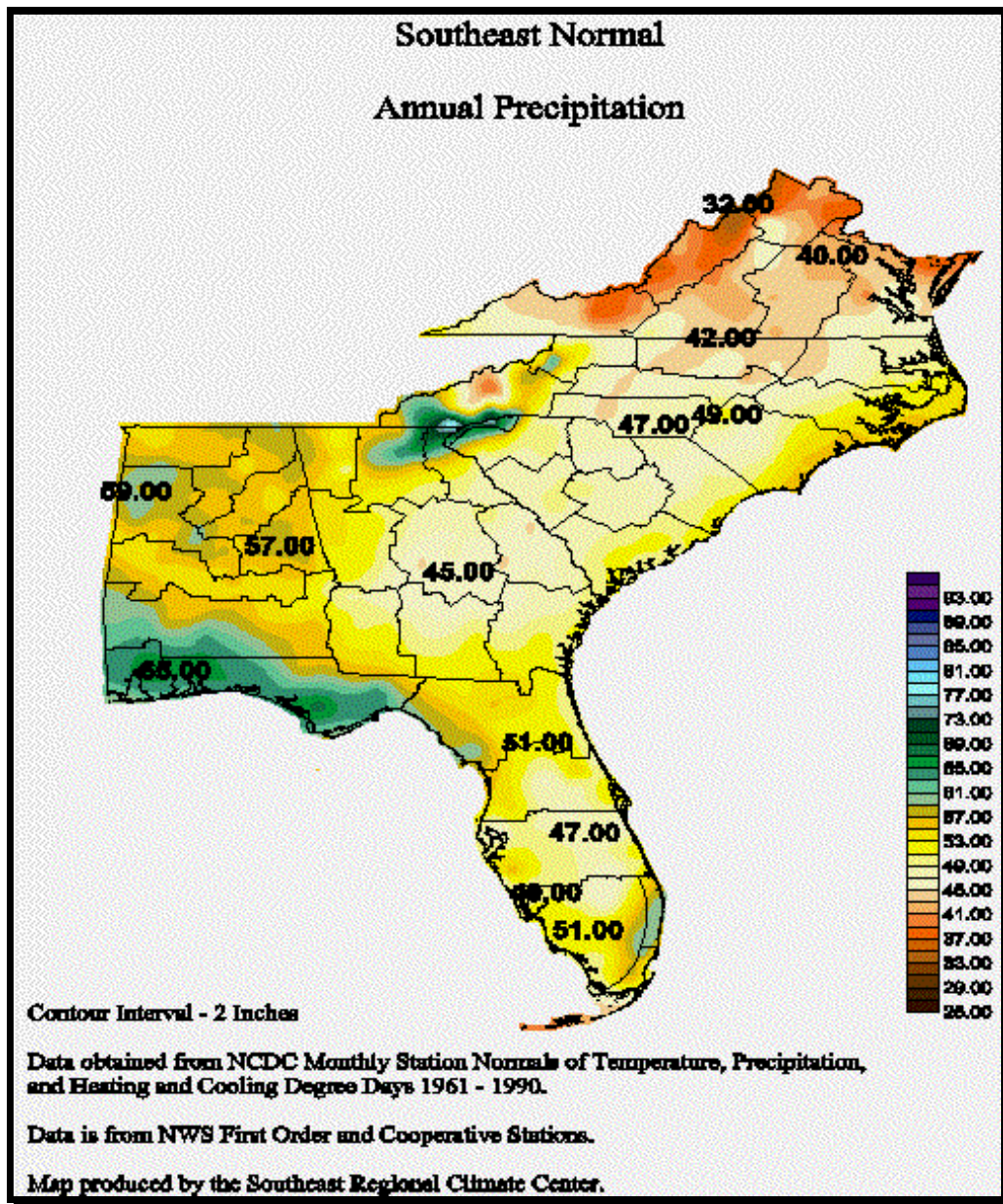


FIGURE 2.11
Average annual precipitation in the Southeast
Map produced by the Southeast Regional Climate Center

Precipitation levels in Virginia are not considered an essential limiting factor for fruit crops. Most recording stations across the Commonwealth record between 35 and 50 inches of precipitation a year (Figure 2.11), more than adequate for most vine and tree fruit species which usually consume somewhere between 30 and 40 inches (Childers, 1976). In the upper Shenandoah Valley, which experiences the minimum of precipitation for the state, enough falls to make it, “equivalent to eastern portions of Texas, Oklahoma, and Kansas and southern Iowa and Wisconsin. It is thus not surprising that the Shenandoah Valley is one of the finest agricultural areas in eastern North America.” (Hayden, 1979)

What is of greater significance with precipitation is *when* it is received. Low rainfall, especially during grape maturation, is beneficial in reducing disease incidence and facilitates grape harvesting. Rain during the harvest season--August, September, October--can reduce crop value in that it, “...dilutes sugar concentration and causes fruit deterioration, splitting, and rot,” (Morton, 1985).

Average Precipitation, Veraison Months

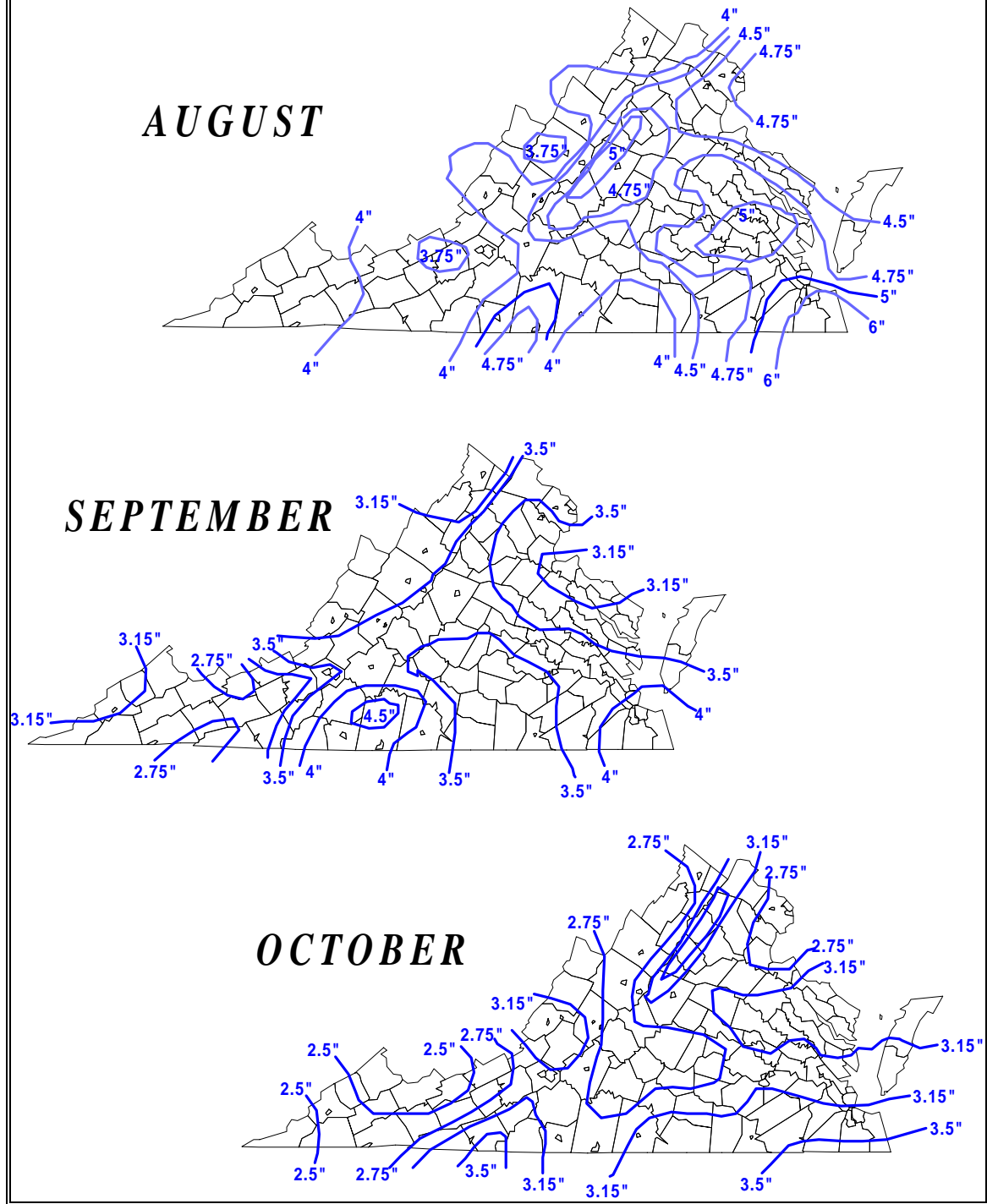
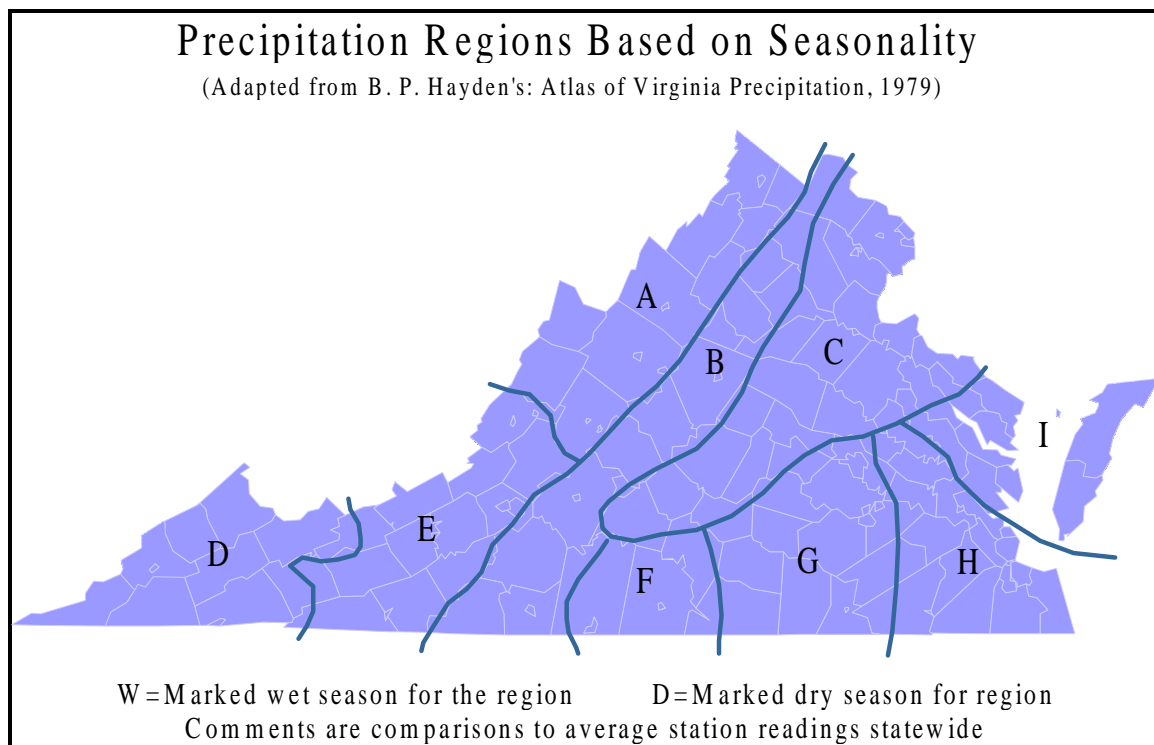


FIGURE 2.12
Precipitation, August - October
(adapted from Hayden, 1979)

The images in Figure 2.12 show a breakdown of average monthly precipitation distribution for a thirty-year return period, 1941-1970. August and July constitute the heaviest precipitation period of the year. Most every part of the state receives at least 100mm in August, with parts of the Tidewater area receiving double that amount. Tidewater and southern sections of the Piedmont receive the most precipitation in September. And once again the topography plays a very decisive role in distribution of climatic factors as evidenced by these maps--the role of the mountains.

Notice the increased amounts on the Blue Ridge Mountains in August-- a trait that is displayed in October as well. The orographic effect outlined in Section 2.1 is the causal agent behind this phenomenon. This becomes of particular importance because, "While the prevailing flow of air is from west to east, the occasional weather systems which track up the coast are responsible for the heaviest storms and *over half* the total annual precipitation," (Woodward and Hoffman, 1991). As warm, wet air masses are pushed up the flanks of the mountains, they lose temperature and dew point is reached (de Blij & Muller, 1993), accounting for the greater precipitation rates in the Blue Ridge area.

Seasonality of precipitation is of major concern for vineyardists. The following seasonal regionalization is based on the work of climatologist Bruce Hayden.



	Name	Winter	Spring	Summer	Fall	Comments
A	Shenandoah	D				Drier all year, fall:moist early, dry late
B	Blue Ridge	D		W		Wetter all year, esp. hurricane season
C	Northeastern Piedmont		D		W	Summer slightly drier; fall slightly wetter
D	Southwestern Mountain	W			D	Wetter all year, driest during hurricane season
E	New River			W	D	Drier all year
F	South central Piedmont					Slightly wetter all year
G	Eastern Piedmont			D	W	Average, slightly wetter fall
H	Tidewater				W	Much wetter all year, esp. hurricane season
I	Chesapeake				W	Wet late fall, early winter

FIGURE 2.13

Regions based on precipitation seasonality
(adapted from Hayden, 1979)

The Tidewater, Chesapeake, South central Piedmont, and parts of the Blue Ridge are areas associated with increased risk to the vineyardist. This is based on the characteristic of moderate to high rainfall levels in these regions during the grape maturation, of prime importance as explained earlier. The higher rainfall during this period (August to October) is associated with hurricane season-- mostly affecting coastal regions, but also defined on eastern slopes of Blue Ridge chain. In the month of September, "10 to 40 percent of Virginia's rainfall comes from hurricanes and tropical storms," (Hayden, 1979) a trait that is not alluring to a potential vineyard site.

Inversely, the driest parts of the state during harvest are west of the Blue Ridge--Shenandoah, New River, and Southwestern mountain regions (see Figure 2.13). These areas are identified as having drier than average autumns compared to the rest of the state--a very promising feature to the fruit grower.

As important as precipitation and its seasonal distribution may be, what is of still greater significance are the climate regimes created from the combination of precipitation with temperature. Particularly, the combination of high precipitation with high temperatures is of momentous consequence to the fruit grower. The humid conditions created by such climates are serious deterrents to vineyard establishment.

Negative effects of humid climates stem primarily from the potential disease control problems. According to Winkler:

“...the more humid the summer weather, the more difficult are diseases to control. This is especially so for fungus and bacterial diseases...

Particularly harmful are frequent summer rains--especially when accompanied by high temperatures. “ (Winkler *et al.*, 1974)

Black rot, downy mildew, black mold rot, white rot, and Botrytis or noble rot--all fungi promoted by moist weather. Not only do these organisms thrive in the humid conditions, but are further promoted by frequent rains which help disseminate their spores. This situation is particularly detrimental to *vinifera*, as the species is not adapted to such a climate, and therefore mostly defenseless to the fungal and bacterial organisms of the East.

Quantifying the relationship between heat and precipitation is a difficult task. Records of humidity levels at individual weather stations are not enough to go by, as they are too few and too spread out to make adequate assessment. Also, humidity readings are much too variable hour to hour, much less day to day, to be of significance at a regional level. However, comparisons of average temperatures directly against average precipitation seems to present a viable model to measure this trait. What is presented below is another image from the work of Scott Klopfer (Klopfer, 1997). (Figure 2.14)

Comparison of Temperature and Precipitation

Regionality based on Average Temperatures plotted against Average Precipitaion

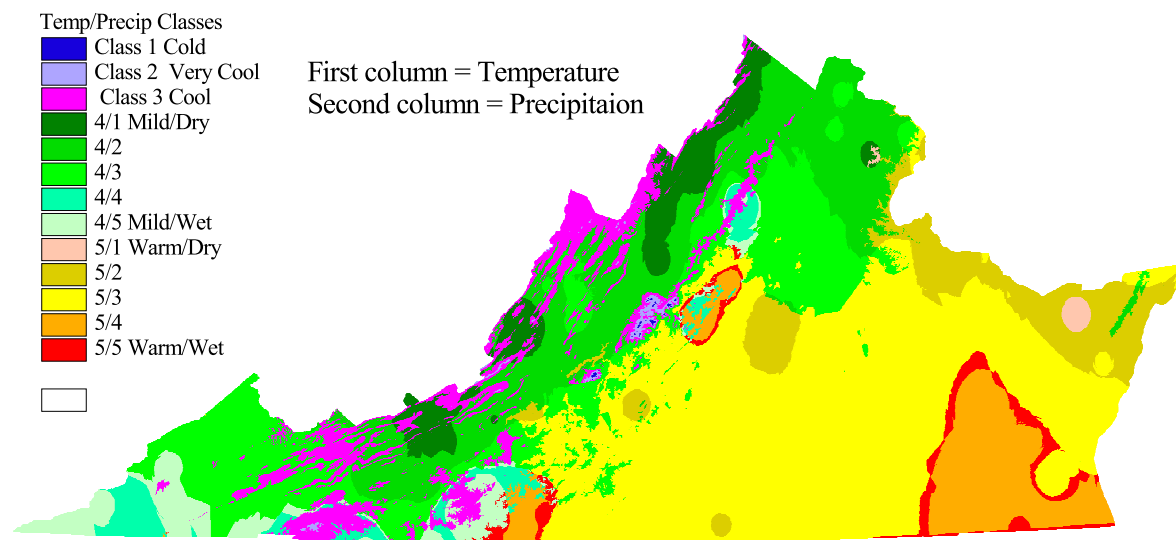


FIGURE 2.13
 Temperature/Precipitation classes

Classes for the image run from 1/1, the coolest and driest region, to 5/5, the hottest and wettest. All other classes fall in between, i.e. 5/1 is in the warmest temperature regime/with lowest precipitation for that regime. While not a perfect model, it does display some climate characteristics that are difficult to express through other means. The humidity issue is much better defined in this sort of presentation.

Classes 5/3 to 5/5 designate the warmest and wettest regions of the state based on the averages. This region constitutes a great portion of the central and southern Piedmont and all of the Tidewater area. Referring back Figures 2.9 and 2.13, this classification is corroborated by occurrences of maximum temperatures, and with high rainfall averages. Northern Piedmont and into the Valley and Ridge, there is a downstep of temperature class, and accelerated drops with increasing elevation/westward travel. Only at elevation extremes are the three cooler classes displayed.

“Rain in warm temperature conditions is more damaging than rain in cool temperatures. In investigating a new district it can be quite revealing not only to discover the rainfall in the two months before vintage, but to find out if it is predominately warm or cold. The latter is much preferred”
(Jackson and Shuster, 1987).

Thus, the southern Piedmont and Tidewater are likely to have greater disease pressure and would not be as desirable for disease-susceptible crops like grapes. These same areas, along with the Blue Ridge, also receive excessive precipitation during the maturation period which coincides with hurricane season. For the factors of precipitation, the areas of highest fruit potential lie in the Northern Piedmont and all areas west of the Blue Ridge.

2.2.4 Day Versus Night Temperatures

Another important factor for adequate fruit development and subsequent fruit quality is the nighttime minimum temperature of the area. This is due primarily to a positive correlation between cool nights and higher levels of acid retention and coloration of the fruit. High night temperatures induce the plant to maintain daytime metabolic processes, particularly respiration rates--rates which can increase exponentially with temperature increases (Kozlowski & Pallardy, 1997).

Respiration involves the oxidation of food in living cells to bring about the release of energy; energy in turn used for maintenance and growth of plant tissues (Kozlowski & Pallardy, 1997). Acid degradation is a bi-product of normal respiration, but also is a product of the last stages of fruit ripening (Kozlowski & Pallardy, 1997). Thus, increased respiration due to higher temperatures in the final ripening stages can drastically reduce acid retention prior to harvest.

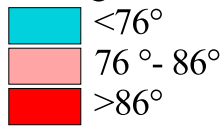
Studies done on the day/night acid retention rate include Bremond who found that cooler nights promote acid retention while night temperatures in excess of 86° tended to cause a sharp decline in acid levels (Bremond, 1937). Total acidity was increased and pH reduced in several varieties under night temperatures of 60° as compared to nights of 95°; night temperatures of 50°, 60°, 68° were also shown to increase acidity in a linear fashion as compared to temperatures of 77° and 95° (Kliewer, 1972). On coloration: cool night temperatures (60° to 68°) were found to greatly increase level of pigmentation in skins of several varieties of grapes versus higher temperatures (77° to 86°) (Kliewer and Torres, 1970). In apples, “the benefit of cool nights appears to indirectly affect color by reducing respiration loss of carbohydrates,” (Westwood, 1993). This reduced respiration rate/higher fruit coloration scenario (due to lower temperatures) applies equally to grapes in that, “...pigmentation of skins is greater in cooler temperatures , and in areas with greater temperature contrasts between night and day,” (Jackson and Shuster, 1987).

To regionally assess the difference in night versus day temperatures, I first constructed interpolations for July, the hottest month of the year, in an effort to show the greatest disparity in the temperatures.

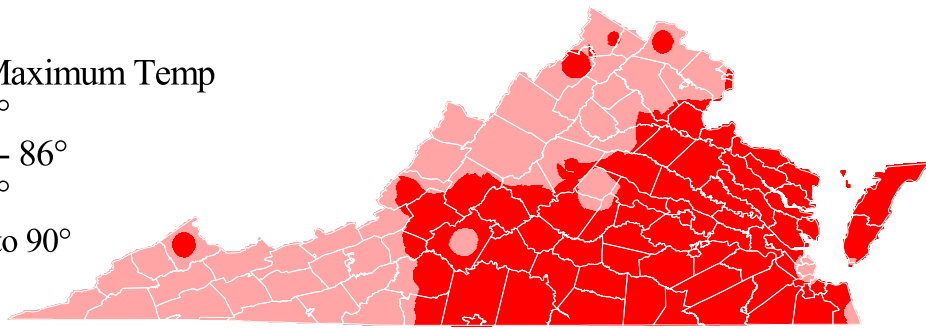
Average July Day vs Night Temperatures

Average Daily High, Average Nightly Low, and Degree Difference Between

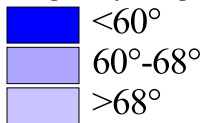
Average Maximum Temp



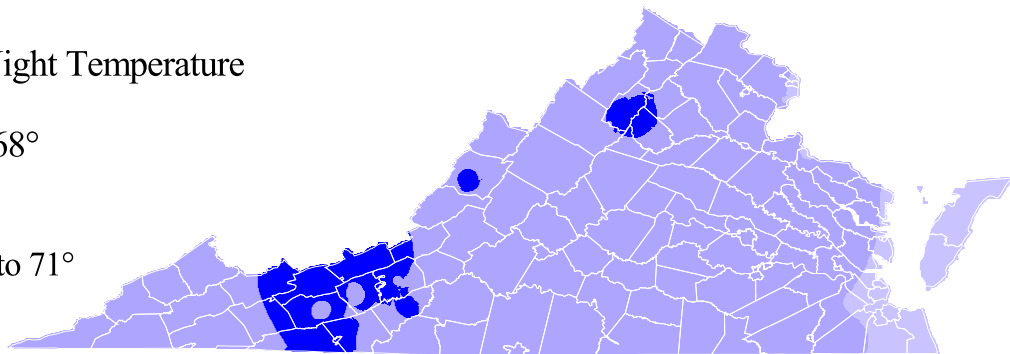
Range: 67° to 90°



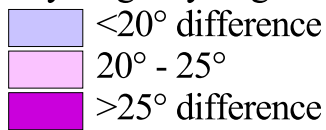
Avg July Night Temperature



Range: 56° to 71°



July Avg Day-Night Difference



Range: 14° to 27°

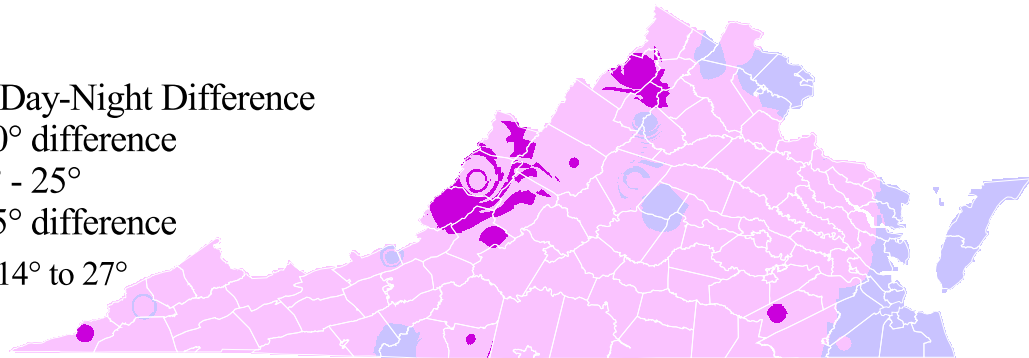


FIGURE 2.15
Average Day/night temperature regime

Using the 68°F temperature established by Kliewer as the target temperature for acid retention and pigmentation, we see in Figure 2.15 most of the state falls within the beneficial range of minimum night temperatures. The Tidewater fringe is the only exception, having night temperatures exceeding 68°, ranging up to 71°. As expected, increasing elevation leads to even lower night minimum (56° to 60°) in the more mountainous areas.

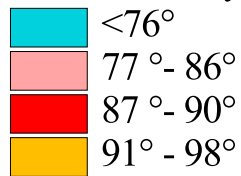
Taking the difference between the maximum and minimum recorded temperatures for July, the bottom image in the figure demonstrates that the range of day to night temperatures is relatively narrow throughout the state. A 14° to 27° total range, more concisely a 20° to 25° difference in more than 95% of the state--meaning that almost all parts of the state have a twenty to twenty-five degree difference between day and night temperatures. Only the highest elevations record greater deviation; only the coastal stations record lower deviations.

However, since most of the stations from the Blue Ridge and west record lower daily maximum, the twenty to twenty-five degree shift at night brings them down to a much lower absolute temperature. The inverse hold true in the southern Piedmont and Tidewater; higher day maximums are paralleled by higher night minimums. An analysis of an actual summer's day temperatures illustrates this relationship (Figure 2.16). July 8th, 1996 was picked at random as a day typifying a mid-summer heat event. On this day sky conditions across Virginia were mostly sunny with scattered clouds, nonexistent to slight winds from the west, and no precipitation--excluding very local events.

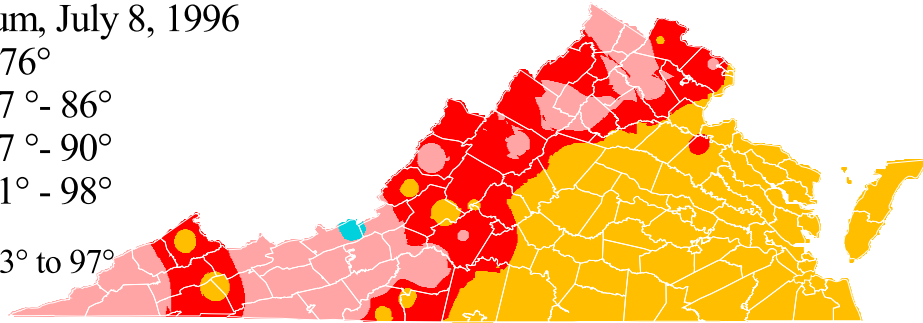
July 8-9, 1996 Temperatures

Average Daily High, Average Nightly Low, and Degree Difference Between

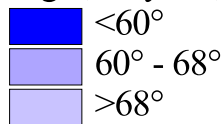
Maximum, July 8, 1996



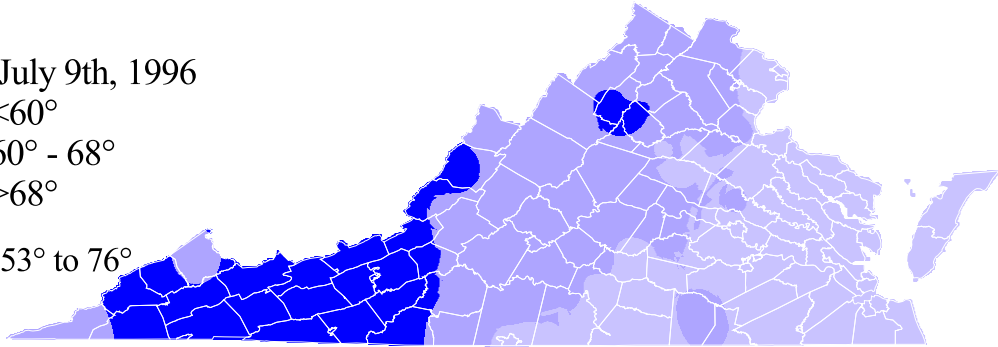
Range: 73° to 97°



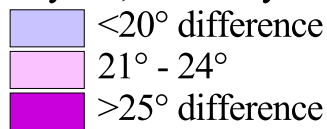
Night, July 9th, 1996



Range: 53° to 76°



July 9th, 1996 Day-Night Difference



Range: 16° to 35°

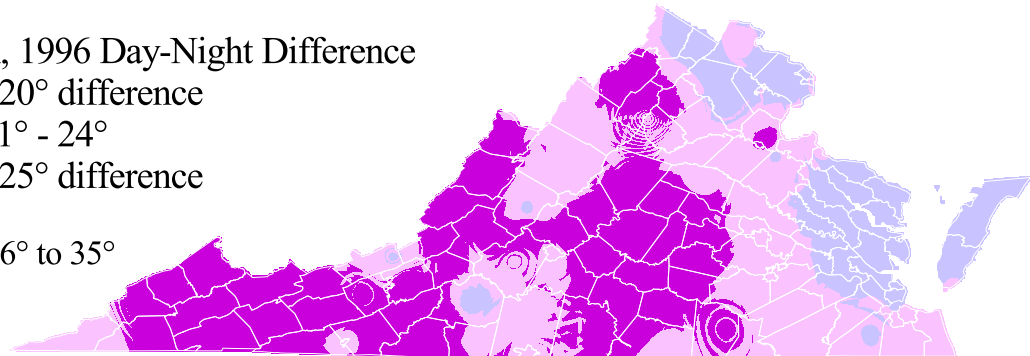


FIGURE 2.16
Day/night temperature regime; July 8-9, 1996

Daily high maximums were much higher than the average on the day of the eighth, ranging from 73° to 97° across the state, with the predominantly highest temperatures located in the south central Piedmont and Tidewater areas. Subsequently, the cooling difference from day to night was much more drastic, from 16° to 35°.

But notice the minimum temperature image in the center: most of the Piedmont and Tidewater still maintain night temperatures in excess of 68°--even after the considerable cooling difference. This is particularly significant when the total minimum range is considered: 53° to 76°--the high end reaching a point that becomes detrimental to acid retention and color (Kliewer, 1971). This is an in-depth look at a single event, and the extremes reached on this day, both day and night, are not typical of the entire season. The example is used primarily to graphically depict a typical cooling pattern statewide.

In summary, while no part of the state exceeds damaging night temperatures on a regular basis, sites located in cooler night regions would be expected to produce a higher quality and consistency of grapes. Sites at higher elevations, and higher latitudes, seem to possess the positive attribute of lower night temperatures, from a combination of slightly greater cooling rate and lower daytime maximums. The area of south central Piedmont and eastward to the coast possess hotter daytime temperatures, lower day/night cooling ratios and therefore are more at risk to have trouble with acid retention and fruit coloration.

2.2.5 Growing Season

The number of continuous days above 32°F is the conventional definition of a site's growing season. Basically, it is the average number of days between the last freeze of spring and the first freeze of fall. Different fruits and different varieties within a fruit type can range drastically in their required growing season: the Lodi apple may take only 75 to 100 days to mature to harvestability while the Granny Smith variety requires over 200 days to mature (Barden, 1998). In general most temperate fruits fall between these extremes.

Most varieties of grape require around 165 days to fully mature and acclimate for the coming winter (Wolf, 1989). Almost all sites in Virginia can accommodate this length

of growing season. However, some varieties such as Cabernet Sauvignon require many more days (Wolf, 1989). Figure 2.17 is offered to delineate average growing season across the Commonwealth to assist with variety selection.

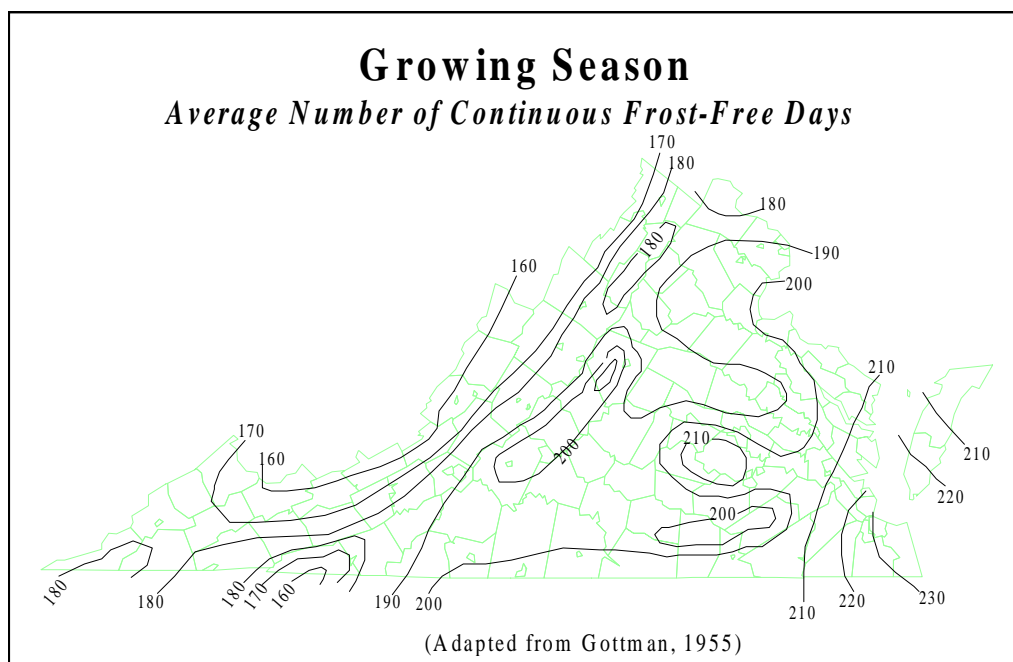


FIGURE 2.17
Growing season length in Virginia
(adapted from Gottman, 1955)

While an overwhelming majority of the state does provide enough frost free days to support grape maturation, there are areas that do not. As evidenced by the 160 day isoline, the higher elevations ultimately become obstacles for successful fruit culture. The eastern flank of the Allegheny Mountains and southernmost parts of the Blue Ridge are just such areas. Below is an abridged weather station listing which compares the effect of increasing elevation with length of growing season (Table 2.2).

TABLE 2.2
Growing season/elevation for select weather stations

Station	Growing Season (days)	Elev. (feet)	Station	Growing Season (days)	Elev. (feet)
Colonial Beach	213	10	Bedford	194	975
Tangier Island	246	10	Lexington	170	1060
Norfolk WSO Airport	241	22	Roanoke WSO Airport	193	1150
Suffolk Lake Kilby	211	25	Covington Filter Plant	159	1230
Williamsburg 2 n	199	70	Rocky Mount	175	1235
Richmond WSO Airport	200	165	Dale Enterprise	164	1400

Danville	200	410	Pennington Gap 1 w	166	1510
Louisa	176	420	Pulaski	152	1850
Farmville 2 n	175	450	Blacksburg 3 se	156	2000
Warrenton 3 se	194	500	Galax Radio WBOB	151	2385
Piedmont Research Station	193	515	Wytheville Post Office	158	2450
Winchester 3 ese	181	680	Wise 1 se	163	2570
Charlottesville 2 w	209	870	Floyd	141	2600
Woodstock 2 ne	170	875	Burkes Garden	135	3300
Martinsville Filter Plant	161	900	Big Meadows 2	143	3535
Appomatox	191	910	Mount Lake Biol Stn	142	4025

Similar to the threat of minimum winter temperature risks, increasing elevations lead to shorter and shorter growing seasons, but not in a fixed manner. The Blue Ridge eastern flank, being more moderate in its temperature range than the continentally dominated Alleghenies, provides adequate growing seasons as high as 2500 to 3000 feet asl. On the western flanks, and into the Allegheny chain, anything over 1500 to 2000 feet is risky, as supported by the stations listed past Dale Enterprise in the column on the right. Most stations over 1500 feet do not meet minimum criteria of 165 frost free days in the growing season. In summary, only the extremes of elevation--especially in the Alleghenies and Appalachian Plateau--are limiting to viticulture potential as far as growing season is concerned.

2.2.6 Topographic Considerations

A brief analysis of topographic considerations completes this section of important variables at the state scale. Distilling two key factors from the topography--slope and absolute elevation--will assist in delineating the areas containing the highest potential for fruit crops.

Land with even the most moderate of slope is generally more desirable than flat land for a couple of reasons. First, sloping land facilitates air drainage--specifically, cold air drainage from higher to lower places--promoting frost avoidance. Increased air flow is also beneficial in that it expedites drying after rains and morning dews, decreasing fungus and bacterial promotion (Gladstones, 1992).

Figure 2.18 displays only the broadest classes of slope across the state. It was produced from 1:250,000 scale quadrangle from the United States Geological Survey (USGS), which equates to a ninety meter (300 foot) resolution--very coarse, but adequate

for this state scale analysis. Zonation identifies areas with no slope (flat land), one to two percent slope, and three percent and above. Greater than three percent but less than fifteen is generally regarded as the best for vineyards (Wolf, 1998). This issue will be addressed in more detail at the local scale, in the site analysis phase.

Upland elevations, due to atmospheric lapse rate, are generally cooler in the summer, cooler at night, and possess lower humidity. This promotes greater acid retention, better coloration, and less pressure from fungus and bacteria, which do not thrive as well in the cooler, drier conditions (Pearson & Goheen, 1988). In the words of one veteran planter, “Fungi, probably the number one enemy of the premier wine vines east of California, can be greatly reduced by planting at higher elevations depending on the latitude,” (Brady Jr., 1981).

In addition, higher elevations are sought out by fruit growers for their air drainage qualities--especially for frost avoidance in radiational freeze situations. As described earlier, cold air will ‘flow’ downhill and settle in flat valley bottoms and lowlands, displacing warmer air upwards to higher elevations--hopefully where the orchard or vineyard is located. “Orchards are often planted on rolling hills or hillsides, with less than ideal soil, strictly to have adequate elevation for air drainage,” (Marini, 1988). Absolute elevation is a significant consideration to the vineyardist as well in that, “Both grower experience and historical weather data suggests that the incidence of late-spring and early-fall frost in the Piedmont and mountain regions of the state is greater below about 800 feet above sea level (asl) than at elevations of 800 to 2000 feet asl,” (Wolf, 1989).

General Slope of Virginia

County Borders



Slope



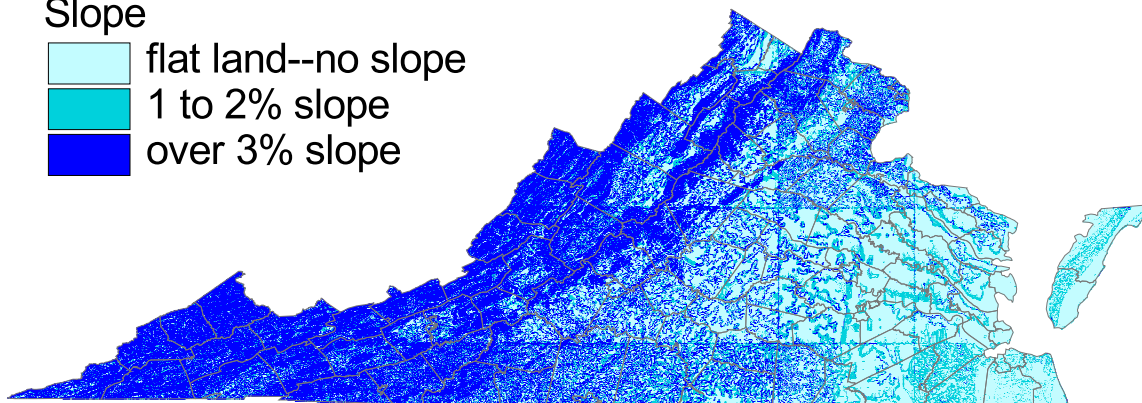
flat land--no slope



1 to 2% slope



over 3% slope



Elevation of Virginia

County Borders



Absolute Elevation



<500 feet asl



500 - 1000 feet asl



1000-3000 feet asl



>3000 feet asl

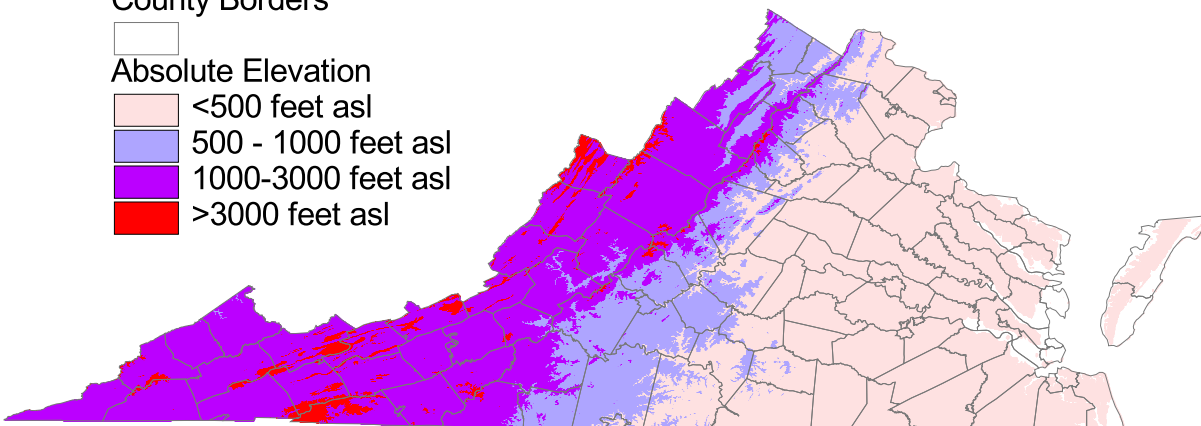


FIGURE 2.18
Slope and Elevation of Virginia

Figure 2.18 also shows the absolute elevation rating I have chosen as obtaining the highest potential for fruit crops. Based on the comments from fruit growers, historic records, and expert opinion, I believe that--a very conservative--minimum absolute elevation of 500 feet asl and above hold the highest potential for top quality fruit growth in the state. Previously discussed in minimum winter temperatures and growing season, there is a limit to beneficial increases in elevation. This cutoff is very locale dependent, particularly Blue Ridge versus Alleghenies, but 2500 feet is a very liberal number, above which only the very hardiest of varieties with very short growing season requirements.

Again, the issues of slope and absolute elevation will be addressed at the local scale during site analysis. Their importance for cooling summer temperatures, lowering humidity, and particularly, frost avoidance cannot be over-emphasized. and merit evaluation at the local scale.

2.3 Selecting Region with Highest Viticulture Potential

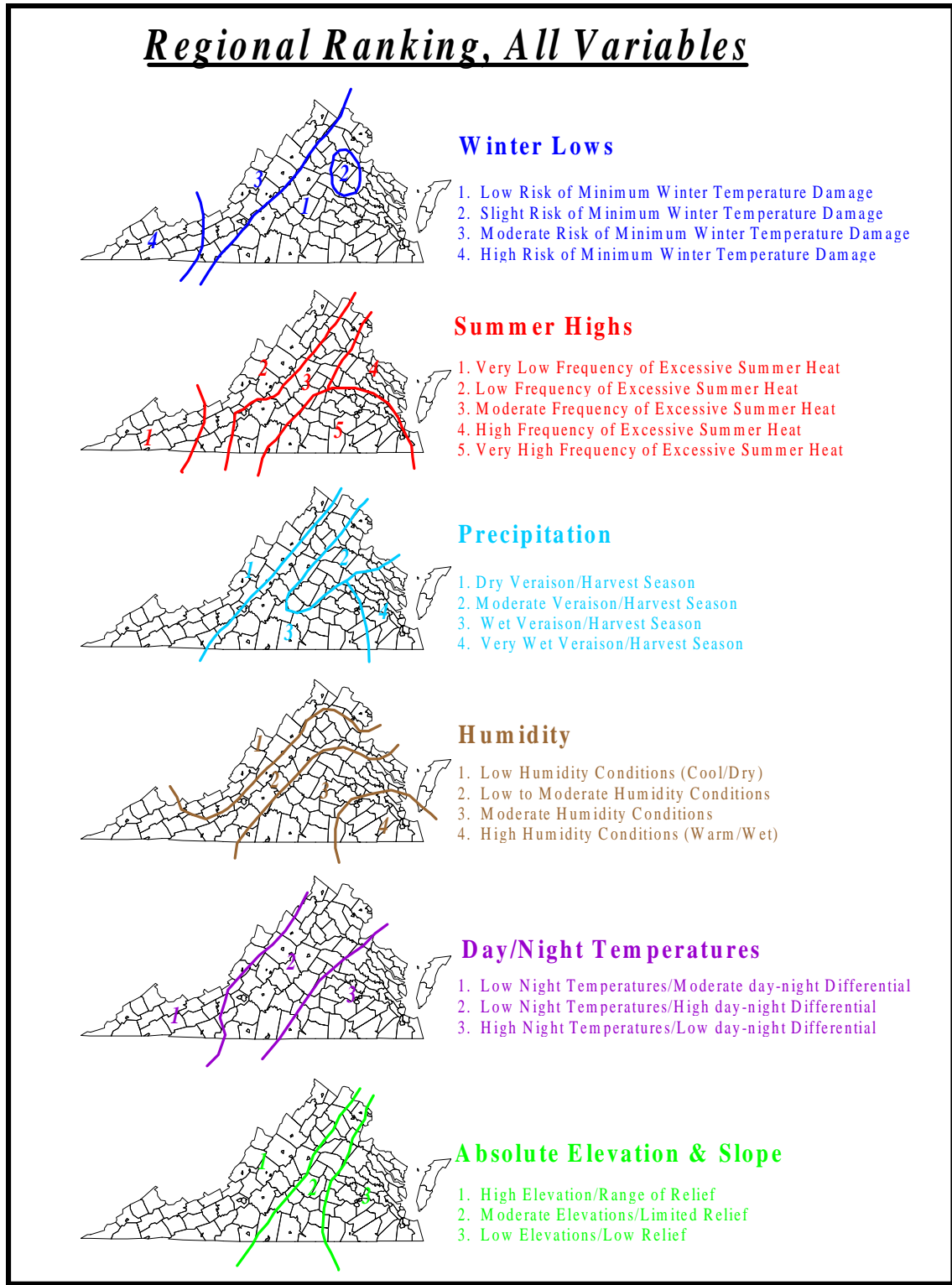


FIGURE 2.19
Regional Ranking, all variables

Figure 2.19 is a regional summary of variables discussed in this chapter. Numeric rank for each category ranges from one, the best situation, to four or five, the least desirable. From this the final regional classification will be derived. A brief review of the diagram is in order. Consider the following:

“One overwhelming conclusion that can be made is that lowered temperatures, wherever or whenever applied, give higher malate levels; this conclusion is keeping with the idea that malate is respired during ripening and that respiration rate is increased by temperature,” (Coombe, 1987).

“The greatest geographic variation in temperature extreme is from west to east across the state where both altitude and oceanic influence come into play,” (Bailey and Tinga, 1968).

These two statements embody the regional selection of viticulture potential. On one hand, it is a well accepted fact that grapes do better in climates which allow a long, cool season for them to mature; thus developing a better balance of sugar and acid, promoting their character, aroma, etc. On the other hand, as one progresses to cooler regions, the chance of damaging low temperatures increases in a linear fashion. In Virginia, this linear conundrum is east to west--as one progresses west, winter temperature risk increases alongside cooler growing season; traveling east, quality enhancing coolness decreases, but so do damaging low temperatures.

Most sites east of the Blue Ridge Mountains possess decreased risk associated with damaging winter temperatures. However, warmer summer temperatures, hotter and more frequent temperature extremes, warmer night temperatures, and higher precipitation levels in the vital months of maturation all increase drastically heading eastward from the mountains. Departing westward from the Blue Ridge, one finds cooler temperatures in all categories considered, and even the driest harvest conditions statewide--but it comes at a high price. Winter lows in this area can be prohibitive, if not impossible, for vine growth. In addition, winter minimums strike a broad range of elevations in the Alleghenies, making it difficult to identify a ‘safe’ zone to potential planters.

Selection and analysis of the variables in Section 2.2 were made in an effort to quantify these relationships. Combining the factor analysis, values of fruit growers I have

interviewed, opinions of state experts, and a thorough literature review, Figure 2.20 proposes the following regional rating system for viticulture potential.

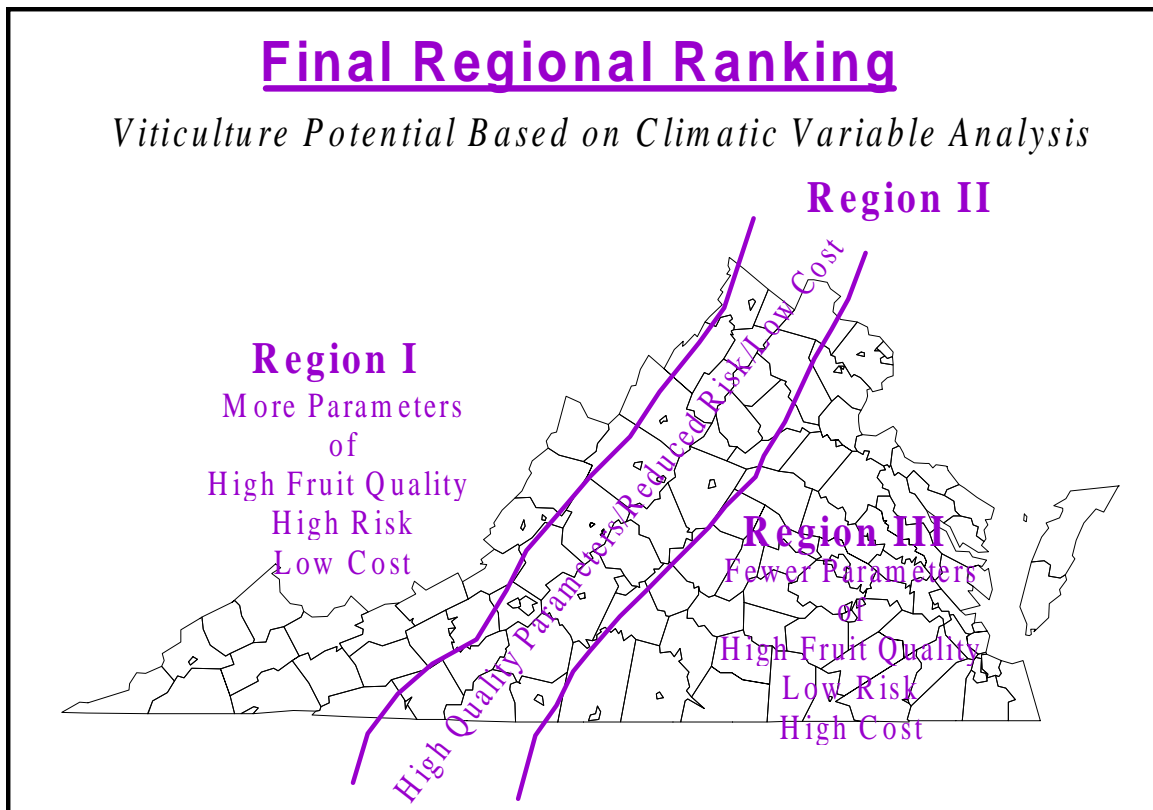


FIGURE 2.20
Final Regional Viticulture Potential

Region I contains the eastern flank of the Alleghenies, the westward ‘half’ of the Ridge and Valley province, and the Appalachian Plateau of the southwest. These areas contain all of the best attributes for cooler growing season temperatures and the precipitation regime most desirable for viticulture (dry autumns). The coolness and dryness promotes high berry quality while reducing costs of fungicides, pesticides, and crop loss due to poor harvest conditions. However, they are also the highest risk areas of the state, and low winter temperatures may be prohibitive to vine establishment and/or survival.

Region II constitutes the Blue Ridge Mountains, Valley of Virginia, and the Inner Piedmont or foothills. Probably the area of highest potential due to its possession of many positive attributes of cooling, associated with elevation increase, combined with its much decreased risk of low winter temperatures. High quality is maintained by lower summer

temperatures, lower night temperatures, and lower humidity; but untimely rains can increase cost expenditures and crop loss. Succinctly put, "...where elevation cools the summer heat, saturation and excessive rain can be the price," (de Blij, 1987, p.119).

Finally, Region III encompasses the Outer Piedmont and Tidewater areas, a warmer than average area due mostly to the maritime influence of the Atlantic and Chesapeake Bay. The area does contain the lowest risk rate of winter damage--if any reasonable risk at all--but unfortunately lacks all other positive attributes of both temperature, humidity, and precipitation. Sites selected in this region will probably have greater expenditures for fungicides, herbicides, and pesticides, and probably have much more crop loss due to unfavorable precipitation and poor berry development.

The final selection of regions with the greatest viticulture potential is difficult due to the great variety and variability of macro- and micro-climates across the state. It must be stressed that the 'homogenous' regions of climate characteristics identified in this analysis are anything but homogeneous as one gets closer to the individual site scale. Data utilized in the analysis are at a very coarse scale, and are not intended to be interpreted as actual figures from sites within these regions. As such, these variables attempt to delineate the best *regions* of the state; there is no dispute that very good *sites* exist outside of the best regions, and that some very poor *sites* exist within the best regions.

The goal of this chapter was to identify the regions containing the greatest probability of good sites, based on the number of positive attributes contained by the region. It will help correlate the physical factors associated with the distribution of apple and other tree fruits into their current landscape in the next chapter. If my hypothesis is correct, the delineation of these regions of greater or lesser viticulture potential based on physical factors will be corroborated by the historical geography of the tree fruit industry traced in Chapter Three.

Chapter 3 Analysis of Past and Present Fruit Landscapes

A central theme in this research is identifying areas of high viticulture potential based upon characteristics of lands occupied by other fruit crops, specifically apple. Thus, I am assuming that the current fruit landscape is a product of evolutionary forces; an evolution which has concentrated fruit crops into areas containing physical characteristics most conducive to their success. This is not an uncorroborated assumption. Tracing this evolution will reinforce the selection of physical factors focused on in the previous chapter's state analysis, and will serve to support regional and local site selection based on experiences of the past.

Fruits grown in Virginia--both presently and historically--can be categorized as either tree fruits(e.g. apple) or small fruits(e.g. grape). The biology and physiology of vine growth make grapes more similar to tree fruit than to other more classic small fruits such as strawberry and blueberry. For purposes of this review, the historical development presented in Section 3.1 centers on apple, but includes peach and pear as well. Grape industry progress will be considered independently in Section 3.2. A outline of current conditions and comparison of the industries will complete the chapter in Section 3.3.

3.1 The Historical Landscape of The Apple

The history of the Virginia apple industry, and other fruit industries in the state, begins in the pre-Civil War era of Virginia history.

“The year 1854 marked an outstanding development in the horticulture history of Virginia. In that year the steamer Roanoke carried the first shipment of vegetables and strawberries from Norfolk to New York. This marked the beginning of commercial fruit growing in Virginia,”
(Oberle, 1976).

Prior to the Civil War, the only fruit grown at a commercial scale was the strawberry which was confined to the Tidewater area of the state. Plantation type (cotton and tobacco) and subsistence farming defined the Virginia agricultural landscape up to this

period. Both probably included small orchards as part of their operations but not at a scale or consistency to include in this analysis.

Shortly after the Civil War, a boom of extensive fruit plantings began in the same coastal flats which supported the strawberry industry. Thousands of pear, peach, and apple trees were set between 1858 and 1875 in the Tidewater region. Initially, yields were high and profits made from northern markets were phenomenal, spurring even more intensive growth (Oberle, 1976). Unfortunately, fire blight--a bacterial disease promoted by high humidity--attacked and decimated the pear population. Brown rot, a fungal disease also promoted by humidity, was foiling the peach crop. Compounding this situation was a series of late spring frosts which finished off the remaining pear trees, wiped out all the peach trees, and damaged the apple crops. By 1887 the pear and peach industries had completely disappeared, and by the early 1880's the apple industry was dying out, never to return.

Paralleling the Tidewater fruit 'experiment', fruit expansion was occurring elsewhere in the state during the post-war period. In the 1860's, a proliferation of apple tree plantings took place in the Shenandoah Valley around Winchester, and on the eastern flank of the Blue Ridge Mountains in the counties of Amherst, Albemarle, and Rappahannock. This event is attributed to the desire to reinstate profitable industries to the war-ravaged farms of the Virginia landscape. These plantings were also facilitated by the network of railroads built into the Piedmont, Shenandoah Valley, and into the Southwest between 1840-1860--thus creating market accessibility for the growers in these areas.

Unlike the Tidewater experience, growers in the western parts of the state met with great success, and thus began the establishment of the state as one of the top apple producers in the nation. From the 1880's to 1920, massive expansion of apple and peach tree numbers were encouraged by high fruit prices, development of refrigerated boxcars, efficient cold storage practices, and pesticide and herbicide development. These factors served to extend the season of fruit availability and consumption, open distant markets and burgeoning metropolitan areas to export, and produce a better quality/higher valued

product. At this time, Virginia is considered a "...one-fruit state," concentrated primarily in apple. (Oberle,1976)

Another important factor to consider in this period of tremendous expansion is the role of speculators in the apple industry. Induced by the soaring prices of fruit, speculators and businessmen who had little to no agricultural knowledge, developed stock company orchards from investor dollars.

In the words of one horticulturist, "These nefarious schemes were Promoted by cold-eyed promoters from northern cities. Large blocks of land, usually not suitable for fruit growing, were planted to apples and then divided into tracts of five or ten acres. These were sold for \$300 to \$500 an acre to widows, underpaid clerks.... and others who cannot tell a York apple tree from a Kieffer pear." (Oberle, 1976)

Inevitably, many of the trees planted in this period, especially ones planted in unsuitable areas, never met their expected potential and soon were abandoned. This happened as a result of the decline of the apple market in 1921 due to overproduction. The market was further decimated by the economic crisis of 1929 and fluctuating markets as a result of the two World Wars.

Since World War II, the industry has stabilized, leveling off to a 10-12 million bushels per year average production rate (US Agriculture Census, 1880-1990). This period has been marked by a specialization of fruit growers to a single crop. Innovations of agricultural technology and specialization of equipment have forced growers--and all other types of agriculturists--to concentrate their efforts, and dollars, on one specialty. "Diversification is just not as profitable as it used to be," says Richard Marini, Virginia Extension Horticulturist in Tree Fruit (Marini, 1998). In the past, diversification was a way to spread out risks; the loss of one crop was alleviated by success of other crops, or cattle, etc.. The profit margins were high enough to outweigh the risks of sporadic crop loss.

However, in the modern era, "...in the increasingly competitive global market, [growers] can no longer afford to lose a crop, it affects profitability too much."(Marini, 1998) Expensive specialized equipment, intensive knowledge requirements for every

species, and the need for consistent high quality/ high production crops: all are factors which have combined to force specialization of crop, AND to identify areas most suited to that crop production. “Thus, sites most suited to apple production went exclusively to apple. Sites marginal to fruit production have generally gone to whatever land use was most profitable for them.” (Marini, 1998)

Figure 3.1 graphically displays the evolution of the apple industry over the course of the last hundred years. The distribution patterns of apple are representative of all the tree fruits--including peach, pear, plum, nectarine, and cherry (US Agriculture Census, 1880-1990). Notice the shift of the tree fruit industry to the Shenandoah Valley and the Blue Ridge Mountains over time. The analysis of Chapter Two, has addressed the climatic and topographic reasons behind this shift.

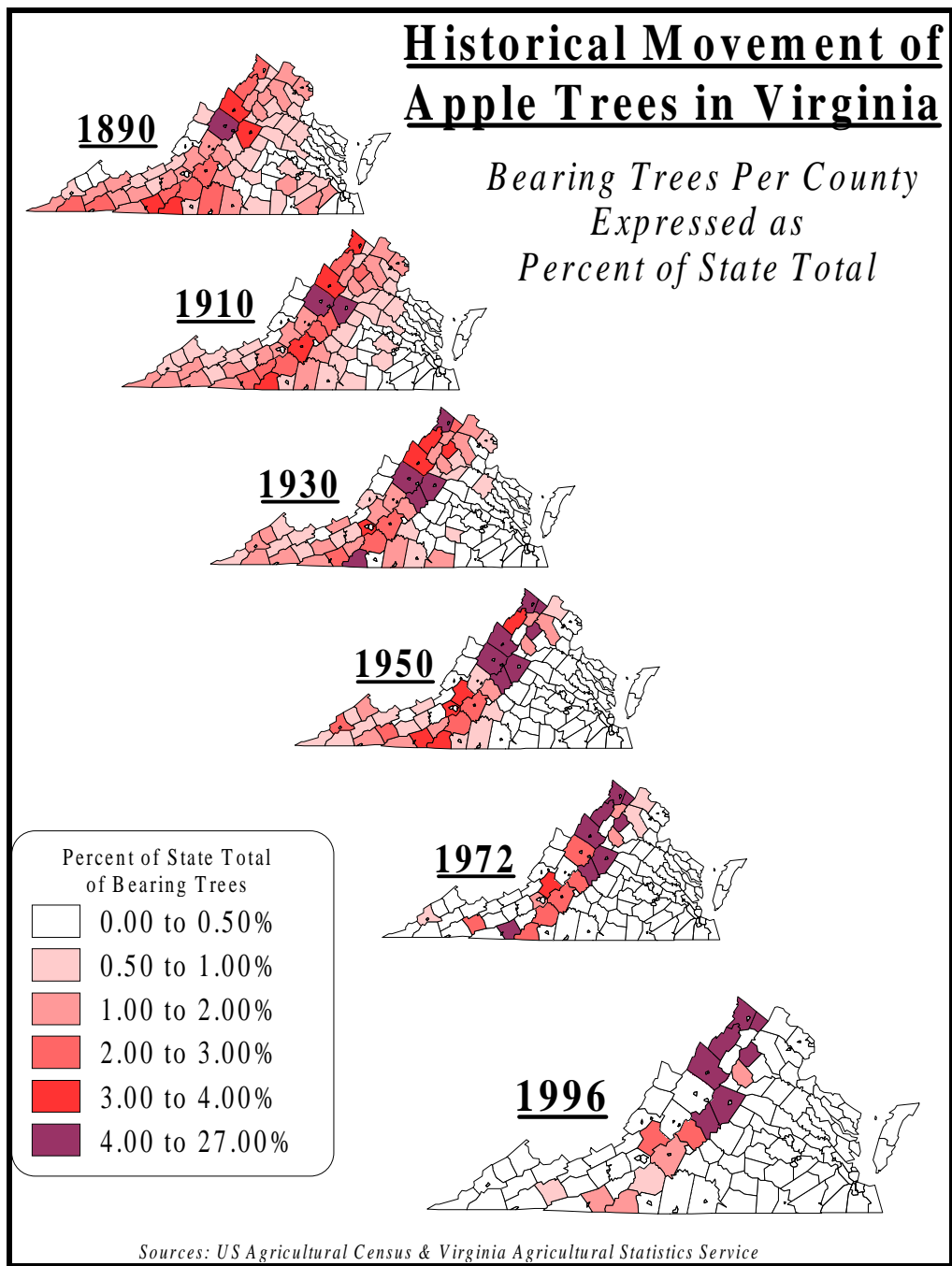


FIGURE 3.1
Evolution of the apple in Virginia

To summarize, this history, depicted in Figure 3.1, serves to greatly strengthen the regional distinctions made in the previous chapter. Ninety-five percent of current apple growth is concentrated on the slopes of the Blue Ridge and upper Shenandoah Valley--areas of high potential and moderate risk as outlined by the state analysis (refer back to

Figure 2.20). This evolution from wide state distribution to concentrated areas was facilitated by physical factors of the environment. Increased frost risk and high humidity drove the fruit industries from the Tidewater and Outer Piedmont regions into the mountains. In the case of the apple, cultural and economic influences have stimulated apple experimentation across the state, but physical factors of the environment have eventually influenced areas most conducive to apple, and therefore financial success.

3.2 The Historical Landscape of The Grape

The grape industry in Virginia has a history even longer than the apple, but not as continuous or flourishing. It is characterized more as a ‘hit and miss’ enterprise than an industry. As suggested in the introduction, viticulture has been an endeavor of Virginians since colonial times, with Jamestown colonists making wine from the native New World grapes--primarily *V. riparia* (Figure 1.1)--as early as 1609 (Unwin, 1996). This largely unpalatable product stimulated efforts to establish the wine grape of choice, *V. vinifera*, by cuttings and rootstocks brought over from Europe (Unwin, 1996).

Numerous acts of the first House of Burgess encouraged, and sometimes enforced, plantings of *vinifera* stock in an attempt to create a wine industry in the colony (Lee & Lee, 1993). The English were intent on developing a source of wine in order to diminish their reliance on France and Germany for the increasingly popular drink of choice. In addition, successful establishment of a wine source would equate to tremendous profits for the grower and/or winemaker, since foreign and local demands were already high and supply was low. These strong incentives propelled continued experimentation for the next 200 years, but resulted in no real commercial success.

Why the complete lack of success? Biological problems, induced by physical factors outlined in the previous chapter (section 2.2), were the main culprit. *Vinifera* brought over from Europe was at once faced with a variety of biological assaults against which it had no defense, and no natural adjustment. Some of the problems faced by Virginians included, “drought, black rot and mildew from the humid summers; root aphids; caterpillars; cold weather destruction of roots and stems in winter; and destruction of buds and leaves by late spring frosts,” (Lee and Lee, 1993). Many of these factors,

especially the environmental, were outlined in the previous chapter as being detrimental to vine success.

Even after the Revolutionary War, as the English demands for colonial viticultural attempts was eliminated, impetus remained to maintain experimentation in viticulture. Such notable names as George Washington, James Madison, and particularly Thomas Jefferson, encouraged and experimented with viticulture in various locations across the Piedmont. However, it was not until the intervention of natural selection that minor successes came in the form of hybridization of different North American species.

The first of these hybrids to receive attention was the Alexander, a variety discovered around 1740 in Pennsylvania and widely planted by 1800. Alexander was even touted by Jefferson to be the catalyst for quality American wine production. Around 1820, a Washington, DC resident identified and cultivated the Catawba. Other important hybrids include Isabella, Niagara, Delaware, and Concord.

Indeed, the 1800's are referred to as the era of hybrids (Lee & Lee, 1993). The period is best characterized by the experimentation of local agriculturists and hobbyists. During this phase, "Hybridizers used trial and error, coupled with intuition based on experience. This process more nearly paralleled that of an Easter egg hunt than scientific research,"(Lee & Lee, 1993). The Concord, Delaware, Niagara, and Norton, once discovered, quickly became widely planted varieties in Virginia and the East as a whole. In fact, the popularity and acclaim of Norton could be considered the impetus of the peak of the Virginia wine industry around 1880--at 232,500 gallons production (US Agricultural Census, 1880)--a peak which would not be surpassed for the next hundred years.

The unfortuitous circumstances of the Civil War seriously hampered viticulture growth, as many vineyards were destroyed or deserted during the course of the war. However, it is important to note that, "...in 1865 fewer than 100 acres of grapes were reported...by 1870 the acreage had increased to 3000," (Oberle, 1979; p.139). This indicates that grape production expanded in the post-war era which had the biggest acreage of vines in the state's history--3000 acres in 1870 is double what exists even today.

Plantings of these varieties occurred mostly in Albemarle County, just north of Charlottesville, in the Rivanna River district. The area was so heavily planted by the German immigrants who settled there that it came to be known as “the Rhine of America” or the “Little Rhine”. Other plantings were located in the Shenandoah Valley outside Front Royal, and scattered throughout the northern Piedmont region. (Oberle, 1979). While most plantings met with initial success, several factors were converging to quell the growth of the industry and ultimately eliminate it altogether.

Among the detracting factors were increasing competition from the highly successful California market, the prevailing economic depression in the post-war era, and the increasing influence of the Prohibition movement. In addition, the Virginia viticulture and wine markets were very disorganized, making it difficult to secure consistent quantities and qualities of grapes/wine year to year--not very appealing to would-be marketers and distributors. Most interesting to this study were the severe grape crop losses due to the appearance of black rot and downy mildew; two fungal diseases which are highly dependent upon existence of high humidity and/or excessive summer rains. These diseases often destroyed entire crops and, although a pesticidal remedy was developed in the mid-1880's, it came too late to salvage the already waning industry (Barden, 1998).

Ultimately, it was the combination of these physical and economic factors which served to drastically weaken the wine grape industry. At the onset of Prohibition--1914 in Virginia, 1919 nationwide--less than 500 acres of vines existed. Although nearly 300 acres survived Prohibition, this acreage constituted mostly table grapes and small scale wine production for home consumption. Even after Prohibition appeal, “..the nucleus of expertise in wine grape growing and wine making within the Virginia farm community had essentially disappeared,” (Lee & Lee, 1993). By the 1960's, less than 20 acres of table grapes were counted for the agricultural census. Viticulture in Virginia was, for all practical purposes, non-existent.

However, this legacy was to radically change in just the last three decades. Growth of the premium wine market in the country, growth and expansion of the Northern Virginia area, or perhaps just out of pure curiosity: whatever the reason, a

rejuvenated interest in viticulture formed in Virginia in the early 1970's. While the Virginia industry had disappeared, eastern producers--mainly in New York, Pennsylvania, and Ohio--had maintained a healthy industry based on 'American' varieties which were now supplemented with 'French' hybrids.

The 'French' denotes a group of hybrids developed in France which possess selected disease/pest resistance and have flavor characteristics/complexity of *vinifera*. These hybrids were created primarily to combat the phylloxera root louse--an eastern US native which decimated *vinifera* in Europe in the nineteenth century. Some examples of these hybrids include Seyval, Vidal Blanc, and Chambourcin. French hybrids had met with much success in the other wine grape regions of the East, and in the late 60's and early 70's plantings began to appear in the northern Virginia region.

As these new vineyardists began planting the French hybrids and meeting with promising results, some began experimenting with *vinifera*. The Vinifera Wine Growers Association (VWGA) was formed in 1973 by a group of hobbyists in an effort to share their knowledge and experiences on growing *vinifera*--which had not even been attempted in several hundred years. Organization had to come from the local level, because at this time the USDA and VPI&SU did not support and even discouraged *vinifera* growing due to its long history of failure.

However, experimentation and participation was soon growing rapidly. By the mid-1970's the first large scale commercial *vinifera* plantings occurred at Barboursville Plantation north of Charlottesville. An Italian entrepreneur, Gianni Zonin, defied the advice of state officials and planted exclusively *vinifera* varieties. The success of Barboursville radically stimulated other growers to embrace *vinifera*, and serious interest began to develop from local agriculturists as well as outside investors.

During the 80's, plantings began popping up in such diverse environments as the eastern shore, the rolling Piedmont, and to the upper elevations of the Blue Ridge Mountains and Shenandoah Valley. While good records of vineyard development are not available, winery establishment is a good indicator of vineyard locations. Many winery operations were formed as either a complement to vineyard operations initially or as a result of very successful vineyards. Figure 3.2 (below) displays the historic development

of wineries but is shown here more as an indicator of distribution of *vinifera* plantings.

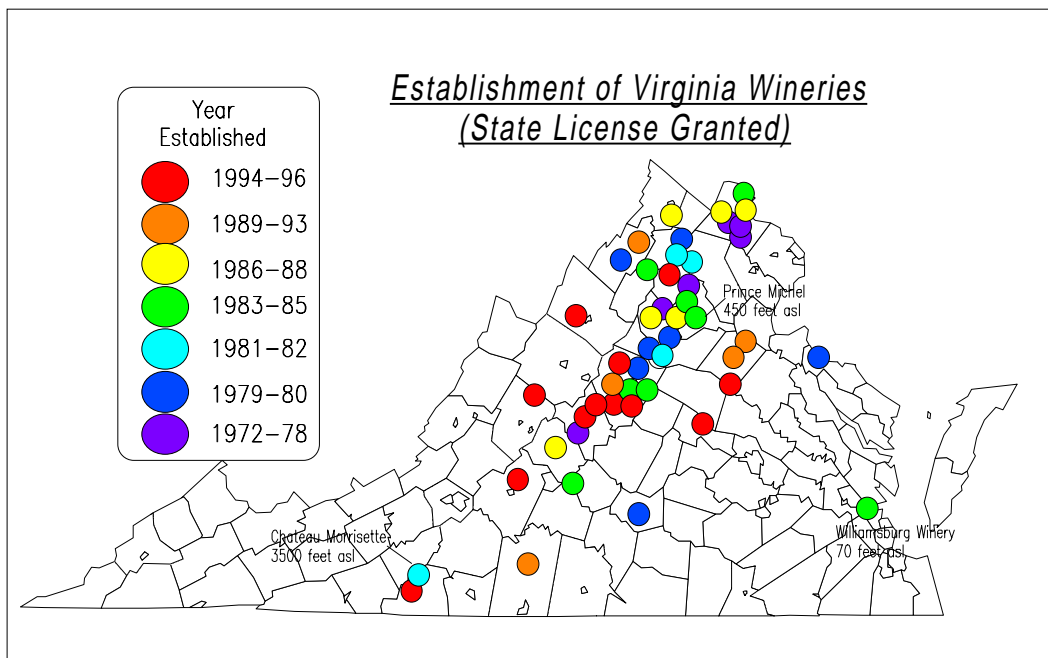


FIGURE 3.2
Winery/Vineyard Establishment

Many trends can be interpreted from this image. One immediately identifies the eastern face of the Blue Ridge Mountains, running SE to NW, as a heavily planted area. However, at this scale, it is hard to discern the true diversity of plantings within these areas--some at high elevations, some low, some in the Piedmont, others at ridge tops. And don't overlook the dozen or so wineries that do not adhere to the trend at all--both older and very recent establishments. Typifying this diversity are the locations of the three biggest wine producers in Virginia in the current era: Prince Michel outside Culpepper, Williamsburg Winery in James City County, and Chateau Morrisette in the mountains of Patrick and Floyd Counties.

As more of these *vinifera* plantings materialized during the 80's, the industry became more organized. In 1980 the state legislature passed the Farm Wineries Law which established rules and regulations for wine sales and production, streamlining both. 1985 saw the establishment of the Virginia Winegrowers Advisory Board (VWAB), an entity created to reinvest wine sales tax funds into research, promotion, technical assistance, and information sharing among the industry. Much of the success of the wine

industry in Virginia can be credited to the creation of this infrastructure and the growth it has stimulated.

In thirty years, the grape industry has gone from a backyard table grape hobby to a large scale, vinifera-based enterprise. Evolution of grape types is summarized in Table 3.1.

TABLE 3.1
Acreage Change Over Time
(adapted from Lee & Lee, 1993)

	<u>1960</u>	<u>1970</u>	<u>1976</u>	<u>1979</u>	<u>1982</u>	<u>1987</u>	<u>1991</u>	<u>1995</u>
American Hybrid	16	30	47	57	75	85	76	70
French Hybrid	0	9	107	161	244	330	275	272
Vinifera	<u>0</u>	<u>0</u>	<u>15</u>	<u>68</u>	<u>437</u>	<u>805</u>	<u>959</u>	<u>1075</u>
TOTAL	16	39	69	286	756	1220	1310	1417

This rapid evolution has basically bypassed the dependence on French hybrids that most other eastern producers had to overcome. While wines produced from hybrids still maintain a healthy following, vinifera constitute a dominant 76% of the total market. As the total acreage reaches 1500, many economists are forecasting a 150% increase in acreage to meet demand. With the exponential growth, supportive infrastructure, and increasing popularity and acclaim for Virginia wines, it is not surprising that the vintners in this state find themselves facing a deficit of product.

But has this growth occurred in areas of the state most conducive for its success? As previously stated, it is my belief that much of the planting was initially located according to proximity of planters to their northern Virginia roots rather than through any systematic site analysis. Compounding these initial ties is the role of economic factors influencing location decision-making. While the vineyard is in reality a separate entity from a winery, the two are inherently located in close proximity, if not the same site altogether. Therefore, the proximity to markets and accessibility of tourism have, by default, become factors affecting vineyard site selection.

In summary, the grape has had a long, albeit scattered history in Virginia. The viticulture landscape we see today is the product of only the last three decades. Prior to the current era, planting could be best described as ‘hit and miss’; today it could be best characterized as experimental in its site variety and geographic scope. Unlike the apple, vineyard siting has much less acreage, less field testing, and less geographic compactness of location.

The most important aspects of the grape history for this study are contained in the failures of the early years. Problems faced in the Tidewater and outer Piedmont regions by the apple industry were encountered by the viticulturists several hundred years earlier. A plague of problems stemming from environmental factors seem to be the main reason for the lack of tree and vine fruit industries in these areas--but not all fruit, as the strawberry and other bush fruits thrive well in these areas. In addition, improvements in pest management materials and knowledge have mitigated some of the pest problems endemic to those regions.

3.3 The Current Landscape of Fruit in Virginia

Covering the history of the fruit industries displayed the major influences and patterns that have shaped the current orchard and vineyard landscape of today. Many trends are shared by the two, but important variation does exist. A comparative map is given to highlight similarities and differences of the apple and grape geographies:

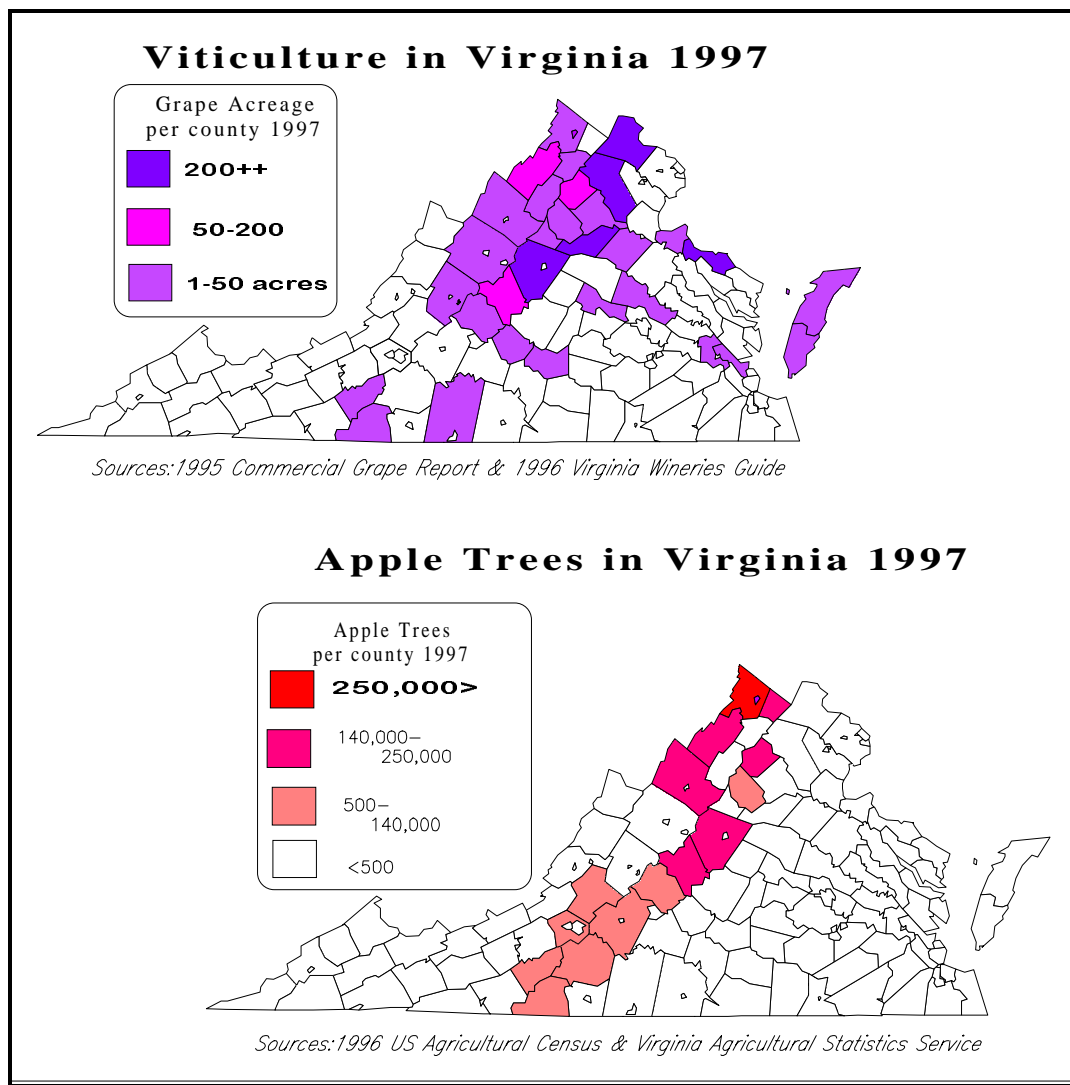


FIGURE 3.3
Apple and Grape Distributions

The most impressive trend displayed by these two figures is the shared attraction to the mountains. Both the apple and grape have considerable stock in the counties containing the SW-NE running Blue Ridge Mountains, and the mountains of the upper Shenandoah Valley--prime areas outlined by my regional analysis. With the exception of Roanoke, Bedford, and Clarke counties, all major apple counties also produce grapes. However, the inverse does not hold true: none of the grape counties east of the counties containing the Blue Ridge possess any significant apple acreage.

Other major departures also exist. Grapes appear to have a much wider distribution of counties, in fact, it is two to one: fifteen major apple producing counties to

thirty grape producers. The apple distribution precisely flanks the Blue Ridge throughout the entire length of the state but the major producing counties are mostly within the Shenandoah Valley. Grape distribution is much more concentrated throughout all of the northern counties, and its major producing counties include Westmoreland to the east in the Northern Neck.

Referring back to Figure 3.1, the diffusion of apple in the early part of this century appears to be very similar--although in much greater scale--to the current distribution of grape. Apples were produced in a greater number of counties and across a wider range of topographies and climates at the turn of the century--just as the grape currently is. As explained in the history of apple in section A, speculated profitability of apples was the main influence which led to those manifold plantings--just as the grape is now a highly valued crop. And fungal/viral problems pushed the apple, peach and pear out of the Tidewater region just as they decimated the original vinifera plantings there two hundred years earlier.

Not all of the current fruit landscape's attributes are tied to physical factors. Indeed, the diminishment or disappearance of the apple in many counties is related to displacement due to higher valued land use. Some examples include strip mining in Wise and Dickenson counties, and residential development in Roanoke, Botetourt, Loudoun, and Fauquier counties. Inversely, the appearance of grapes in many counties is based solely on proximity to wineries and/or proximity to markets which promote distribution and tourism. It is the combination of these physical and economic conditions which have formed the apple and grape distributions we see today.

Many parallels exist between the apple and grape histories and geographies, but many disparities exist in the present. Of major concern is the difference in planting experience that has been alluded to throughout this chapter: apple having continuous production for 150 years, vinifera grapes only thirty. This difference in experience and knowledge is best summarized by the actions of present day planters of both fruit crops.

“Our office deals with two distinct types of potential growers,” says State Viticulturalist Dr. Tony Wolf, “those seeking the best grape sites in the state and those seeking the best grape sites on the land they currently own. Of the two, the latter is the

vast majority.” (Wolf, 1996) Dr. Wolf is the State Viticulturist working from the Alson H. Smith Agricultural Research & Extension Center in Winchester. Bennett Saunders, owner/operator of Saunders Bros., Inc. in Nelson County represents a much different view. “We know where the best orchard sites are around here, its just a matter of gaining possession of the land,” explains Bennett about site selection. (Saunders, 1998)

These comments encapsulate the disparity of the issue. Broadly speaking, the orchardist will plant only where he feels it is environmentally sound and therefore economically viable, basing site decisions upon local experience. However, the potential grape grower is more likely to experiment with viticulture as an alternative land use on presently owned land, regardless of the land’s identified suitability. This is due to two factors: the gap between experience levels and market demand. The unusual market circumstances of grapes merits a brief explanation.

As elaborated in Chapter One, to be labeled as a Virginia wine, the product inside the bottle must contain a minimum of 75% of grapes grown inside the state. This effectively eliminates all outside competition for Virginia grape growers. With demand chronically exceeding supply, the market value is much higher than if Virginia viticulturists were competing with the world supply, which is what the orchardists are doing. Hence, viticulture--presently--has a higher potential value and is worth experimentation to the landowners, even if risk and uncertainty are involved. Unfortunately, orchardists are not afforded this luxury in the highly competitive apple and peach world markets. To revisit Marini, “..they [apple and peach growers] can no longer afford to lose a crop...it affects profitability too much.” (Marini, 1998)

It is my hypothesis that the higher potential prices for grapes parallel the market boom for apples in 1900-1920; and once demand exceeds supply, like the apple, the grape acreage located in areas most conducive to high quality and minimized risk will survive and those in marginally suited lands will fade. The attributes of the land that make it successful for *quality fruit* are physical, topographic, and climatic. Economic factors, such as transportation costs, may facilitate or be prohibitive to a site’s *financial* success. However, they do not affect the product quality and are therefore not addressed by this thesis.

My regional delineation of fruit potential (Figure 2.20) is largely reinforced by the histories described above. For the various environmental reasons alluded to throughout chapters two and three, the Tidewater, Outer Piedmont, and lowlands of the Inner Piedmont have been largely abandoned by commercial fruit growers, excepting perhaps the modern viticulturists who are now experimenting throughout the state. The mountain regions have qualities most conducive to fruit success. Hopefully, the experience of the apple industries--and even earlier grape efforts--will not become a lesson that must be learned *again* by the current wine grape industry.

This completes viticulture analysis at the state scale; I now will turn my attention to building a viticulture potential model which focuses on the local scale. The vehicle for this construction is linking physical factors to the successes and failures of the preceding apple and grape histories on a site to site basis. By quantifying climatic and topographic factors across Virginia conducive to the apple and grape at the local scale, I intend to build a site selection model supported by the fruit landscape evolution of the past, which in turn will be verified by fruit acreage of the present.

It should once again be stressed that what I am attempting to identify are the best sites simultaneously propitious to minimal risks and high quality fruit. Undoubtedly there exist sites all across the state which will support apple, peach or grape growth. Indeed, with enough time and investment, one might grow coconuts successfully in all parts of Virginia--this work is not deterministic in its scope. However, while viticulture may be possible on every square inch of the state, there certainly exist areas which naturally hold more potential than others.

Chapter 4 Assessing Viticulture Potential at the Local Scale

Now I turn my attention to the local scale by developing and testing a viticulture potential model geared toward individual sites. That is, after selecting the general *regions* of the state most conducive to viticulture (Chapter 2), I now want to develop a methodology for selecting the best *sites* within those regions. This requires a shift of scale. It is a natural progression, as sites are assessed and crops actually planted at the local level--thus the need for a more in-depth analysis of viticulture potential at a more practical scale.

This assessment consists of using a Geographic Information System (GIS) approach to separate and analyze individual components of the landscape, create a ranking system for each, and then combine the ranked components into a single layer which will identify areas of greatest/least potential. Output from this analysis is a series of maps which show the individual layers, and the final composite map which can be viewed at a variety of scales: from the county scale to a 30² meter area if desired.

After selecting a study area for focus in Section 4.1, the physical variables considered in the local analysis will be outlined in Section 4.2. Finally, I will build a GIS model which will delineate sites within the study area as having greater or lesser viticulture potential from a physical and climatological basis in Section 4.3. Factor layers, constructed at the county scale, will be produced from a series of physical databases, representing viticulturally desirable features of the landscape. This section will also offer an atlas style layout of the graphic output obtained from this method for a select county within the study area.

4.1 Selecting the Study Area

Outlined in Figure 2.20, the Blue Ridge region ranks as the highest in viticulture potential, in terms of promoting high fruit quality, harboring lower risks, and reduced maintenance costs. From this region, I chose a sub-region for local analysis. This study area was selected based on a variety of criteria including: topographic and climatic homogeneity, adequate amounts of apple acreage, adequate amount of grape acreage, and

proximity to my home base (travel time factor). The counties of Madison, Greene, Albemarle, Nelson, and Amherst formed just such a region. (Figure 4.1)

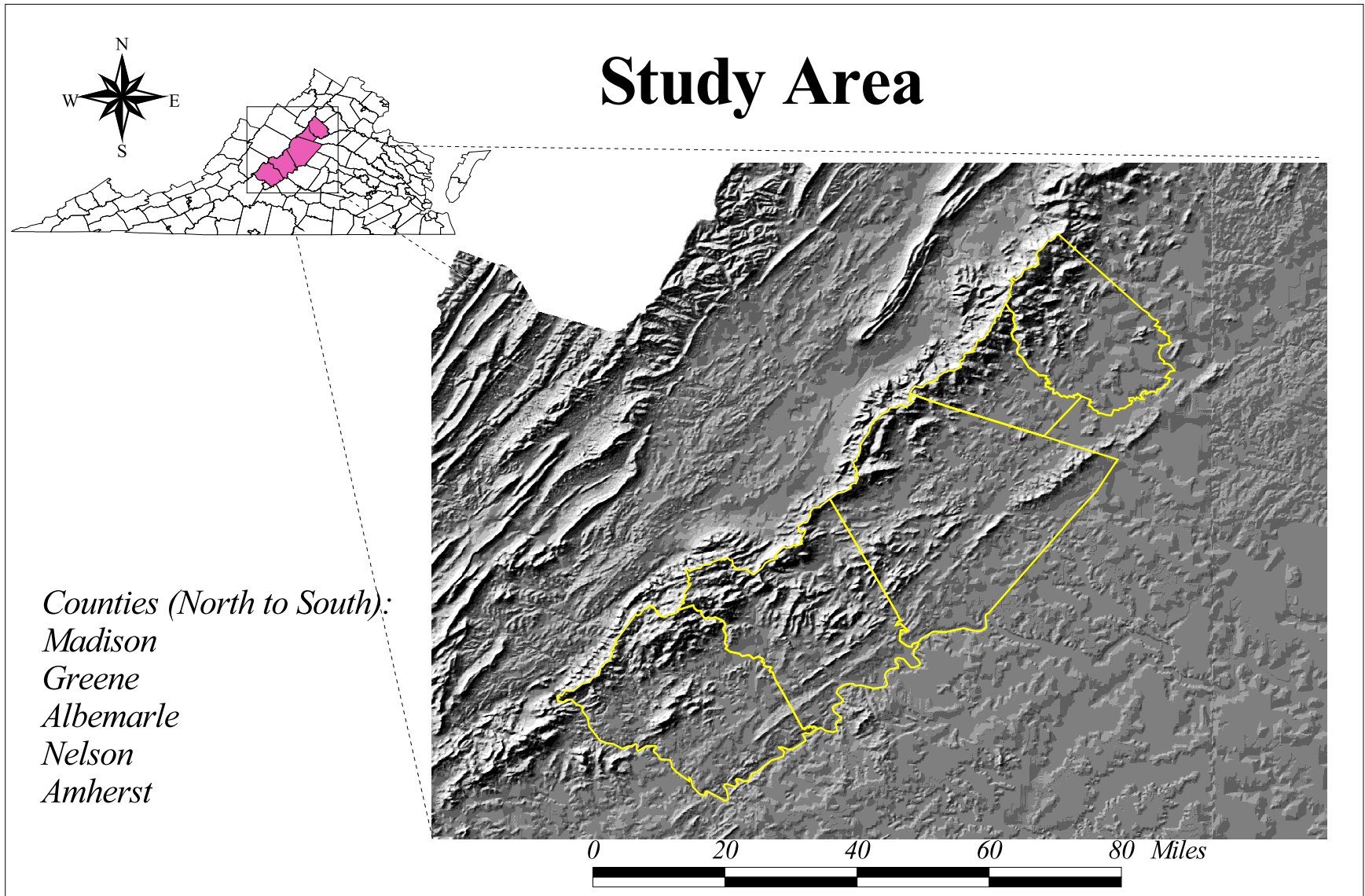


FIGURE 4.1
Location and Relief of Study Area

This study area lies in the central part of the state, in the center of the highest rated viticulture region. These counties all flank the eastern face of the Blue Ridge Mountains, reaching from the ridgeline summits to the lowlands of the Inner Piedmont. Elevation ranges from over 4000 feet at ridge top to under 200 feet on the banks of the James and Rapidan Rivers. Climate can be classified as continental, with temperatures having the possibility of fluctuating rapidly on a day to day basis. However, strong variations of the main climate regime frequently occur over short distances, setting up a series of meso-climates across the hilly terrain.

The region encompasses many well known physical features: Afton Mountain (I-64 gap), many of the western monadnocks such as Carter Mountain (Monticello resides on it) and Southwest Mountains, the city of Charlottesville, the Jefferson National Forest, and Skyline Drive/Blue Ridge Parkway--which forms the counties' northwest borders.

Predominant land cover consists of deciduous and coniferous forests, with scattered patches of shrubland and open pasture. While there are some urbanized areas, the landscape is predominately rural, and agriculture is still a viable and potentially lucrative land use option. In fact, the apple and peach industries have thrived in this part of the state for over a hundred years. This history of successful fruit production was one of the stimuli for selecting the study area. Over 2000 acres of fruit are currently in production in the area, many of these belonging to second- and third-generation agriculturalists.

This area was also chosen for the type of fruit production that dominates most of the eastern flank of the Blue Ridge. For most fruits, particularly apple, there exist two major grower agendas: fresh market fruit and processing fruit. Fresh market producers are more concerned with balanced sugars, fruit coloration, and fruit appearance, as their product must meet high standards to be accepted and bought in the marketplace. Inversely, processing fruit growers are sending their product to the industries which produce applesauce, juices, canned fruits, etc., and subsequently concentrate on bulk, not appearance (Barden, 1998). Figure 4.2 denotes major fruit production in the state and their functional focus.

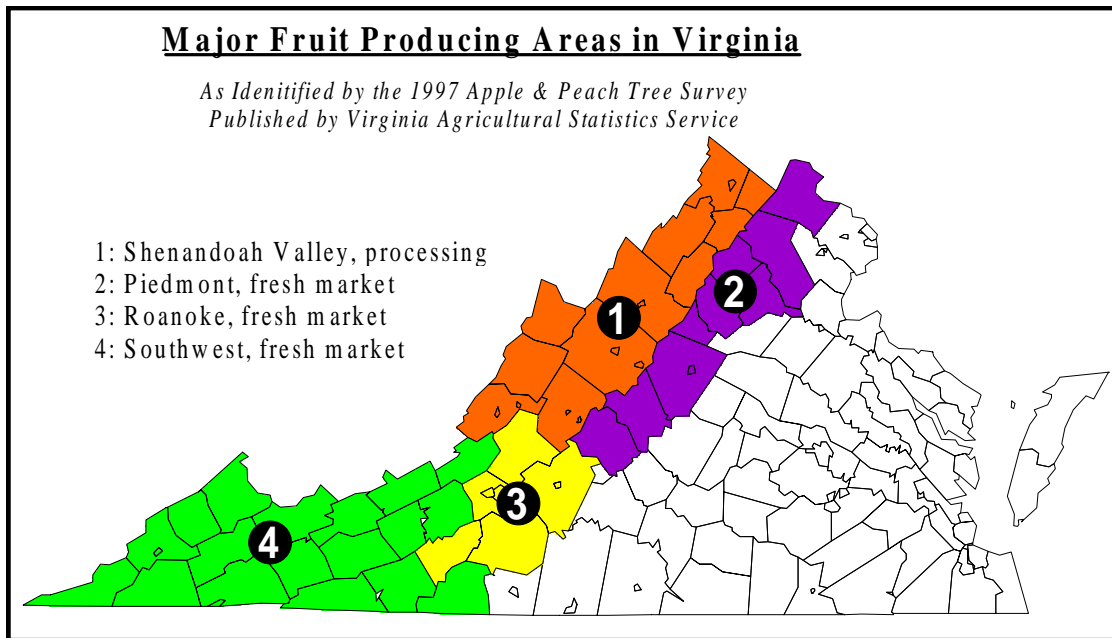


FIGURE 4.2
Fruit regions and grower dominance

In the Blue Ridge, designated as the Piedmont region above, fresh market produce is the norm. The Shenandoah region, the largest fruit producer in the state--particularly Frederick County, specializes in the processing varieties. Growers east and south of the Shenandoah Valley cater to fresh market not entirely by choice, but because transportation cost to the processing plants (all in the Valley) cannot be defrayed by lower profit margin of low-valued processing fruit.

In summary, because the apple and peach growers in the Blue Ridge focus on the fresh market, their site values and production techniques are more in alignment with those of the viticulturists, who also strive for good sugar balance and coloration in their fruit. Additionally, apples and peaches are not all that is grown in the area. A very large chunk of existing grape acreage is located within these five counties, around fifty percent of the state total. This sets up an interesting scenario to compare and contrast the apple versus grape acreage, a topic that will be addressed during the final model validation.

4.2 Variables Affecting Viticulture Potential at the Local Level

Like the state scale analysis, I will now cover some of the variables to be considered in this local assessment. All of these variables do not necessarily represent the best or most important to focus on, but the best that can be quantitatively expressed with existing data.

For instance, while more climatic variables would have been desirable, definitive temperature and precipitation data are greatly lacking in the state; existing data are too coarse to adequately adjust to specific sites.

However, like the state scale analysis, many of the variables considered here are very good indicators of other desirable climate attributes. For example: as alluded to previously, elevation directly affects many aspects of temperature; so by examining and identifying elevation classes, we indirectly are identifying temperature relationships that are important to viticulture potential. Variables for the local scale analysis include: aspect, slope, land cover, soils, and elevation. A brief discussion about absolute versus relative elevation supplements the elevation category.

4.2.1 Aspect

Aspect refers to the direction the slope of the land faces. Categories of aspect are labeled according to the cardinal compass direction which the slope faces. Aspect's main contribution to site selection involves the role of light interception, particularly how much light the plant receives--directly affected by a combination of aspect and slope, as seen in Figure 4.3.

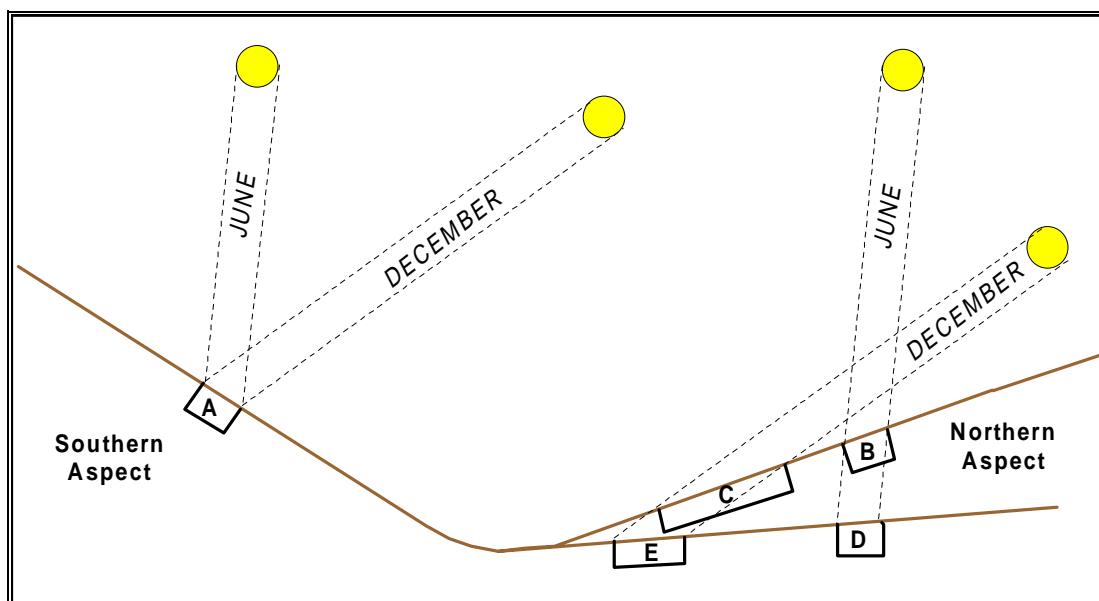


FIGURE 4.3
Role of aspect
(adapted from Cox, 1923)

As derived from this diagram, different aspect and slope combinations radically affect light interception depending upon season of the year (Becker, 1984). In Virginia, the sun is highest in the sky in June (June 21st; the Summer Solstice), so high that light distribution is roughly equal on all aspects, evidenced by boxes A, B, and D. As the slope of the northern aspect increases, so does the surface area over which the same amount of light will cover. This is more striking when comparing the low angle December sunlight path. The southern aspect box (A) still receives the same amount of light, but notice the variation between the higher and lower sloped boxes of the northern aspect (C and E): the surface area which the light covers drastically increases with increasing slope, meaning that the same amount of light is striking a much wider area. This in turn equates to lower temperatures on the north versus south aspects, especially during the winter season (Becker, 1984).

While there exists no vast amount of literature on the subject of superiority of certain aspects over others, there are some valid points to consider. In the mid-Atlantic region, it is generally accepted that the north to north-east to eastern aspects are desirable for a variety of reasons.

First, northern aspects by their very nature are cooler than others as explained above (Becker, 1984). This can be a positive attribute in that summer maximum temperatures are lower, which can slow ripening and increase fruit quality. In spring, the cooler temperatures retard bud break and therefore minimize spring frost damage. In essence, the northern aspect remains cooler longer than the southern, and the plant is 'fooled' into maintaining winter dormancy. However, these traits must be weighed against the risk of damaging lower winter temperatures. Since northern aspects are cooler, critical minimum temperatures are more likely to occur on them, especially with increasing elevations and slopes.

Eastern facing slopes have the advantage of the first sun exposure, facilitating rapid dew and precipitation drying, which discourages fungal disease (Gladstones, 1992). Northern aspects may be susceptible to more fungal and mildew threat, as they lack this drying effect (Gladstones, 1992). Eastern slopes also benefit from delayed bud break of the northern aspect, but to a lesser degree--probably to their benefit. In addition, eastern

and northern aspects have a slow cool down period before sunset, as they are already shaded prior to the actual set--an important trait in winter, as described below.

South and west aspects tend to be less desirable; due mainly to higher summer temperatures, increased frost damage related to premature bud-break, and bark\trunk injury related to rapid heating and cooling in association with the rising and setting of the sun in the winter (Marini, 1988). In the cold season, the more direct light rays received on southern slopes warm the trunks of vines and trees to a higher temperature than other aspects. This in itself is not bad. However, these aspects receive the sun's rays until sunset; setting up a very rapid cooling situation which can become destructive, or deadly, as the accelerated cooling causes the heated wood to split (Childers, 1976).

In summary, eastern aspects probably contain the most positive elements: rapid morning drying, cooler summer temperatures, gradual winter cooling, and some spring bud delay. Northern are probably the second choice, following the practice of many orchardists, but contain increased risk in winter and possibly increased risks associated with dampness. Southern and western aspects are problematic in our area due to winter trunk splitting--a problem on fruit trees, but not grape vines. That situation can be combated, as can be witnessed in many orchards, by painting the trunks with white latex paint; thus reflecting light and maintaining a lower wood temperature.

4.2.2 Slope

Slope is another factor for which there is not much empirical evidence to denote better or worse categories; common sense prevails over of the decisions made concerning its desirability. To begin, slope refers to the degree, or percent, of inclination of the land at a particular site. Thus, reference to a forty percent slope means that for every ten feet of horizontal movement, there is four feet of vertical movement; or a hundred feet to forty feet (Figure 4.4).

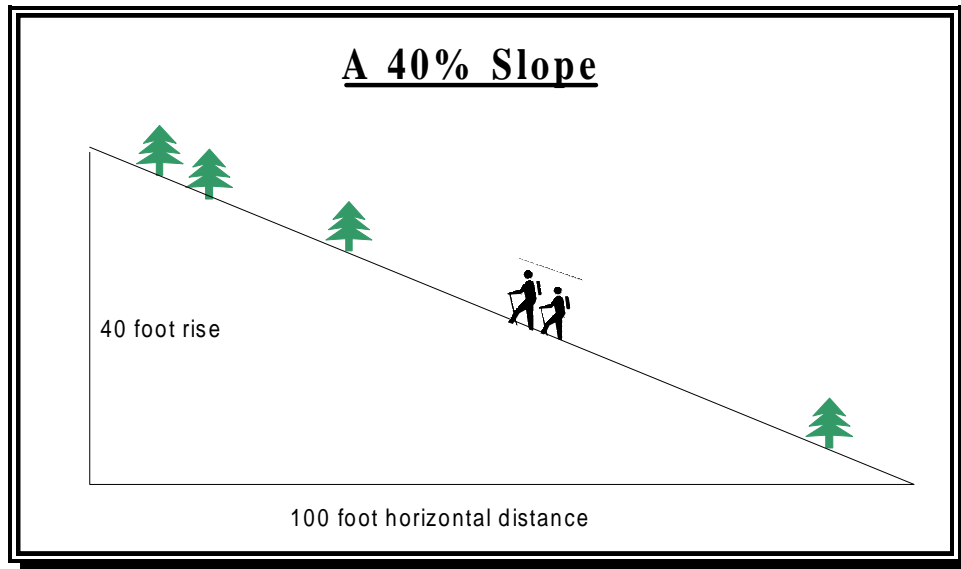


FIGURE 4.4
Slope

“The greater air movement found on slopes reduces frost risk and limits the occurrence of pests and disease,” (Jackson and Shuster, 1987). Frost prevention is indeed facilitated by cold air movement, as will be described in the elevation section, and may be the most important argument in support of at least a moderate slope over flat land. In addition, increased air flow can contribute significantly to drying time after rains, greatly decreasing fungal and mildew opportunities, and facilitate development of cooler temperatures during hot, humid weather (Gladstones, 1992).

Moderate slopes also encourage water drainage from soils, of particular significance to fruits like the peach and cherry, which have low tolerance to ‘wet feet’ (Childers, 1976). This stems from a high susceptibility to root rots and mildew when roots are allowed to remain damp or waterlogged for excessive periods of time. This applies equally to grapes, as a waterlogged soil will reduce root growth, ultimately affecting the health of the vine (Gladstones, 1992).

Inversely, excessive slopes can become disastrous from a management perspective. Slopes much over fifteen percent become very dangerous to operation of farming equipment, such as tractors or mechanical harvesters. Land on steep slopes, once cleared for fruit planting, is also highly at risk for massive soil erosion, especially during

precipitation events. “Soil erosion is responsible for an average of two to eight tons of lost soil per acre each year in Virginia,” (Wolf, 1989).

4.2.3 Land Cover

Although land cover is not a direct indicator of a good site from a purely viticultural sense, it can be studied to eliminate non-productive areas (wetlands, lakes, rock outcropping), and to devalue areas that pose a hindrance to fruit development. Certainly another factor of prime importance to the potential agriculturist is the cost of site establishment, that is, how much effort and expense will be incurred clearing or otherwise altering the site to allow planting. There are a couple of different opinions on the subject.

Viticulture is a very capital intensive endeavor, costing somewhere around four to five thousand dollars per acre to establish (Wolf, 1998). Any labor or expense saving options become a high priority to the viticulturist for minimizing input and increasing profit margins. Sites located on herbaceous, or cleared agricultural lands, are more highly valued due to decreased conversion costs. Inversely, the cost of clearing a thick forest stand may be restrictive to a planter, and thus an undesirable trait.

However, many other fruit growers who typically operate on a much greater scale than the viticulturist, would not view forest cover as a detriment but possibly as an asset. “If we think its a good site, clearing costs are rarely a consideration,” says Bennett Saunders, “...you can usually make your money back with the timber sales,” (Saunders, 1997); typical clearing average \$1000 per acre. When forest may become a hindrance is during frost events, as dense stands of trees can hinder cold air flow downhill. Areas directly above and below a vineyard or orchard site should be cleared of trees to prevent cold air pooling at the treeline. This will be addressed in more detail during consideration of elevation. Thus, even a larger portion of forest area must be cleared to establish fruit planting--this extra portion not being planted, and in turn not returning a profit.

In addition, many peach growers will not put an orchard into anything but virgin ground, usually taken out of forest growth. This is tied to what is referred to as PTSL or Peach Tree Short Life syndrome, a mysterious condition affecting many of the peach trees in the South (Marini, 1998). Trees that seem healthy simply begin to fade and die in their

fifth or sixth year, not really even half the normal tree longevity. Many factors point to soil pathogens which seem to be harbored in soils of previous fruit stands (Marini, 1998). Thus, virgin sites are desired to avoid these pathogens, and the tactic has met with much success, even though the exact cause of PTSL remains unknown.

Land use then is not a particularly important function of a site's climatic or topographic potential, but it does contain several factors that merit attention. Land conversion costs can be particularly important to the potential grape grower. However, the main purpose for using land cover in this analysis is to eliminate completely useless areas--like bodies of water or urbanized areas--from consideration in the model.

4.2.4 Soils

Issues of soil influence on grape quality have been debated and disputed over a variety of forums since the formation of the American wine industry. The loose translation of the French term *terroir* to mean *soil* has been a major source of many of these disagreements. Intricate chemical analysis of the soil in determining grape--and hence wine--quality are not within the bounds of this research. Tree or vine health, productivity, longevity, and quality of fruit are affected by properties of the soil. My focus is more on plant health and productivity, rather than relationships with fruit quality.

Most fruit types and their sub-varieties will tolerate and adapt to a variety of soils. In addition, temperate fruits have a wide range of pest- and disease-resistant rootstocks available to them, further increasing their soil adaptability. However, there are certain minimum qualifications the soil must meet to be considered viable, and there are soils that are superior to others for vineyard establishment. The major soil characteristics fall into two broad categories: physical and chemical.

Chief among the physical soil characteristics are water drainage and soil depth (Gladstones, 1992). These relate mainly to adequate root development and health. Attributes of pH and nutrient holdings of the soil are chemical in nature, and are not considered as a vital component since they can be adjusted by man (liming and fertilizing), however, over-fertility, or a very nutrient-rich soil, is of some consequence.

The single most important soil trait to consider is internal drainage. Well-drained soils are more desirable than poorly drained ones due to a number of factors. Waterlogged

soils due to poor drainage increase root rots, fungus, and pathogen probabilities (Childers, 1976; Barden, 1998; Marini, 1998). In addition, vines or trees allowed to grow in water saturated soils develop very shallow root systems--as there is no oxygen to support deeper root growth, and all its water requirements are met near the surface. This type of growth quickly becomes problematic during even moderate droughts, as the shallower rooting system is immediately water starved. In tree fruits, the shallower rooting system also decreases root strength, making the plants unable to support themselves in strong winds and wet weather.

Soil depth is also a key contributor to internal drainage capacity and rooting potential. A standard desirable range of soil depth is three to four feet for fruit trees; maybe slightly less for grapes (Barden, 1998; Wolf, 1989). Soil depth in this circumstance refers to the amount of permeable soil before hitting bedrock or a hardpan (a layer of soil particles so compacted that it does not allow for free movement of water). Rooting systems in shallow soils, or those with a hardpan, exhibit the same weaknesses of the shallow root system that results from water logged soil; both because the roots are physically restrained from going deeper and because shallow soils typically contribute to poor drainage/high water table problems.

“The deeper the soil, the greater the water holding capacity,” (Marini, 1988), and in turn, the deeper the root system is allowed and encouraged to penetrate. This is enhanced, or hindered, depending on the soil aeration. Aeration describes the amount of air and water in the porous space between soil particles: “...under optimal rooting conditions, the space between soil particles should be occupied by 50% air and 50% water,” (Childers, 1976). Poor aeration, even in deep soils, can cause the same array of problems typified by poor internal drainage and can drastically reduce the growth rate of the entire plant.

Finally, desirable soils are those with moderate fertility. Although it seems contradictory to suggest that very rich soils are not good for a plant, this is the case for fruit growth. However, over-fertility isn't necessarily bad for the plant but for the fruit of the tree or vine. Soils with excessive nutrients encourage the tree or vine to produce much more vegetative growth--be it leaves, stems, or woody parts--than a more moderate

soil. This explosive growth becomes problematic for fruit development, especially for ripening, as the fruit becomes blocked from the sunlight by the excessive vegetation. This type of growth also becomes more costly during pruning and fruit thinning, making both more time and expense consuming.

In summary, a moderate to well drained soil is the most desirable characteristic for fruit production. Medium- to fine-grained textures, good aeration, with three to four feet of permeable soil depth, complement the internal drainage functions and allow for the best rooting development. Moderate to low vigor soils also give the orchardist or viticulturist more control over the growth process, and enhance fruit quality.

4.2.5 Elevation

Elevation of a site inherently affects a multitude of climatic variables, many of which have already been discussed in the state scale analysis of Chapter Two. Minimum winter temperatures, maximum summer temperatures, growing season length, humidity, and day versus night temperatures; all factors prominently affected by absolute elevation, or height above sea level. Perhaps of greatest importance to the fruit industry is the role elevation plays in frost avoidance. The critical period of bloom and fruit set in early spring is regularly threatened by frost which can effectively decrease or eliminate a crop, depending upon severity. Potential loss of a crop makes the elevation variable the single most critical value in site consideration.

However, absolute elevation by itself does not cover the topic entirely. Topography, or relief, of an area plays a large part in the movement of cold air and temperature distribution. Blocking, steering and pooling effects of topography serve to modify and control temperatures within a region. Relative elevation of an area--describing land as higher or lower than its surroundings, regardless of height above sea level--affects temperature distribution even more as one gets increasingly closer to the individual site scale. Differentiation of absolute versus relative elevations warrants a brief discussion after the role of cold air movement is considered.

4.2.5-1 Radiational Frosts and Inversion Layers

The single most detrimental factor to a potential fruit site is damage evolved from frequent frost. According to Geiger: “It is incomprehensible that even today the most fundamental laws of microclimatology are disregarded time and again, when new orchards are laid out at great cost in notable frost hollow,” (Geiger, 1966). Geiger, amazed at poor orchard siting over three decades ago, would continue to be disappointed today. Frost probably incurs more damage to fruit crops than any other two factors combined.

As briefly covered in the minimum winter temperatures section, the major types of cold events are advective (large cold frontal systems) and radiational (mostly spring and fall frosts). Radiation freezes occur during clear, calm nights as the ground dissipates its heat, and begins to naturally cool the air above it. Higher elevations, due to the atmospheric lapse rate, naturally start cooler and cool faster than lower ones--establishing the colder air reservoir up high. If the ground is sloped, the cooled air will flow in a viscous manner downhill, settling in the lowest area, driven by gravity. This cold air movement is referred to as katabatic wind (Geiger, 1966). (See Figure 4.5)

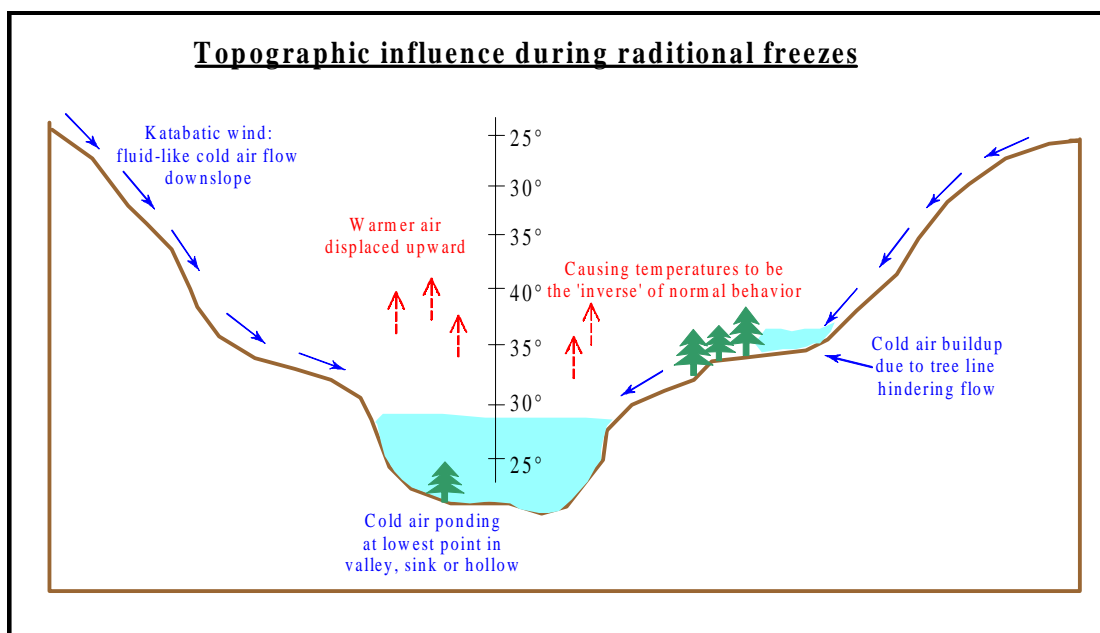


FIGURE 4.5
Cold air movement of radiational freeze

As the katabatic wind settles in the lowlands, the warmer air in these vicinities is displaced upward, forming what is conventionally known as a thermal belt--a zone on

hillsides which benefits from the increased temperatures caused by this cycle. As seen in Figure 4.5, the zone is defined on its topside as increasing elevation eventually conforms to the air lapse rate, and air temperature again decreases with increasing elevation. The entire system is called a temperature inversion, as the temperature/elevation relationship becomes the inverse of normal behavior.

The model above is just the basic nature of the flow. Many more factors affect the distribution and intensity of these frost temperatures including slope, aspect, season, and most importantly topography, which is covered in the next section. Even in its simplest form, the importance of the phenomenon cannot be underrated to fruit growers.

This inversion layer is very important to fruit growers. “On long slopes on quiet nights there will often be temperatures from 1° to 14° higher than at the top or bottom....If his orchard is located on a slope well above the frosty bottoms, yet at an altitude not sufficiently high to reach the realm of high top freezes, his fruit may pass safely through the frosty periods, while elsewhere the crop may be a total failure,” (Hutt, 1910). This observation was made by a former North Carolina state horticulturist almost ninety years ago. In fact, the mountains of North Carolina have been a source of much of the earliest studies done on inversions. Silas McDowell, the ‘discoverer’ of thermal belts in the 1840’s, was a naturalist and agriculturist living on the eastern flank of the Blue Ridge when he first noted and wrote about the existence of such ‘vernal zones,’ as he termed them (Dunbar, 1966).

In the early part of this century, a formal study was undertaken by the USDA Weather Bureau in these mountains to record and explain the phenomenon. Henry J. Cox set up sixteen different recording stations, with five to six data loggers per station, on various elevations of a slope over a four-year period. His findings corroborate the inversion scenario:

So far as the minima are concerned, it is obvious that great care should be taken in the selection of a site for an orchard. Valley floors must in nearly all cases be avoided. There the temperature on critical nights of inversion often falls 15° to 20°, and sometimes even 25° or 30°, lower than higher up on the slope. (Cox, 1923)

A temperature difference of even half of what Cox reported is enough for fruit growers everywhere to consider moving to higher ground, but simply avoiding valley bottoms is not quite descriptive enough to realistically designate areas of higher or lower potential. Before I get into absolute ranges of elevation most conducive to frost avoidance, it seems pertinent to discuss more of the relationship between relative and absolute elevation as it relates to topography when dealing with this issue of inversions.

4.2.5-2 Absolute versus Relative Elevations

Absolute elevation is the vertical distance above sea level; relative elevation is the height of an area in comparison to its immediate surroundings--with no numeric values prescribed. This becomes a very important concept in cold air drainage, as a site's absolute elevation is not really important as long as the relative elevation puts it above the cold air basin. That is, the height above sea level is completely irrelevant at the meso-scale, as long as the height is greater than the surrounding relief.

This concept is easier comprehended in graphic form, Figure 4.6.

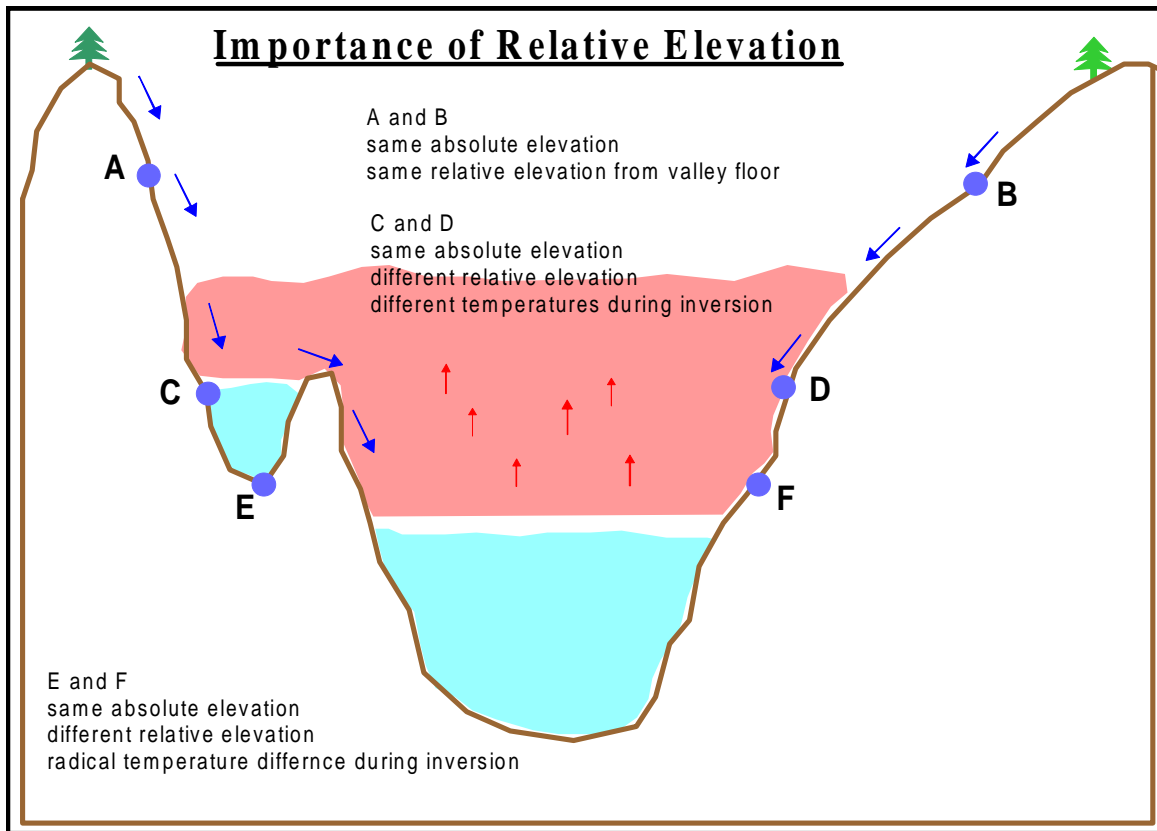


FIGURE 4.6
Relative versus absolute elevation

Viewing Figure 4.6, one can visualize the importance of having good relative elevation within an area of good absolute elevation. As points on opposite sides of the valley have equal absolute elevation, it is evident that the elevation relative to surrounding topography becomes a decisive factor in which sites receive frost and which do not. Thus, absolute elevation range is important when considering the *entire* drainage system in determining the absolute range of the inversion; but, as one focuses closer to the site scale, the relative elevation plays the more crucial role.

The cold air pooling displayed by the terrain around point E is not strictly limited to protrusions of relief. While hollows, narrow valley channels and other closed or limiting terrain features, do account for most of the cold air ponds during inversions, they are not the only culprits. As touched upon in the land use section, tree lines can effectively hamper cold air drainage and cause build-ups of lower temperatures behind them. (refer back to Figure 4.5) Any major air flow impedance throughout and down slope of a potential site should be avoided. These are all factors of the *relative* location of the site.

Another influence affecting the distribution of the inversion layer comes from the topography of the drainage system as a whole. Shape of the valley, width of valley floor, and/or proximity of adjacent mountain face all affect how and where the inversion layer shows up on the slope. (see Figure 4.7)

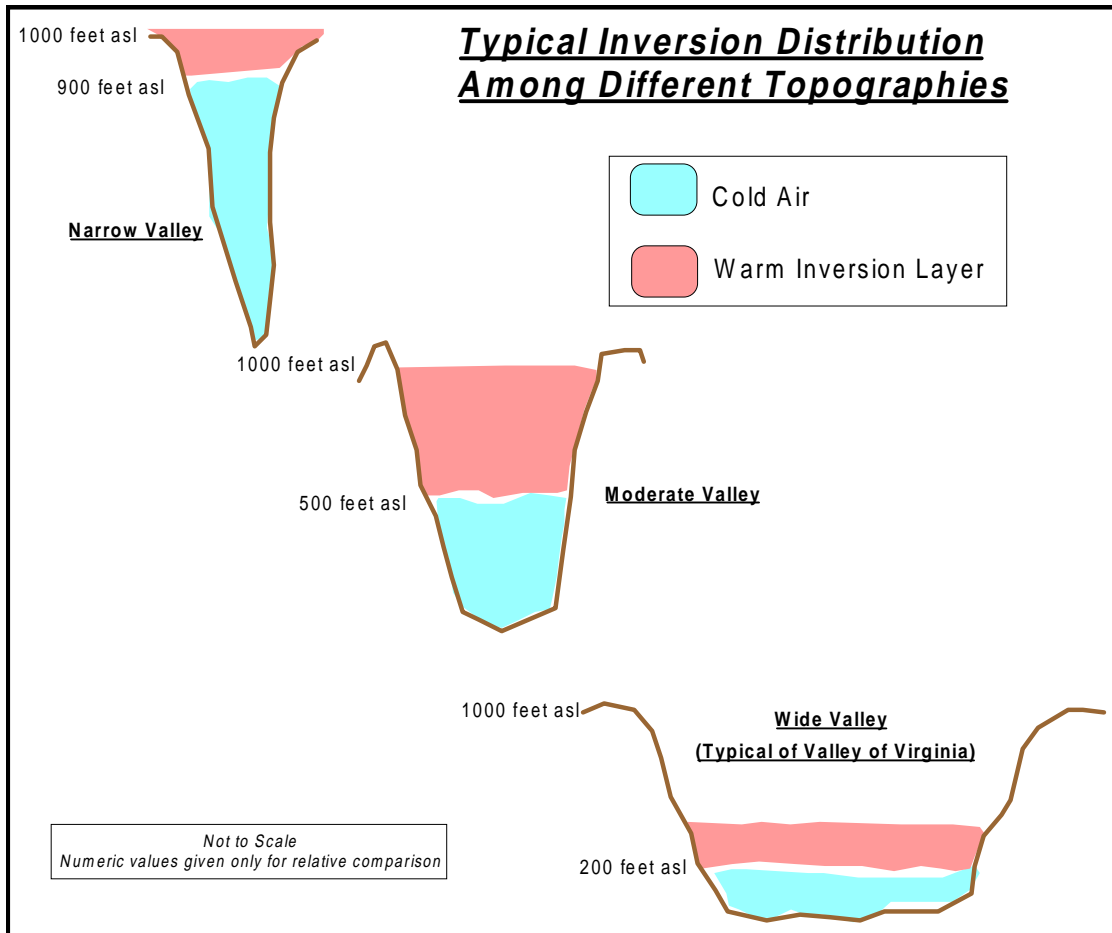


FIGURE 4.7
Role of topography

Illustrated in the figure above, the shape and width of the valley system is manifest in not only the location and depth of the cold air lake, but also the location and depth of the inversion layer on the slope (Geiger, 1966). A good analogy would be to pour equal amounts of water into a long-necked vase and into a large bowl, both half-filled with shredded Styrofoam. Although equal in amount, the water reaches a higher level in the vase than the bowl; and, the Styrofoam is displaced higher and thicker in the vase, flatter and lower up the sides of the bowl. The same principle is at work in inversion sequences except with different densities and temperatures of air.

Different landforms and varying slopes have major impact on the position, depth and flow pattern of the thermal belt created by inversion. The wide variety of scenarios and factors affecting them have been studied by numerous climatologists (Geiger, 1966;

Vorontsov, 1960; Yoshino, 1975), and coverage of the scope is not the intention of this paper. However, one of the most promising landforms for inversion occurrence is epitomized by the Blue Ridge Mountains. Consider this, again from Cox:

“An ideal slope for fruit growing is one of moderate elevation above sea level...fairly steep and culminating in a knob with no surrounding mountains, or if any, at least, situated so far distant as to have no effect upon temperature conditions of the slopes involved...” (Cox, 1922).

In summary, all relative and absolute lowlands are to be avoided by the fruit grower. Hillsides typically display higher temperatures than the bottom or top of the slope. Even with the inversion layer, in the increasing elevation above the layer, air will resume atmospheric lapse rate and cooler temperatures result.

4.2.5-3 Absolute Elevation

Now that the inversion process and the role of topography have been addressed, the real question still remains: What are the elevations, absolute or relative, in which the beneficial inversion occurs? There are several, mostly contiguous, views based on the observations of climatologists on three different continents:

--Depth of the cold air lake at the foot of the slope is approximately 0.20-0.25 of the relative height (relative height being top of the ridge subtract valley floor).

(Vorontsov, 1960)

--Height of the thermal belt center appears 100-400m (325-1300 feet) above the valley bottom, in most circumstances, 200-300m (650-975 feet). (Yoshino, 1975)

--On average [depth] of the thermal belt is approximately 0.25-0.30 the relative relief. (Obrebska-Starkel, 1970) In other words, the width of the warm air component is 0.25 of relative height. This is a relative descriptor, as it only describes the warm air belt, but does not physically locate it on the slope--

“usually on a slope having an elevation of 1000 feet or more above its floor the safest level....is from 300 to 700 feet [above the valley floor].” (Cox, 1923)

In the selected study area, the total relative relief ranges from 200 to 4050 feet asl, giving a 3850 foot difference, but these are the extreme values. Ranges from top to

bottom vary with local topography. Taken as a singular whole system, average ranges fall around 425 to 2225 feet asl--an 1800 foot difference. Using this figure of 1800 feet as the average relative height, the dimensions are easily ascertained from the simple formulas given above:

Depth of cold air lake: $0.20-0.25(1800) = 360-450$ feet

Height of thermal belt center: $(650-980) + 425 = 1075-1405$ feet asl

Depth of thermal belt: $0.25-0.30(1800) = 450-540$ feet

Cox's thermal belt location: $425 + (300-700) = 725-1125$ feet asl

Figure 4.8 shows the continuity of these different approaches.

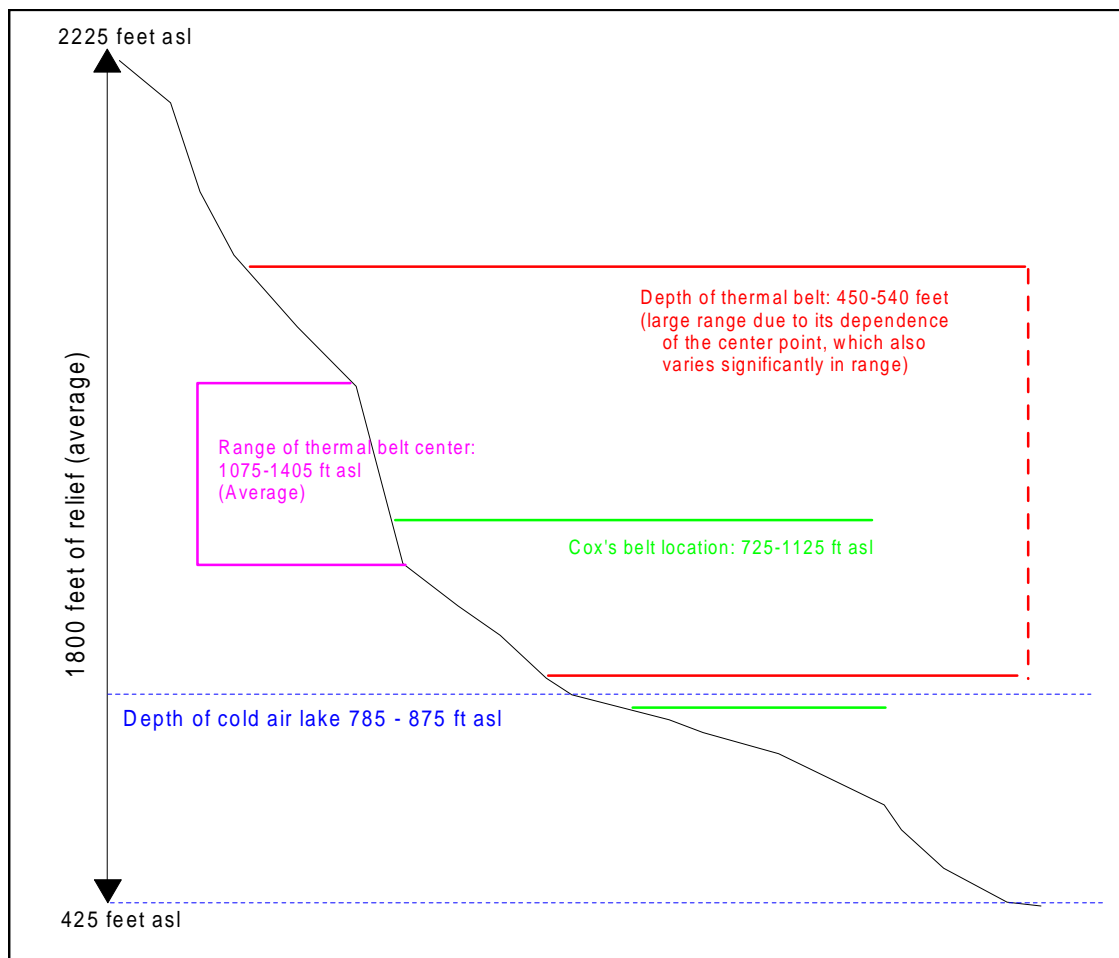


FIGURE 4.8
Inversion calculations

It is important to note that the area designated as center point of the inversion belt equates to the point at which temperatures cease to increase with increasing elevation, and revert back to decreasing with increasing elevation. As such, the temperatures above the center point are still significantly higher than the minimums, and will remain higher until elevation increases enough for the atmospheric lapse rate to resume temperature of non-inverted air masses at higher elevations. This verifies Cox's decision to locate the 'average' thermal belt in the area in which temperature is continuing to rise--the true inversion scenario. Overlapping, or fuzzy boundaries, exist among all of these calculations, and are not meant to represent exact, defining zonation.

While perfect correlation does not exist between the different inversion identifications, enough similarity exists to give merit to a collaboration of all the techniques when assigning values to elevation ranges. Again, reconsider some input from growers in the area:

“Sometimes our lower peach orchards, around 780 feet, get hit with frosts. We are always on the lookout for good sites higher up on the hills,” (Saunders, 1998).

“We will not plant any tree lower than 800 feet elevation; that is our magic number for frost avoidance,” (Chiles, 1997)

From the calculations above and from grower surveys in the area, the typical inversion--or frost avoidance zone--appears to occur roughly between 800 and 1200 feet asl. Several hundred feet of elevation above and below this zone can be considered transition in nature. The higher spectrum would be both larger and 'safer' from a frost standpoint--its extent is much less prone to radical temperature shifts as opposed to the transition zone above the cold air lake.

Lower elevations are certainly more dangerous and, as alluded to by Cox, valley bottoms should in all circumstances be avoided. Reviewing the history of the apple's evolution across the state reinstates this fact: lower elevations are the most frost prone in just about all parts of the state and have greatly affected fruit survival--and hence economic survival.

4.3 Building the GIS Model

Geographic Information Systems (GIS) are becoming more and more popular as spatial and graphic systems for data analysis and land/resource management. GIS, originating in forestry and natural resource management, have been integrated into a wide array of fields in the last twenty years--including city planning, transportation routing systems, earth studies, surveying and even agriculture. The main power of a GIS is its ability to rapidly compare, analyze and store vast amounts of spatial data--helping identify the infinite relationships that exist between those various spatial data.

Agriculture, and particularly viticulture, is just recently reinventing itself with the GIS technologies. GIS is being employed in high performance fertilizer and pesticide applications, pest and disease tracking, soil analysis, irrigation monitoring, yield forecasting and analysis, and, of course, climatic and topologic modeling for site suitability. Many of these applications fall under a heading now known as 'precision agriculture'. In California, several commercial organizations now exist which offer services such as these to the viticulturists, and will even get as technical as to design the vineyard layout.

The premise of incorporating a GIS approach into this site selection process is simple: knowledge of spatial variability is one of the important keys to understanding and managing variables that will ultimately affect the quality and health of the vineyard and its crop. This is especially--if not essentially--relevant to the initial site selection, as all decisions made after are affected by the choice of site. And that initial choice is not readily undone, hence the increased value of thorough site analysis prior to planting.

Studies of the GIS approach in site selection are available worldwide--from its use with coffee cultivation in Argentina, to tea plantations in Kenya, to vineyard establishment in New York State. Models of particular interest in the development of my model include Prediction of Vineyard Site Suitability in New York State, (Magarey, *et al.*, 1996); and Mapping land suitability for coffee with ILWIS, (Zuviria and Valenzuela, 1994). Both studies incorporate climatic and topologic variables, or 'layers', into a classification scheme which produces ranked areas of higher or lower potential for the specific crop of interest. It is exactly this type of format which I choose to employ in this study.

4.3.1 Materials and Methods

The concept behind the site analysis process is very simple. Individual variables considered in the previous section--aspect, slope, land cover, soils, and absolute elevation--each comprise an unique layer in the digital database. Each layer is valued a certain number of points, determined by its relative importance--for example, role of aspect is not as definitive to a site as is slope, so it receives a lower total point value than slope. Within each layer, the total point value is distributed across the range of possibilities--with aspect allotted ten total points, a 'good' eastern aspect earns all ten points while a less desirable southern may receive only two.

Finally, all layers are added together to produce a composite image which, by its construction, ranks sites numerically based on the combined attributes of the individual variables. This is accomplished by each cell (representing a 30² meter area on the earth) in the grid having a unique location attribute, in this case in Universal Transverse Mercator (UTM) projection units. Thus, cells with the same 'address' on different layers are associated to each other across layers, and can be added, subtracted or otherwise compared to each other in a variety of ways.

The individual databases (sources and resolution in parentheses) employed in the study include land-use (Virginia Gap Analysis; 30meter² resolution), slope, aspect, and elevation (USGS 1:24,000 Digital Elevation Model; 30meter²), and soils data (USGS Digital Line Graph (DLG-3)). Roads and hydrography layers were also added to assist the user in referencing the output (TIGER/Line® '95 Census Files). Data manipulations and map creation conducted in ArcView GIS and ARC/INFO© Environmental Systems Research Institute, Inc. (ESRI), 380 New York Street, Redlands, CA 92373.

Numeric ratings given to each layer and among the classes in each layer were determined by literary sources, consultations with growers (apple and grape), and recommendations of state viticulturist and pomologists. The rating system is as follows:

- Aspect layer worth a possible 10 points
- Slope layer worth a possible 15 points
- Land use layer worth a possible 20 points
- Soils layer worth a possible 25 points
- Elevation layer worth a possible 30 points
- All combine on the Composite layer for a total of a possible 100 points.

Individual class ranking within a layer, i.e. East aspect versus a West aspect, are explained below and numeric values attached to them are explained for each layer.

Aspect

Referring to the explanations above, the point scheme for aspect represents the positive attributing of northern and eastern aspects in their cooler and faster drying characteristics. Southern and western aspects are devalued due to excessive temperatures, especially in relation to winter day/night temperatures. Highest point value in this category is ten points, due mostly to the lack of research data to support claims of aspect superiority.

- Flat, No Aspect = 3 points
- Southwestern (202.5°-247.5°) = 0 points
- Southern (157.5°-202.5°) = 1 points
- Western (247.5°-292.5°) = 2 points
- Northwestern (292.5°-337.5°) = 7 points
- Southeastern (112.5°-157.5°) = 7 points
- Northern (0°-22.5°, 337.5°-360°) = 9 points
- Eastern (67.5°-112.5°) = 9 points
- Northeastern (22.5°-67.5°) = 10 points

Slope

The rating system for slope is out of a possible twenty points. Based mostly on the desire to have a moderate slope to facilitate air drainage, but not so much as to incur erosion and difficulty with using equipment. Values are as follows:

- Flat land = 0 points
- 1 to 2% = 10 points
- 3 to 10% = 20 points
- 11 to 15% = 12 points
- >15% = 2 points

Land use

As alluded to before, the land use does not directly affect potential, but can significantly affect costs. This layer is intended primarily to devalue the totally unusable lands--no potential--while giving a somewhat higher valuation to easily converted lands.

- The urban\water category includes built-up areas, transportation corridors, wetlands, water, and rock outcroppings. Urban\water receives 0 points.

--Forest includes both deciduous and coniferous, and mixed types. While not greatly detrimental clearing costs can be high. Forested sites score 15 points.

--Shrub category is defined as a succession stage between open fields and forest in which woody vegetation less than ten feet high dominates the area. Shrub land receives 18 points.

--Herbaceous\Agriculture encompasses cropland, orchards, rangelands, pasture, fallow fields, and even recent clear cuts. Herbaceous\Agriculture receives the full 20 points.

Soils

Over forty different soil series were evaluated for their soil depth, drainage capacity, permeability, nutrient content, and particle size. Values were assigned with highest priority given to deep over shallow soils, well drained over poor, and moderate fertility over good or poor. The rating system for soils is as follows:

Poor--No Potential = 0 points
 Acceptable, but wet = 12 points
 Acceptable, but shallow = 14 points
 Acceptable, but overly fertile = 16 points
 Good, may need irrigation = 18 points
 Good, but overly fertile = 19 points
 Excellent--All Aspects = 20 points

Elevation

Values for the elevation layer are out of a possible 30 points, the highest single point allocation, as frost avoidance may be the most important quality of a potential fruit-growing site. As outlined above, a conglomeration of climatological formulas and grower input was employed to devise rating system for the study area:

Poor range/high risk, 0-600 feet asl = 0 points
 Risky range/lower low transition zone, 600-700 feet asl = 10 points
 Good Range/upper low transition zone, 700-800 feet asl = 20 points
 Most Desired/thermal belt, 800-1200 feet asl = 30 points
 Good range/lower high transition zone, 1200-1500 = 20 points
 Risky range/upper high transition zone, 1500-1700 = 10 points
 Poor range/high risk, >1700 feet asl = 0 points

It is important to note that while qualities associated with aspect, slope and soil can generally be applied universally, the elevation values cannot. Location of the inversion

layer is very site specific and site unique depending upon local topography and temperature regime--themselves unique to every site.

4.3.2 Output

Nelson County is the county exemplified in this layout. A topographic overview of the county is provided in Figures 4.9 through 4.14 to assist in visualization of the landscape at a scale appropriate for distinguishing enough detail to show trends of fruit potential indicated by the rating system.

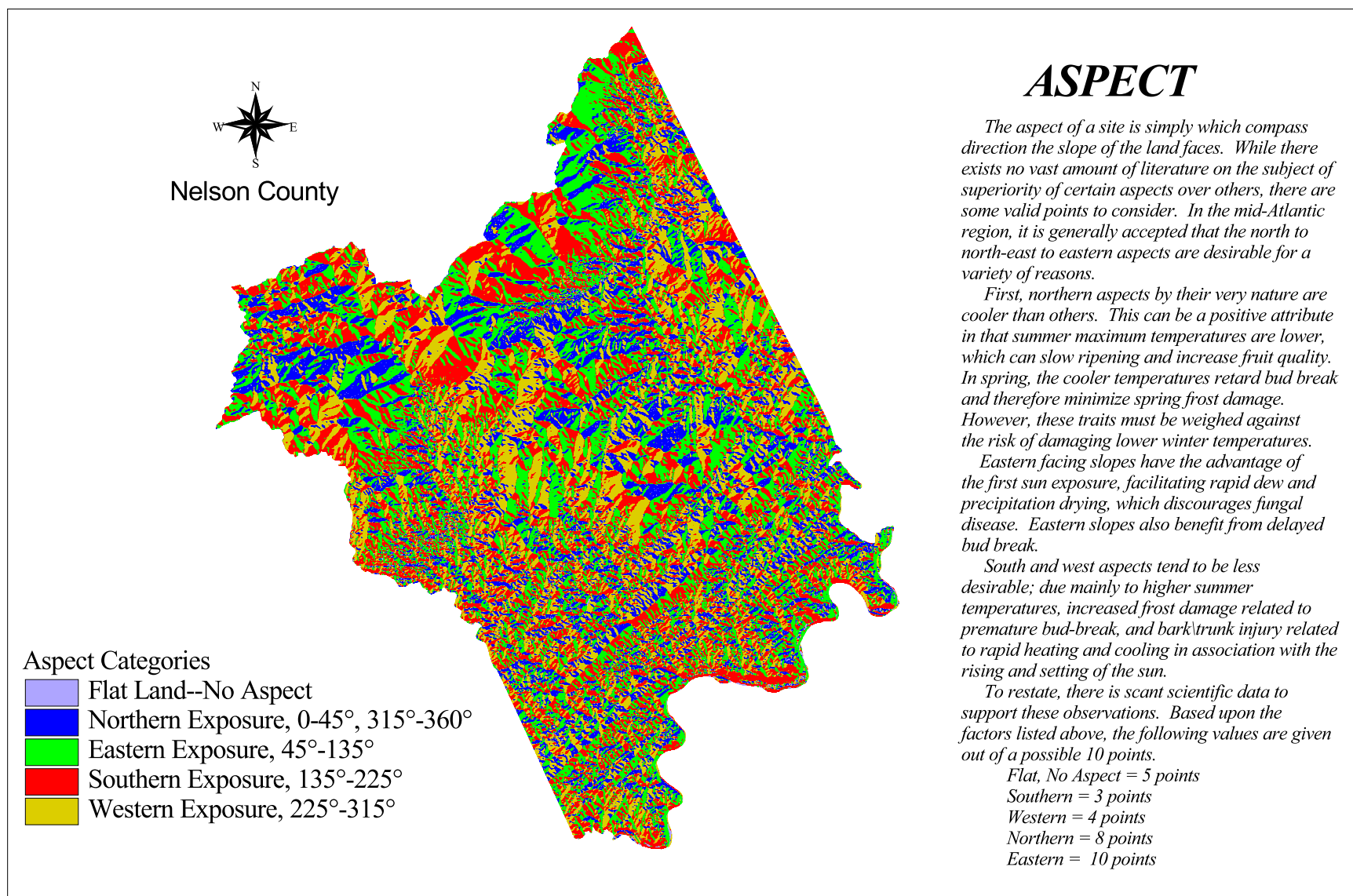


Figure 4.9
Nelson County Aspect Layer

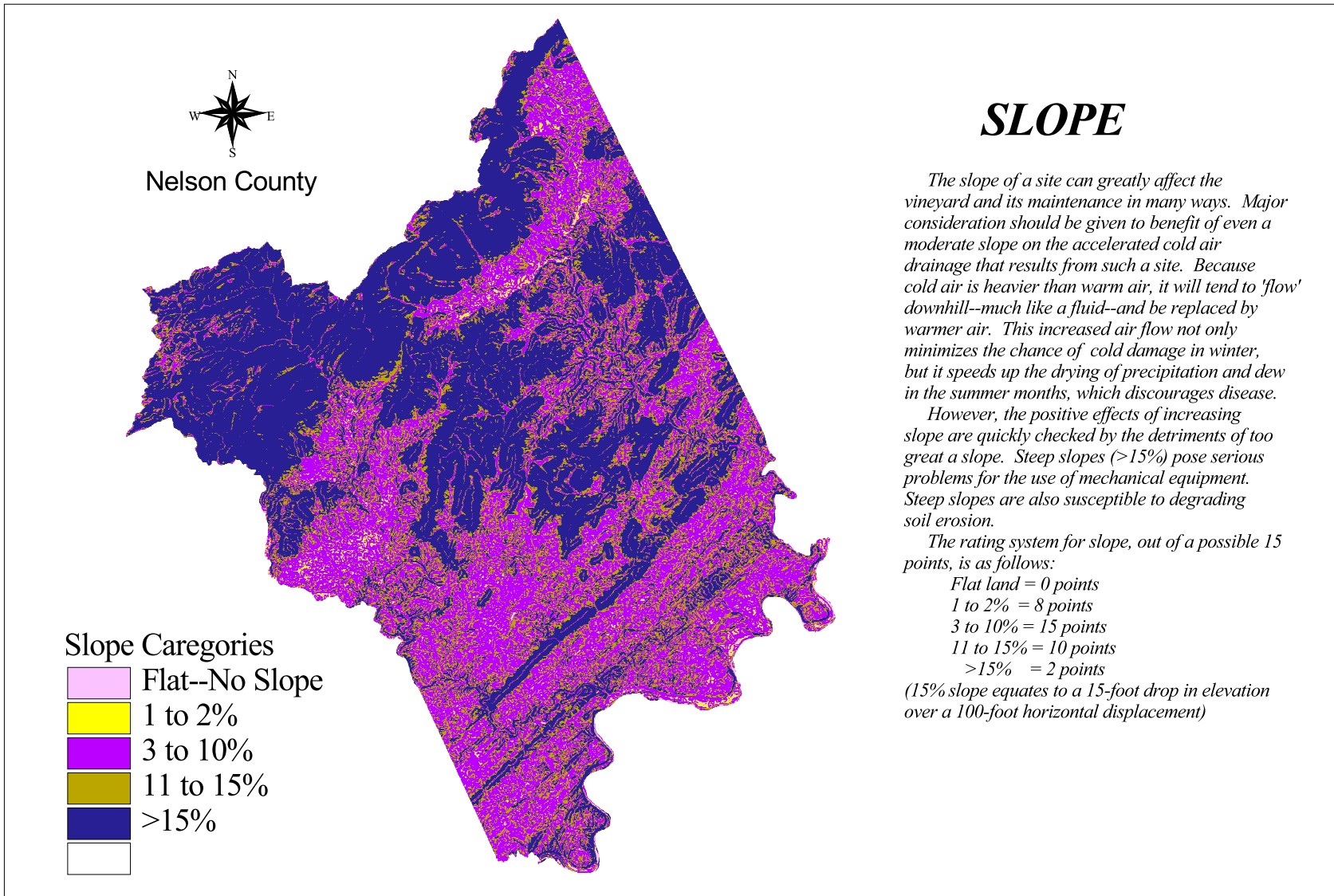


Figure 4.10
Nelson County Slope Layer

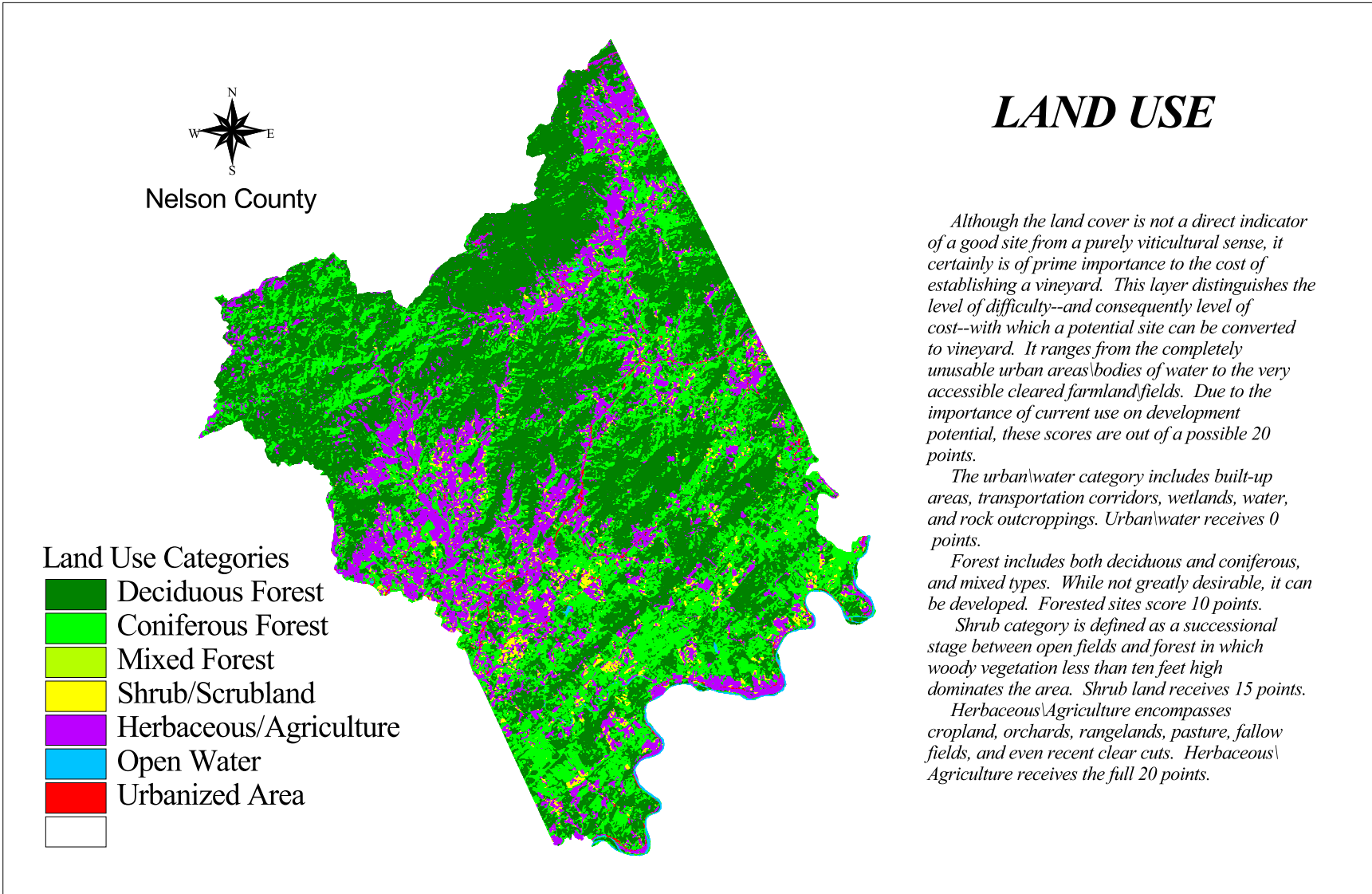


Figure 4.11
Nelson County Land Use Layer

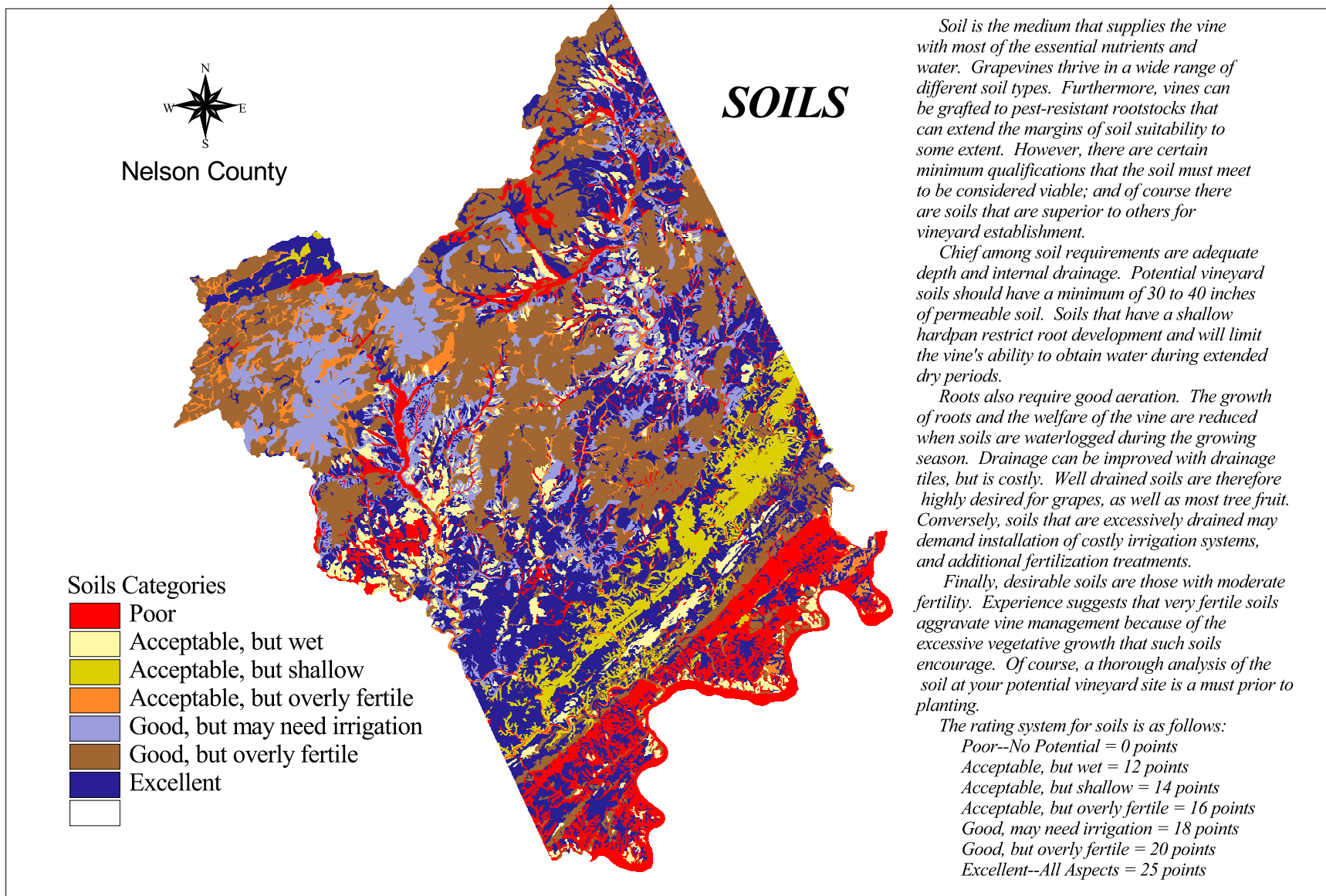


Figure 4.12
Nelson County Soils Layer

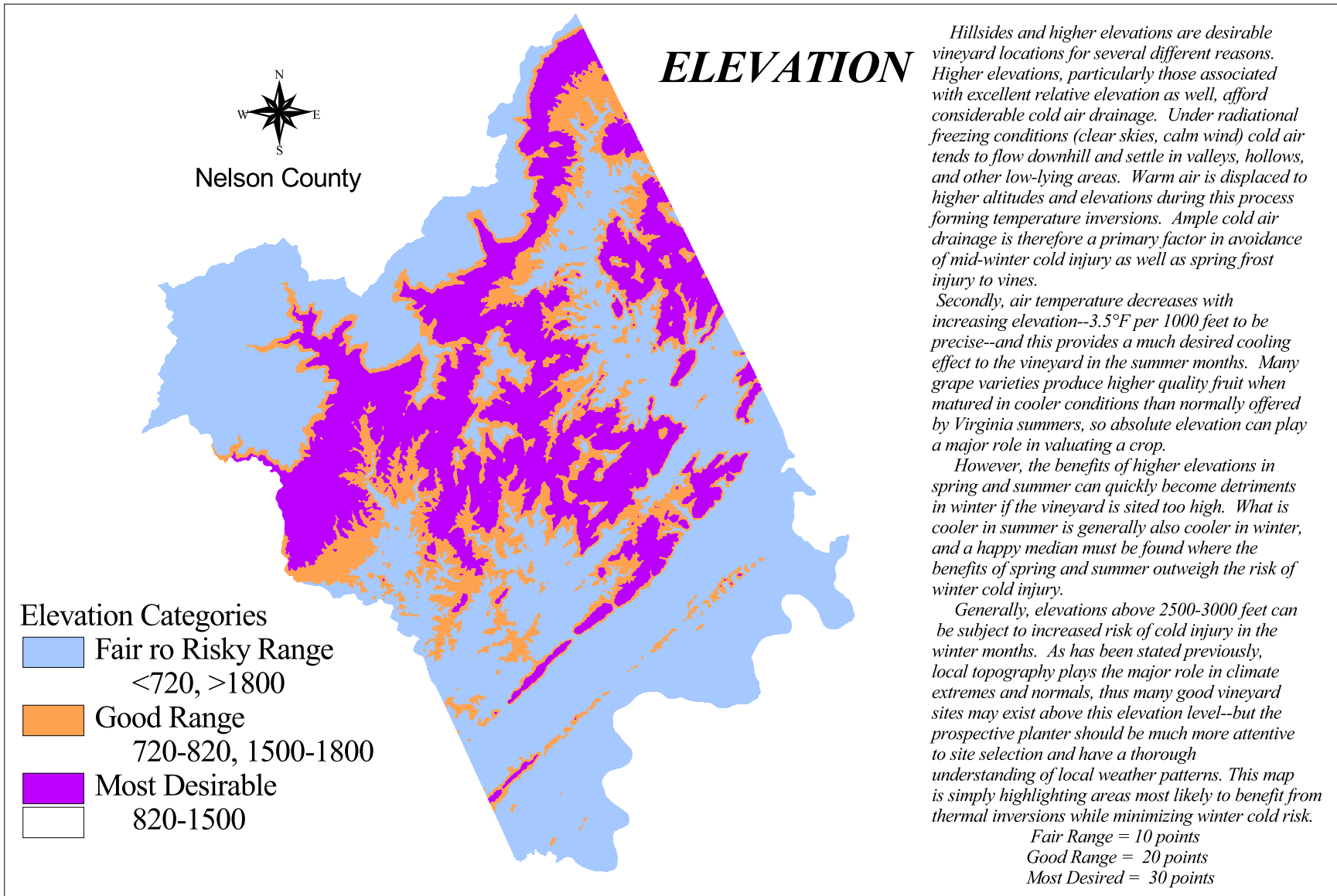


Figure 4.13
Nelson County Elevation Layer

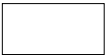
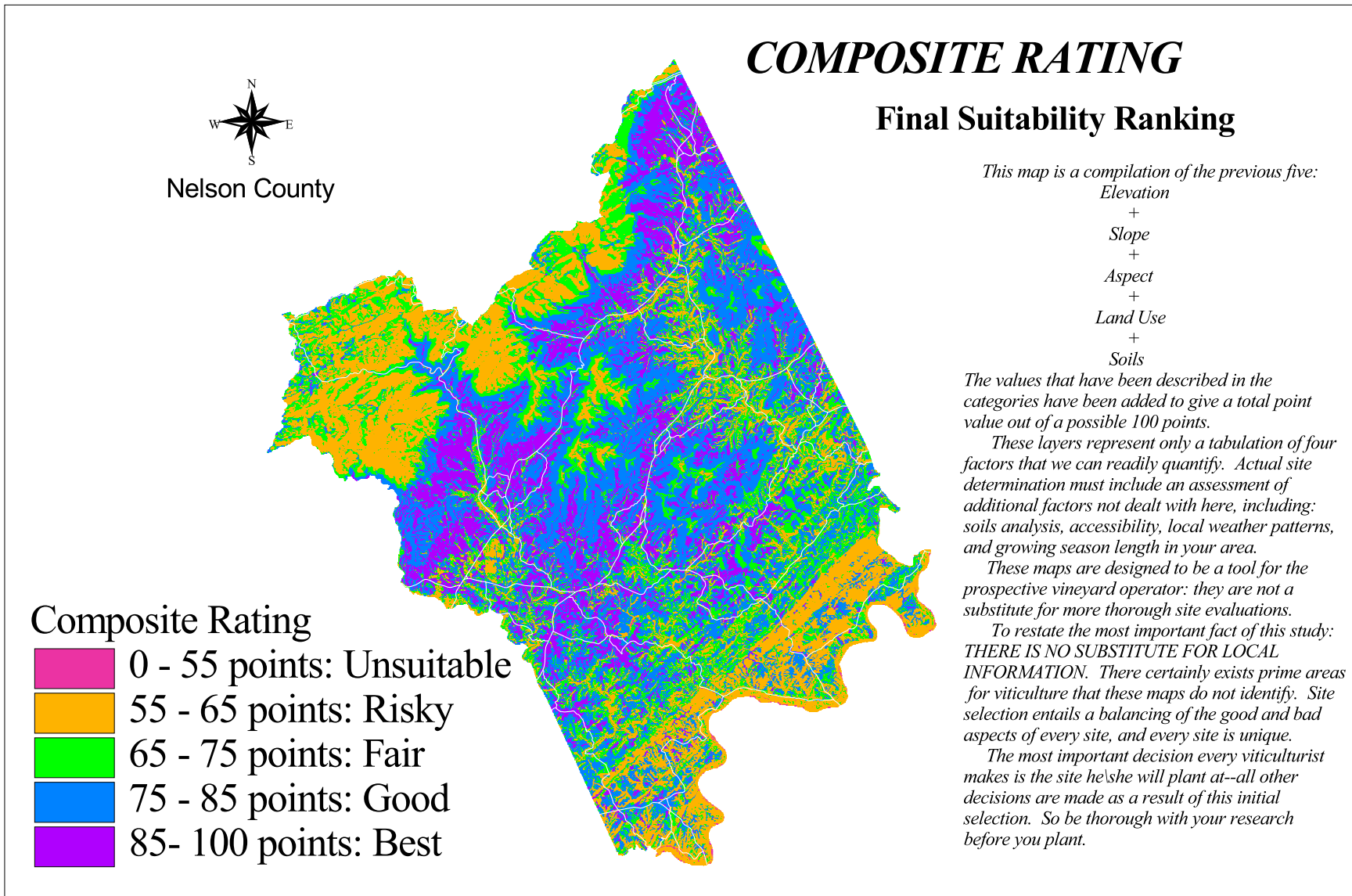


Figure 4.14
 Nelson County Composite Layer

4.4 Summary

The GIS approach to delineating areas of greater or lesser potential has been outlined in this chapter and exemplified by the previous layout displaying the results on a layer to layer basis. Aspect, slope, soils, land use and elevation were evaluated and described in terms of their potential for successful viticulture, or other fruit crops. These factors were then attributed with a point value, all factors combining for a possible 100 points; thus when layers are 'stacked' in the GIS, sites scoring 100 points possess the best of all factors, those with zero points possess none of the positive attributes.

This type of approach allows the builder to pick and assign value to factors as he/she sees fit, making it very versatile user to user. GIS also facilitates visual assessment of the distribution patterns of the individual factors, as well as the combination of those factors. Point systems of this type also allow for presenting variation within the distribution; thus allowing the user to determine potential possibility, instead of merely accepting or rejecting an area. Because this is possible on a factor to factor basis, we can determine why one area is better or worse than another, and perhaps formulate strategies to overcome a potential obstacle.

To restate, the factors chosen for this analysis are not necessarily the absolute best indicators for potential, but are the most readily quantifiable and available. Certainly, more climatological variables would have been desired to employ in this process, but the widely distributed locations and low numbers of weather stations make the data collected from them much too coarse to apply to the local level.

To reiterate, even though the data used in this system is at a relatively fine scale(ninety foot squares) the variability both within the data, and among the reality it represents, can be significant. Best employment of this type of model is in displaying trends at the county scale, as has been presented in Figures 4.9-4.14. Although the data resolution permits evaluation down to the local site scale, it would be more sound to identify broader areas of high potential within the county, and then go on-site to properly evaluate the best land for planting. No matter how well-constructed the model, it is an immense simplification of reality--and as such cannot accurately display the multitude of variables and relationships that must be considered in the site-evaluation process.

Chapter 5 Model Validation and Final Summary

This final chapter involves validating the local scale model outlined in chapter four, comparing and contrasting attributes of apple and grape acreage, and a final assessment of the viticulture potential analysis--both at the state and local levels. The validation process of the model consisted of locating the current apple and grape sites using Global Positioning System (GPS) technology, thus providing an opportunity to relate the prediction of the model to the rigors of reality.

The hypothesis is that well-established apple and peach acreages are already located on prime fruit sites, thus their long history and success. Orchards and vineyards not scoring well, according to the model, should have some negative attributes that can be identified and accounted for. Further verification methods included grower surveys, on-site assessment, and grower interviews concerning climatic attributes of their sites. A combination of these, and other compiled climate data, served to support decisions made in the model-building process--and even the state analysis process.

Section 5.1 describes the validation process, including GPS data collection, statistics derived from overlaying GPS into the GIS database, and data derived from growers. Section 5.2 compares and contrasts the apple and grape acreages involved in the previous section; paying particular attention to major discrepancies, which serve to distinguish the site characteristics of the two fruit types. Section 5.3 summarizes the entire study, both the state scale and local site analyses aspects, as well as future applications.

5.1 Model Validation

The first step in validation was to obtain real data to compare to the predictions of the model. Crop location data were collected with GPS technology and then integrated into the GIS for analysis. After analyzing apple and grape acreage in terms of the GIS model, the two are compared to each other to highlight similarities and differences. Model validation is supplemented in 5.1.3 with data collected from growers about their sites.

5.1.1 Collection of GPS data

Final phase of the project entailed verification of the site potential model. A Global Positioning System (GPS) was used to geo-locate existing fruit acreage in the five-

county study area. Geo-locating means recording the perimeter of an apple orchard or vineyard plot in an absolute coordinate system, which in turn can be overlain onto the final composite map in the same coordinate system.

In this case the coordinate system used for both the model creation and the GPS collection was UTM (Universal Transverse Mercator), Zone 17, NAD27 (North American Datum, 1927). The GPS unit utilized by this study was a Corvalis Microtechnology L1 six channel receiver. Autonomous data was collected and then differentially corrected to the centrally located base station in Charlottesville, Virginia--a fortunate relative location, falling almost perfectly in the center of the study area. No point collected in the study area was more than 100 miles from this base station, thus falling well within the 300 mile limit generally recommended by the literature (Collins, Hoffman-Wellenhof, Lichtenegger, 1994). After differential correction, horizontal accuracy falls within two to ten meters, with error less than five meters typical.

Initially, the collection process consisted of walking the perimeter of each orchard or vineyard block, with the GPS unit in a three-second autonomous mode--meaning that the unit records a unique point every three seconds. I quickly discovered that this set-up was inadequate because it was very time consuming and laborious. Depending upon the layout of the orchard, the perimeter could be easily traversed if area was compact, but exponentially larger perimeters occur as the area becomes less compact. Figure 5.1 illustrates this point.

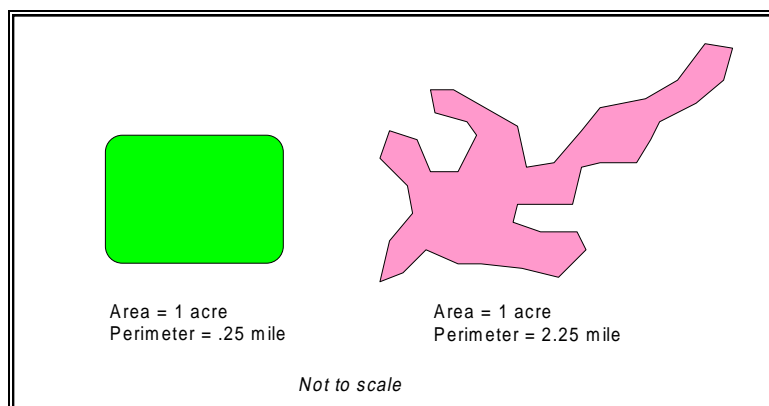


FIGURE 5.1
The problem of perimeter

To remedy this situation, I employed two small, four-wheel drive, all-terrain vehicles to expedite the collection process. It became a two-team, four-man operation, with one driver and one GPS operator per team. This drastically reduced traverse time around the acreage and was more manageable from a time and labor standpoint. To account for increased speed over land, the autonomous mode of the GPS receivers was increased to one-second intervals, meaning an unique point was collected every second.

In total, 2,179 acres of fruit were located within the 138,802 acre study area. Combined apple, peach and cherry acreage accounted for 1910.2 acres, the vast majority of which is apple. Grape acreage in the study area totaled 268.9 acres, roughly twenty percent of the state total. This makes for a good comparative situation as the apple to grape ratio in the study area is somewhat analogous to the conditions statewide. Figure 5.2 is an example of the GPS collection output, zoomed in to an appropriate scale to distinguish level of detail of data. The vineyard shown is from Prince Michel Vineyards in Madison County, in the extreme northern part of the study area.

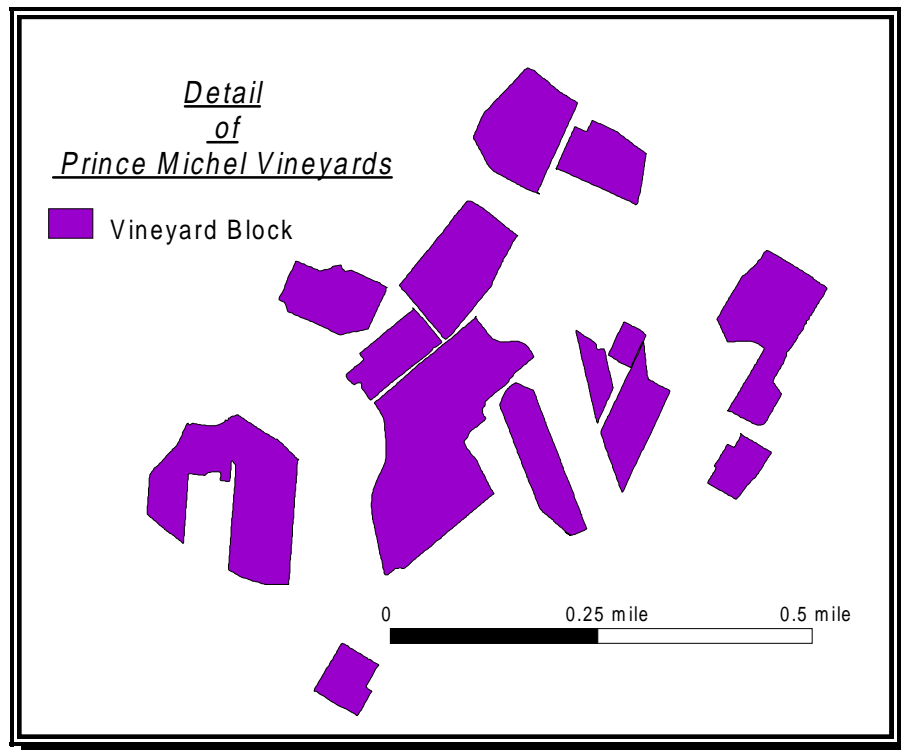


FIGURE 5.2
GPS Data

5.1.2 Real versus the Ideal: Comparing Model to Actual Fruit Acreage

The next step in the analysis was to integrate the GPS data into the GIS which contained the site factor layers described in the previous chapter. Once in the GIS, statistics can be generated for the individual acreages and patterns identified. Focus continues on Nelson County to enhance clarity and identification when offering output examples.

Results of the suitability study for this area of the state are typified by the composite image shown in Figure 5.3. According to the model, roughly 17% of Nelson County falls within the highest ranked category of over 85 points; over the entire study area, only 14,639 acres or 10.5% of total, ranked this high. Descending in ten point increments, the rest of the study area ranked as follows:

85 to 100 points: 14,638.7 acres or 10.5% of total
 75 to 85 points: 31,203.0 acres or 22.5% of total
 65 to 75 points: 28,485.8 acres or 20.5% of total
 55 to 65 points: 40,128.6 acres or 28.9% of total
 less than 55 points: 24,346.6 acres or 17.5% of total

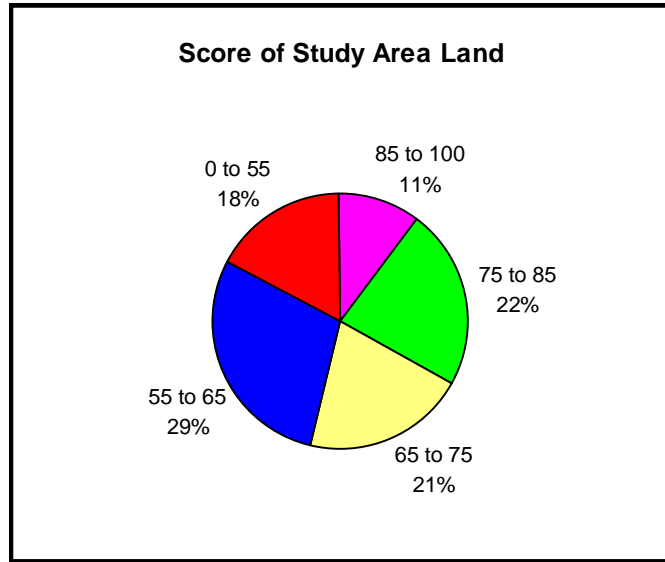


FIGURE 5.3
Scores of land in entire study area

It is important to note that the highest ranking class is the most discriminate, having only 10.5% of total study area in its class. Also, the lowest ranked class, under fifty-five points, is the second most discriminate, having only 17.5% or total. This lowest

category reflects almost entirely unsuitable--or at least very poor--land and would include bodies of water or urban areas. Thus, it would not be expected to be a predominate ratio of the whole, as this study area generally contains agriculturally suitable land.

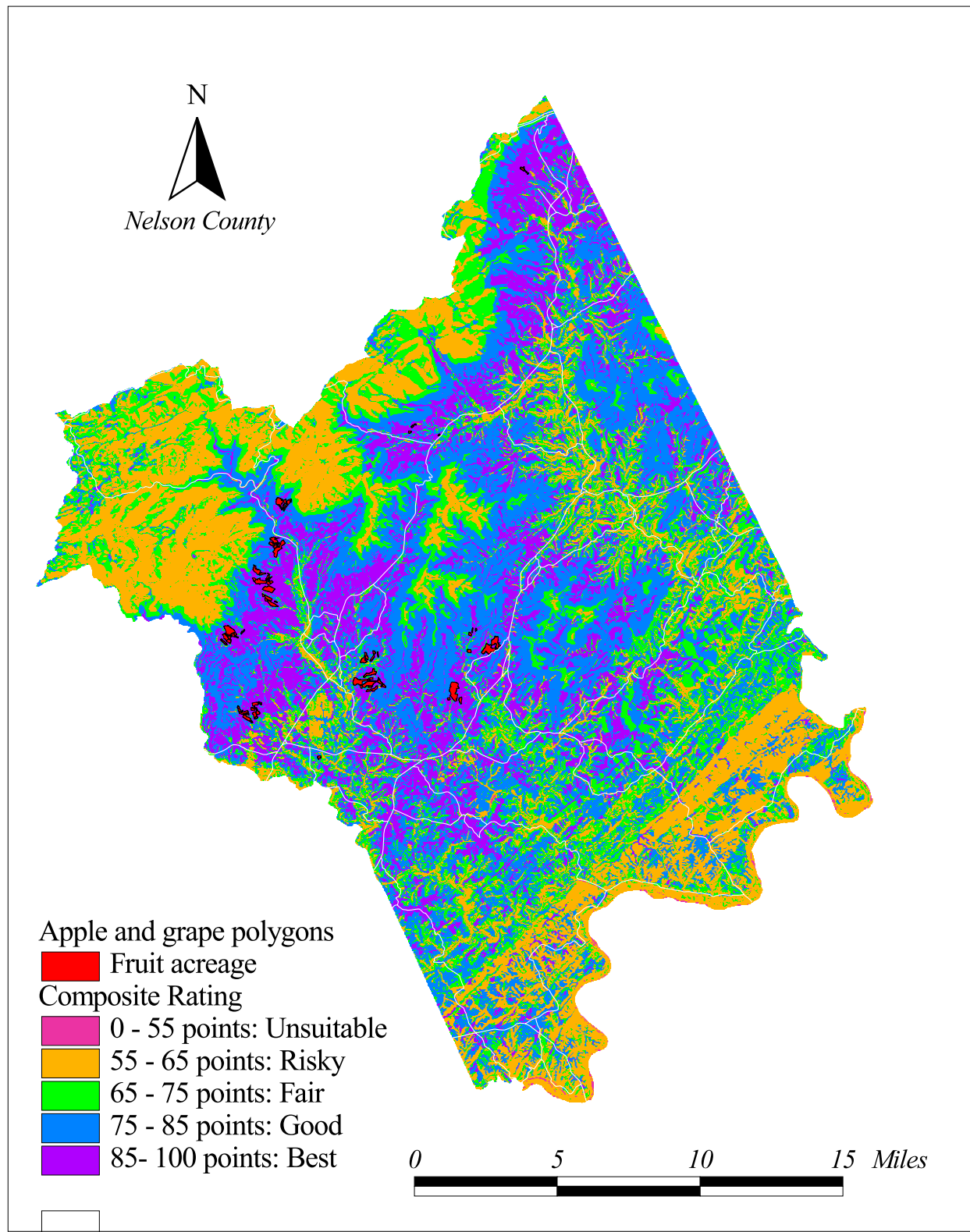


FIGURE 5.4
Composite image with existing fruit acreage layer

Supporting the model--and shown visually in Figure 5.4--are the existing acreages of fruit, which appear predominately in the top ranking class. Much of the existing acreage is in apple, and most of these sites have been in production for approximately 30 years---a positive indicator of a good site. A majority of the current apple, peach and grape acreage, 1091.1 acres, or 50.0%, scored in the 85 to 100 point range--the highest category. This was followed by:

- 75 to 85 points: 739.2 acres or 33.7%
- 65 to 75 points: 159.2 acres or 7.3%
- 55 to 65 points: 139.4 acres or 6.4%
- less than 55 points: 60.3 acres or 2.7% of total existing fruit acreage

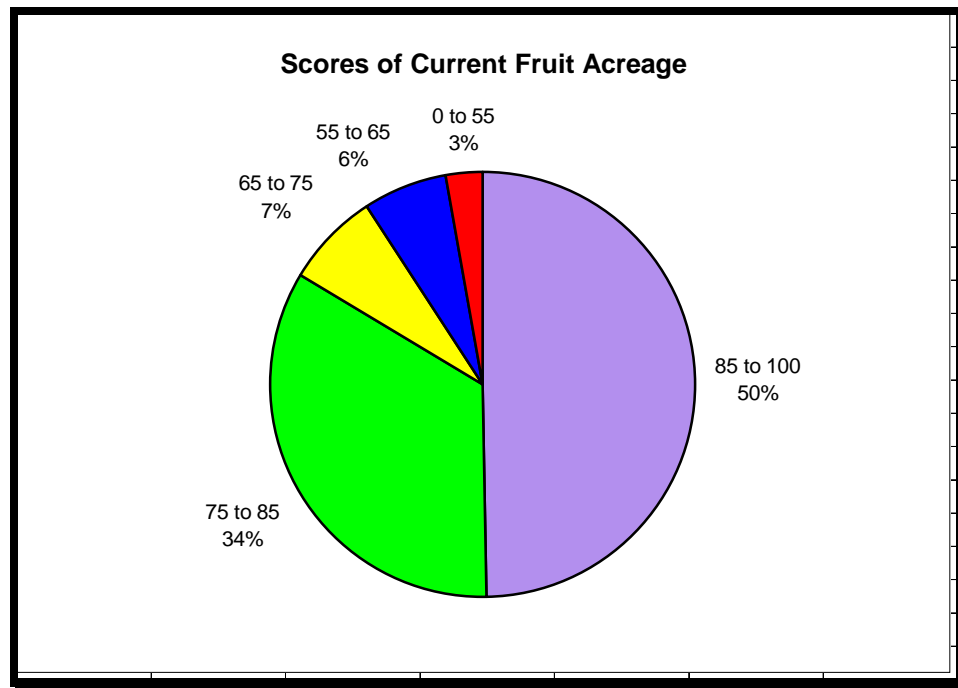


FIGURE 5.5
Scores of current fruit acreage

Taking the highest two classes together (75 to 85, 85 to 100) accounts for 83.7% of total existing acreage: a figure which lends some authenticity to the site potential model. Whether or not one agrees with the factors chosen or the values allotted within the factors, it is hard to dispute the strong correlation between existing acreage and highest point values--note that only 33% of total land area ranked in the top two classes, while 84% of current fruit falls in that acreage.

It was not expected, nor desired to create a system which ranked ALL current acreage in the highest category--as it is not expected that all current acreage is on the best sites in reality. The remaining 16% of current acreage which scored less than 75 points should serve to point out shortcomings of the model if this acreage is in fact on good sites. Conversely, this 16%--particularly the 3% which scored in the absolute lowest class--might strengthen the model if those acreages are indeed poor sites.

5.1.3 Additional Grower-Supplied Comparative Data

In addition to the direct comparison of existing acreage to model values, I collected qualitative data from the growers about their sites. This was accomplished through a combination of written surveys and direct interviews with the apple and grape growers--most data predominately from the latter of the two. (See appendix for copy of mail survey) Table 5.1 below is a summary of select sites within the study area-- sites which generally represent all the data collected.

TABLE 5.1
Select grower data

	AVG	MinTemp	Frost	Heat &	Age	Elevation
SITE (in County)	SCORE	Damage	Damage	Humidity	Of Acreage	(in feet)
Madison Vineyard	56	Medium	High	High	15 yrs	540
Albemarle Vineyard #1	59	Low	High	High	18 yrs	450
Albemarle Vineyard #2	65	Medium	High	High	20 yrs	560
Amherst Vineyard	70	Low	High	High	17 yrs	690
Nelson Orchard #1	81	Medium	Medium	Medium	30+ yrs	800
Nelson Vineyard #1	89	Medium	Low	High	18 yrs	925
Nelson Orchard #2	89	Medium	Low	Low	40+ yrs	1400
Nelson Orchard #3	90	Low	Low	Low	5+ yrs	1600
Nelson Orchard #4	91	Low	Low	Low	30+ yrs	1075
Albemarle Vineyard #3	92	Low	Low	Medium	12 yrs	850
Nelson Vineyard #2	92	Low	Low	Medium	22 yrs	830
Albemarle Orchard	92	Low	Low	Low	40+ yrs	1450
Madison Vineyard #2	95	Low	Low	Medium	12 yrs	1300

The table consists of growers, both apple and grape, which represent a sample of responses from throughout the study area. Of particular note is the very positive correlation between the model's score (column 2) and the occurrence rate of several climatic problems (columns 3,4, &5). As scores get higher, the grower problems of minimum winter temperature damage, frost damage, and humidity troubles *generally* (with such qualitative responses, it becomes difficult to describe anything but the most general trends) become lower.

Even with the limitations of qualitative data, trends of increasing score with decreasing climatic problems are evident. This correlation can also be extended to elevation, as a well defined rift exists between elevations over and under 800 feet elevation (column 6). I'm referring not only to the higher scores achieved by the higher elevations (as to be expected since the point system favors them) but also to the readily identified trend between increasing elevation and decreased frost risk (column 4). However, the issue of humidity and heat based problems does not occur quite so linearly as the others; humidity problems occur across a range of scores and elevations--the model obviously has some trouble integrating this factor.

In addition to these qualitative trends, some quantitative data was obtained from growers which supports the decisions made concerning point valuation of the elevation factor within the model. Figure 5.6 represents a typical frost event in this area which assists in supporting the decisions on absolute elevation range values. The figure was comprised of actual grower data from one of the major orchard operators in Nelson County, Saunders Brothers Orchards. The pattern, and elevations associated with frost avoidance, is reconfirmed from a variety of grower interviews and data obtained from other growers in the study area, included in the table of Figure 5.6.

Typical Frost Event in Virginia

Morning of April 24, 1993

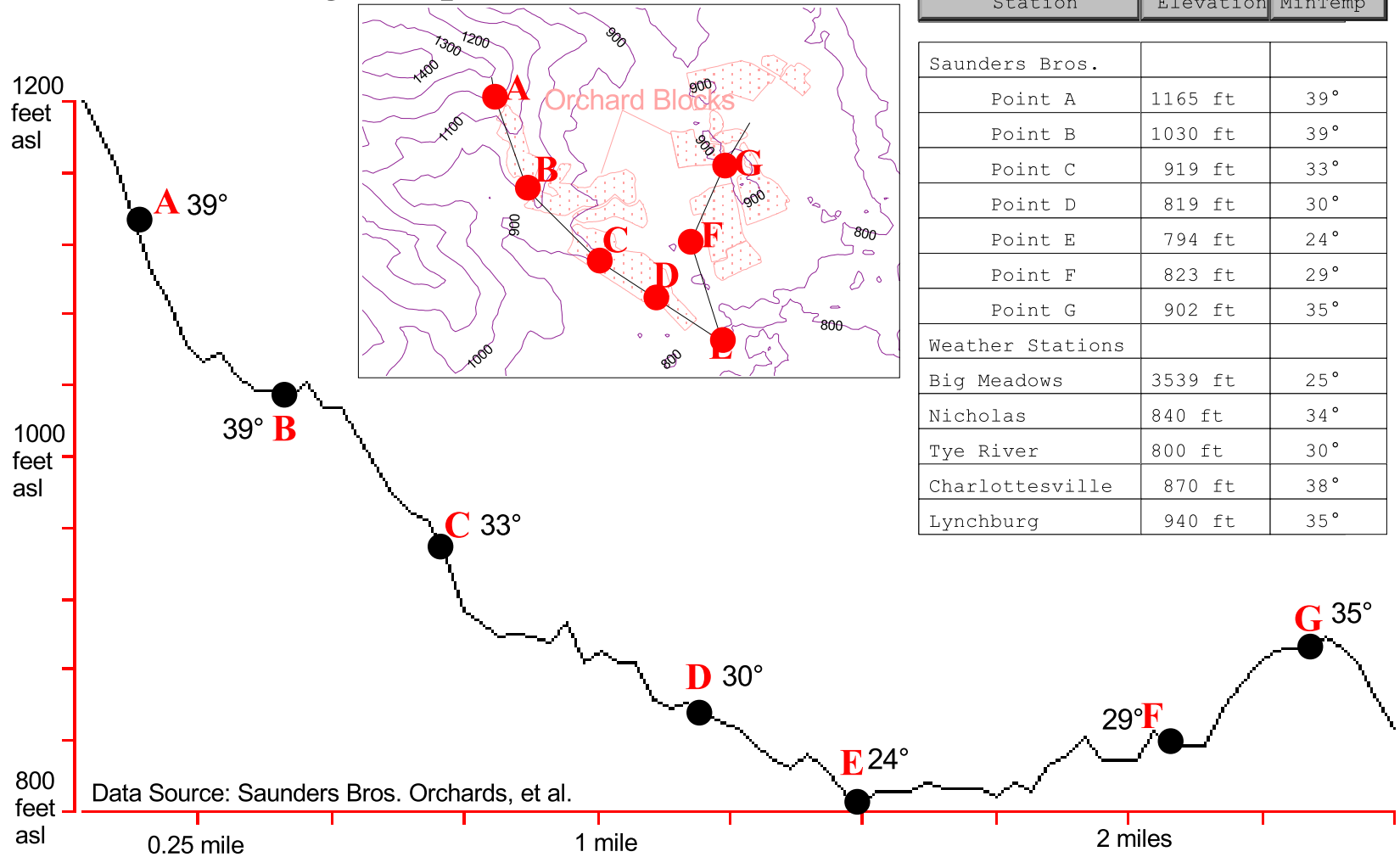


Figure 5.6
Typical Frost Event in Virginia

Elevation, as discussed in the previous chapter, is probably the most important site characteristic for eluding heat and humidity, encouraging lower summer extremes, facilitating air drainage, and most importantly avoiding frost damage. Figure 5.6 aptly demonstrates this phenomenon, graphically displaying the frost event of April 24th, 1993-- a significant frost occurring over all of the study area, as well as most of the east face of the Blue Ridge. The table lists the extreme low temperature recorded at each point on the night/early morning of the 24th. Other weather stations throughout the study area are also listed, offering further support of the importance of elevation.

Of greatest significance in the figure is the fairly well-defined temperature inversion, which supports the values attributed in the model. Taking all stations into account, a definite trend can be identified at the 820 foot elevation mark. Above this break, all sites recorded above freezing (32°F) minimums, and all sites below recorded lower than freezing. The inversion is most readily identified when examining the rising temperatures with rising elevations, particularly from Point E to Point A--equating to a positive 15° difference over a 371 foot elevation climb. The inversion is eventually overcome, as evidenced by the low reading (25°F) at Big Meadows station at 3539 feet asl.

Thus, the viticulture potential model does have justified support in the vast majority of actual fruit acreage scoring in the top classes of the point system. The model process is further supported by qualitative data from the growers, as well as limited quantitative data concentrating on the elevation factor--probably the most important consideration for a variety of factors alluded to earlier and addressed again in the next section.

5.2 Comparison of Apple vs. Grape Acreage in Study Area

Now that I have made a general case for the applicability of the model, the next question to be addressed is that of homogeneity of apple to grape acreages, specifically those employed in the model validation process within the study area. As stressed throughout this work, the apple industry has a much longer continuous history and site selection evolution than the less developed grape industry. So then, are there differences among the current apple and grape sites?

As evaluated at the state scale in Chapter 3, vineyard planting is occurring statewide, while apple and peach are largely confined to the Blue Ridge Mountains and Shenandoah Valley regions (Figure 3.3). Does this discrepancy at the state scale extend to the local site scale? I believe the answer lies in an assessment of the differences among apple and grape sites within the study area.

5.2.1 The Average Apple Site

Compiling statistics from just the apple and peach acreage within the study area, the following table summarizes each factor used in the model.

TABLE 5.2
Apple acreage statistics

Apple and Peach Acreage

Aspect	Attribute	Value	Acres	% of Total
	Flat	5	8.7	0.1
North	9	38.7	2.1	
Northeast	10	253.1	13.2	
East	9	402.3	21.1	
Southeast	5	449.7	23.5	
South	2	365.2	19.1	
Southwest	0	238.2	12.5	
West	2	104.1	5.5	
Northwest	5	<u>50.4</u>	<u>2.6</u>	
Total		1910.2	100	
Slope	Attribute	Value	Acres	% of Total
	Flat	2	8.7	0.1
1 to 2%	8	98.7	5.2	
3 to 12%	15	1733.6	90.8	
12 to 15%	10	50.5	2.7	
over 15%	5	<u>18.9</u>	<u>1.1</u>	
Total		1910.2	100	
Land Use	Attribute	Value	Acres	% of Total
	Unusable	0	12.7	6.7
Forest	17	530.6	27.8	
Shrubland	19	241.1	12.6	
Agriculture	20	<u>1126.1</u>	<u>59.1</u>	
		1910.2	100	
Soils	Attribute	Value	Acres	% of Total
	Poor	0	13.4	0.7
Wet	12	722.1	37.8	
Shallow	14	1.9	0.1	
Too fertile	16	36.3	1.9	
Good, dry	18	150.9	7.9	
Good,	20	202.5	10.6	

Elevation			
Attribute	Value	Acres	% of Total
fertile			
Best	25	<u>785.1</u>	<u>41.1</u>
		1910.2	100
<600	0	16.5	0.9
600-700 or 1500-1700	15	56.9	2.9
700-800 or 1200-1500	20	391.2	20.5
800-1200	30	1437.1	75.2
>1500	5	<u>8.7</u>	<u>0.5</u>
Total		1910.2	100

From these statistics, a typical--or average--site has the following characteristics:

Elevation: between 800 and 1200 feet asl; 1437.1 acres or 75.2% of total

Aspect: eastern and southeastern; 949.8 acres or 49.7% of total

Slope: 3 to 12% slope; 1733.6 acres or 90.8% of total

Land use: predominately classed as agriculture; 1126.0 acres or 58.9% of total

Soils: evenly split between Best class; 783.1 acres or 41.1% of total

and Acceptable but inadequately drained class; 722.1 acres or 37.8% of total

Thus, the majority of acreage falls into the highest ranked classes of each category, with the exceptions being aspect and soils. As expected, aspect varies the most among categories and is one of the reasons it received the lowest total points (only 10 points maximum). Notice the broad distributions of aspects, quantified in Table 5.2. The top ranking category, northeast, attributed only 13.2% of total acreage. East, southeast, and south accounted for over 60% of total acreage, split roughly even between the three. This situation was expected due to the predominance of the northeast to southwest trend of the Blue Ridge, on which most of the acreage is located.

Soils are a more difficult situation to explain. While the majority of acreage, 41.1%, fell into the highest category, a large portion of the remainder, 37.8%, was located in the next to lowest category--acceptable but wet/insufficiently drained. The only category below this one is unacceptable, due to poor drainage and lack of soil depth. Possible explanations for this well-defined division include poor attributing of the soil by the model, of the soil data itself, or the possibility that a lot of the acreage is actually located on poor soils.

Interviews with growers--particularly those which ranked low in the soils category--dispelled the possibility of 37.8% of the acreage being located on poorly drained soils. Certainly some acreage is questionable, but nothing constituting almost forty percent. After reviewing the characteristics of the soil classifications provided by the United States Department of Agriculture Soil Survey (the creator of the database), I am further convinced that point values offered by the model are appropriate and fitting.

The most probable cause of such a large derivation of acreage is due to a combination of some poorly sited orchards and inadequately drawn polygons within the soils database. Soil Surveys are produced from a variety of sources including aerial photography, historical records, and soil sampling. However, soil sampling, the most reliable way to determine soil types, is not employed at an adequate scale or consistency to produce a highly accurate on-ground map. From all of the farmers, agriculture extension agents, and specialists I spoke with, the general consensus is that they [the soil surveys] are correct only about 50 percent of the time. Thus, the main reason for low scoring in the soils category is due to a technical data problem which could be accounted for in the model, but would be better addressed by obtaining more accurate soil data.

5.2.2 The Average Grape Site

Compiling statistics from just the grape acreage within the study area, the following table summarizes each factor used in the model.

TABLE 5.3
Characteristics of grape acreage

Grape Acreage

Aspect	Attribute	Value	Acres	% of Total
	Flat	5	1.1	0.4
North	9	17.9	6.7	
Northeast	10	31.1	11.6	
East	9	47.7	17.7	
Southeast	5	68.3	25.4	
South	2	34.1	12.7	
Southwest	0	33.6	12.5	
West	2	14.2	5.3	
Northwest	5	<u>20.9</u>	<u>7.8</u>	
Total		268.9	100	
Slope	Attribute	Value	Acres	% of Total

	Flat	2	1.1	0.4
	1 to 2%	8	35.4	13.2
	3 to 12%	15	232	86.3
	12 to 15%	10	0.4	0.1
	over 15%	5	<u>0</u>	<u>0</u>
	Total		268.9	100
Land Use	Attribute	Value	Acres	% of Total
	Unusable	0	1.8	0.7
	Forest	17	45.8	17.1
	Shrubland	19	84.3	31.3
	Agriculture	20	<u>137</u>	<u>50.9</u>
			268.9	100
Soils	Attribute	Value	Acres	% of Total
	Poor	0	0	0
	Wet	12	98.7	36.7
	Shallow	14	0	0
	Too fertile	16	9.9	3.7
	Good, dry	18	0	0
	Good, fertile	20	102.2	38
	Best	25	<u>58.1</u>	<u>21.6</u>
		268.9	100	
Elevation	Attribute	Value	Acres	% of Total
	<600	0	169.5	63
	600-700 or 1500-1700	15	28	10.4
	700-800 or 1200-1500	20	37.8	14.1
	800-1200	30	33.6	12.5
	>1500	5	<u>0</u>	<u>0</u>
	Total		268.9	100

From these statistics, a typical existing vineyard site has the following characteristics:

Elevation: less than 600 feet asl; 169.5 acres or 63% of total

Aspect: eastern and southeastern; 116 acres or 43.1% of total

Slope: 3 to 12% slope; 232 acres or 86.3% of total

Land use: predominately classed as agriculture; 137.0 acres or 50.9% of total

Soils: evenly split between Good, but too fertile class; 102.2 acres or 38% of total
and Acceptable but inadequately drained class; 98.7 acres or 36.7% of total

A majority--63%--of existing vineyards ranked in the lowest possible elevation class of less than 600 feet asl. Another 25% fell into the marginal classes, with only

12.5% of total acreage falling into the highest class. This is a major discrepancy from apple acreage, and will be addressed in the next section.

Again, the discrepancy in soils is noted, with a large percentage in a high class, and another in the next to lowest class. However, the vineyard soils did not rate in the highest class, but the second highest: good, but overly fertile. The consistency of the rankings across both apple and grape acreage gives some credence to faulting the soils data itself, as all other contributing factors were accounted for.

Like the apple acreage, aspect was most influenced by the topography of the area, and the vast majority of the acreage fell into the highest class of slope. The model only ranked 51% of the vineyards as open agricultural land, due in part to the size of grape plots--typically small two to three acre parcels. Even with data resolution at 90 square feet, often adjacent forest or shrubland dominates the scene enough to capture the classification. Therefore, the point departures between forest and agricultural lands are minimized--thus allowing the layer only to function in eliminating completely unusable land which is allotted zero points.

On the subject of land use, in both the apple and grape acreage there are some areas allotted zero points, which would be interpreted as unusable area. However, the land use layer is at a resolution which can detect large buildings (packing sheds and processing warehouses) and small bodies of water, like farm ponds. These types of 'unusable' lands were often included in the orchard polygons, and account for this seemingly impossible situation; in which an area in an orchard would rank as unsuitable land for an orchard.

5.2.3 Similarities and Discrepancies

Aspect, slope, land use, and general soil between existing apple and grape acres not only concur with each other, but generally rank in the higher classes within each category. This is a positive correlation of model applicability, if one accepts the hypothesis that these acreages are on sites suitable for fruit production. Since many of the sites have been in continuous production for twenty to thirty, to even seventy years, the hypothesis reception is an easy one. A poor site would not survive that long--particularly in the apple industry, with its appreciable global competition.

To quickly summarize the similarities, the table in Table 5.4 is offered for direct comparison of the apple and grape acres. Only the predominate class within each category is shown. Referring back to Tables 5.2 and 5.3, one can see that point breakdowns of other classes within the categories reflects the similarities expressed below.

TABLE 5.4
Similarities between existing fruit acreage

	APPLE	GRAPE
Aspect	49.7%: east/southeast	43.1%: east/southeast
Slope	90.8%: 3 to 12%	86.3%: 3 to 12%
Land Use	58.9%: agriculture	50.9%: agriculture
Soils	41.1%: best	38.0%: good
	37.8%: acceptable	36.7%: acceptable

Taking these four out of five factors, one might draw the conclusion that there is little to no difference between plantings of apple and grape in this part of Virginia. However, there is one major discrepancy alluded to throughout this chapter--elevation. This single factor accounts for the only major difference, and due to the high point value conferred to this category, starts to explain why much of the grape acreage scored lower than the apple (Table 5.5).

TABLE 5.5
Apple versus grape scores

POINTS	APPLE		GRAPE		
	Acres	Percent	Acres	Percent	
85 to 100	1051.5 acres	55%	29.6 acres	11%	
75 to 85	688.3 acres	36%	50.9 acres	19%	
65 to 75	142.1 acres	7%	17.1 acres	6%	
55 to 65	18.9 acres	1%	120.5 acres	45%	
0 to 55	9.6 acres	1%	50.7 acres	19%	
	1910.2 acres	100%	268.9 acres	100%	Total

As derived from the table, 91% of the apple acreage scored above 75 points, compared to only 30% of the total grape acreage. On the other extreme, only 2% of apple acreage scored less than 65 points while a majority of the grape (64%) scored below this minimum, with almost one-fifth below 55 points--the threshold for a risky to poor site qualification.

As elaborated above, the average elevation of the apple acreage was between 800 and 1200 feet asl; 1437.1 acres or 75.2% of total acreage. Grape on the other hand was typically less than 600 feet asl; 169.5 acres or 63% of total grape acreage.

Looking back to Figure 5.6, the reason for attributing elevation in this way is clear: the most significant climatic factor which the grower deals with is spring frosts. With the ability to wipe out an entire season's crop, frost--or frost avoidance--becomes the overriding factor considered in the site selection process for apple growers. Some grower comments:

“We will not plant any tree lower than 800 feet elevation; that is our magic number,” (Chiles, 1997)

“Sometimes our lower peach orchards, around 780 feet, get hit with frosts. We are always on the lookout for good sites higher up on the hills,” (Saunders, 1998).

In apple plantings, it becomes obvious that trees simply do not go into the ground in places where frost has a large damaging potential.

Unfortunately, many grape growers have not attributed the role of frost with as much importance. As pointed out by Dr. Tony Wolf, many of the current grape acres are a result of growers developing the best sites on land already in their possession, versus seeking out the best sites on the best lands in the state. What happens when land already in possession falls entirely in a frost prone area? The grower may select the best site on his land, but it is still a marginal site overall. In this case, 19% of total grape acreage falls circumstance to this situation in this study area. This is not to say that all the grape acreage is poorly sited for elevation. Nearly 30% of existing grape acreage fell into the acceptable elevation ranges, with 13% of that being in the highest point class.

In Table 5.1, the relationship between the lower elevations and frost occurrence is noticeably borne out. All acreage under 800 feet asl report high occurrence rate of frost

damage, compared to reduced incidence above that elevation. Predominately, if not wholly, the fruit sites at the lower elevations (<600 feet asl) across the state are grape plantings. This is a situation that must be changed not just for the avoidance of frost, but for all the associated benefits of increasing elevation--reduced summer temperatures, greater day/night differential, facilitated air movement, etc.

A final element of support, both to elevation attributed values (in model) and frost/elevation relationship, is the distribution of wind machines in the study area. Wind machines are large windmill-like fans which mix the air, or 'un-stratify' it, during temperature inversions. Helicopters are sometimes used for the same purpose. As can be surmised from previous explanation of frost events, if growers are trying to counter the inversion, it means that they are in poor sites which pool the cold air--the lower elevations, or low spots in local topography.

Since these measures are very expensive (wind machines cost \$15,000 to \$25,000), they are not practical to the small-scale operations and are cost prohibitive to even large-scale operations. The point of this brief discussion is of the nine wind machines I located in my study area, *100% of them are between 400 and 600 feet asl, and 100% are in grape acreage.* To minimize costs, crop losses and crop damage, there is no substitute for well-planned site analysis prior to planting--preferably at the higher elevations.

Thus, the high value placed on higher elevations becomes validated by frost rate of growers in the study area expressed in Table 5.1 and typical frost event outlined in Figure 5.6. Well-defined pattern of wind machine locations also confirms the importance of increased elevation, and explains the gap between the typical apple versus typical grape sites.

5.3 Final Summary of Geographic Analysis of Viticulture Potential

As another offering to validate viticulture potential models at the state and local scales, I offer the following diagram (Figure 5.7) displaying an average cross-section of the study area. Apple and grape sites are indicated on the figure, placed in such a way as to generalize the elevation and topography of their situation in reality.

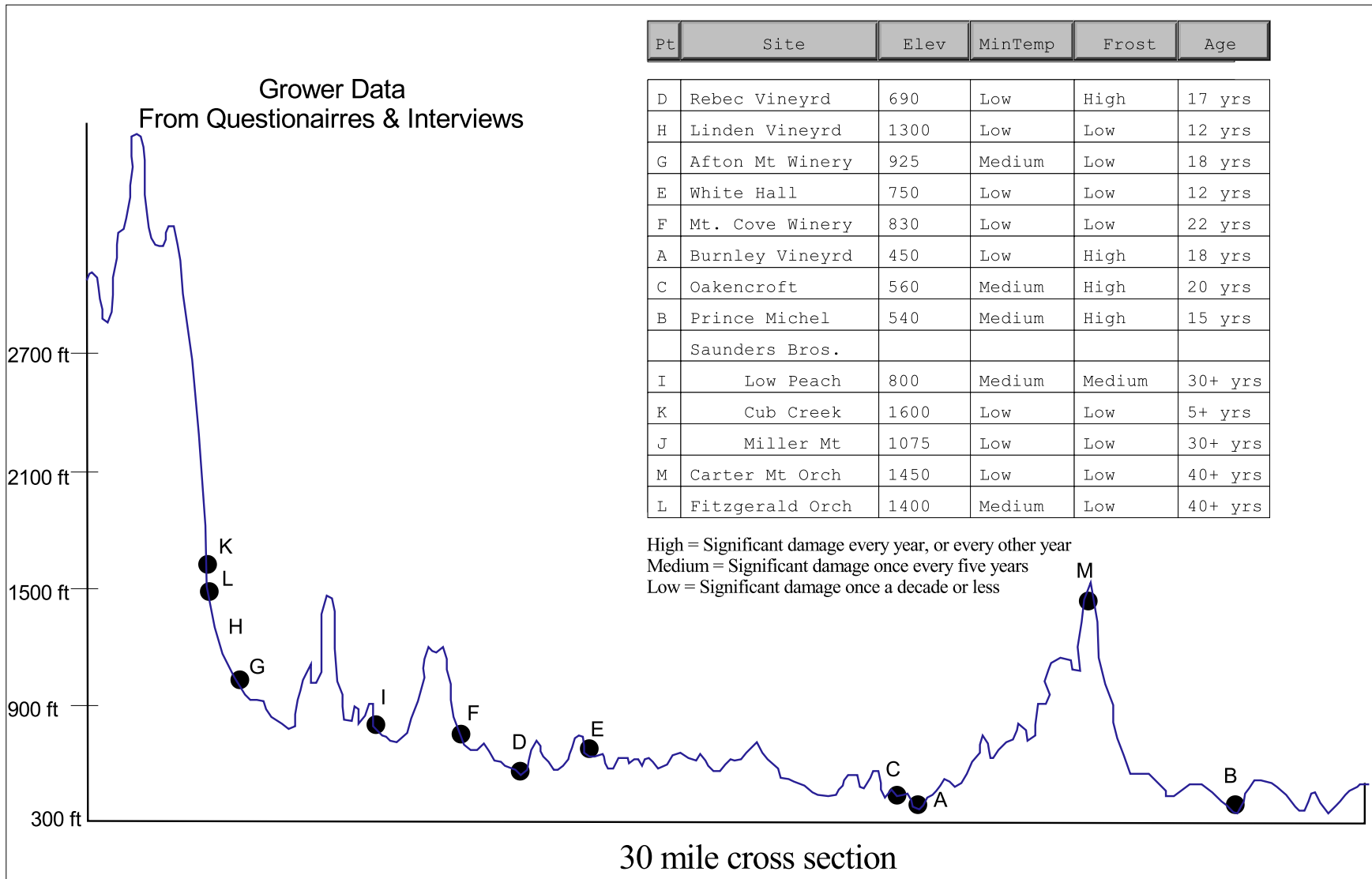


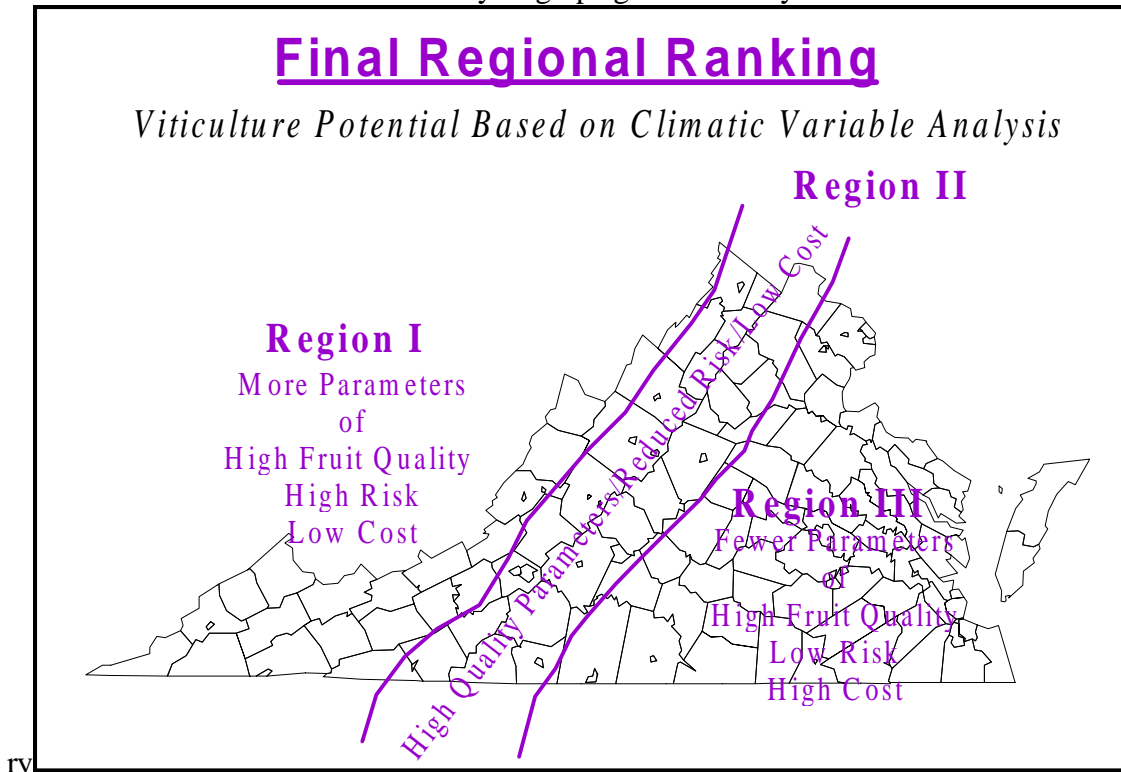
Figure 5.7
Grower Data
From Questionnaires & Interviews

The cross-section transects the study area perpendicular to the southwest-northeast running ridge of the Blue Ridge Mountains. Orchard and vineyard locations are placed on the graph in correct elevation perspective and generalized topographic trends. Increasing elevation can be positively correlated with decreasing frost damage; however winter damage from minimum temperatures does appear to increase slightly with elevation rise. Humidity is problematic throughout the range of elevation and topography, but moderate relief seems to be offered by higher elevations, due primarily to increased air drainage.

This figure encompasses factors from both the state and local level analyses; however, many of the fruit quality related factors--such as day/night temperatures or summer extremes--are much more difficult to quantify for comparative purposes. Fruit quality is as dependent on grower practices and skill level as it is on environmental conditions. Thus, poor quality fruit could come from a good site, just as high quality fruit could be produced from an inferior site when grower inputs overcome climatic constraints. True quantitative differentiation of levels of fruit quality is beyond the scope of this work.

Finally, the grape grower questionnaire used in this work is summarized below in Figure 5.8. The table is broken down into regions developed by the state analysis of Chapter Two, and qualitatively identifies general trends gained from the survey. While over 70 responses were returned, approximately 65% of those mailed, many constituted vineyards of insufficient age to include in the summary. Under five years was the critical age below which the vineyard was not included; around twenty of these responses contained acreage younger than three years old--indicative of the recent growth trends in the industry. The final region ranking figure from Chapter Two is included for reference purposes.

TABLE 5.8
Summary of grape grower survey



REGION	Winter Damage	Summer Heat	Spring Frost Damage	Fall Frost Damage	Humidity (fungus)	Harvest Precipitation Problems	Growing Season Problems	Number of Responses
I. West of Blue Ridge	High	Low	Low to Medium	Low	Medium	Low to Medium	Low	3
II. Blue Ridge	Low	Low	Low to Medium	Low	Medium to High	Medium to High	Low	34
III. Piedmont to Tidewater	Low	High	Medium to High	Low	High	Medium	Low	14

Responses provided in the table above support both the decisions made in the state analysis, and the decisions made at the local level in the model-building process. Notice the greater frequency of minimum winter temperature damage in Region I; the increased summer heat damage in Region III; the slightly greater spring frost damage in Region III;

and increased harvest precipitation in Region II. All of these issues were identified by either the state analysis, the local analysis, or both.

Caution should be taken when reviewing these results, as they demonstrate general trends interpreted from the available responses. As with any type of survey, these answers represent only a sample of the true population, and further, the responses were 'generalized' by region--meaning that there is variability within and among regions. Consideration should also be given to the deviation in number of responses from each area--a direct reflection of the number of growers in each area. While the number of responses may be representative of the number of growers in a region, low response number equates to less assurances of the data obtained: a few growers may not adequately mirror a region's characteristics.

However, this figure, and others presented in this chapter, begins to build legitimate support for the state analysis and local GIS model approach for predicting viticulture potential. While the analysis at both scales would have been much more beneficial with the inclusion of a proliferation of quantitative climatic data, those data do not exist in a systematic format. Even with the limited data and factors chosen for this study, the results are quite positive, as supported by the high scores of the apple acreage and low scores of some grape acreage--low scores which in turn were correlated to high frost occurrence. Thus, the model, both at the state and local scales, has achieved its goal in selecting areas which minimize risks and costs, while maximizing climatic benefits.

5.3.1 Utility of Study

Overall, I believe the history of the apple and grape in Virginia (Chapter 3), along with grower surveys and interviews presented in this chapter, present substantial evidence of the utility of this study. As previously described, the models at both the state and local scales have been shown to identify areas of prosperous fruit production. This has been confirmed by the correlation of high risks associated with fruit acreage that scored low by the models, as well as low risks and costs associated with acreage which scored high in the models.

As has been stressed throughout this work, areas classified into regions are anything but completely homogenous. With its broad range of elevation and terrain,

Virginia is conducive to radical and subtle shifts of climate over very short areas--setting up a variety of meso-climates within even the smallest of regional outlines. There are many good sites within areas designated as poor by the models and equal numbers of poor sites within areas designated as superior. There is no substitute for local information and a thorough, lengthy analysis of local climate conditions prior to planting any crop.

At the local scale, the results of the viticulture potential model are much more defined than the fuzzy boundaries of the regional breakdown of the state. In its rawest form, the model's output can be used to assess and predict a site for viticulture. However, the most powerful application of the GIS model is its user-adaptability. If a user disagrees with the values I associated with different factors, he/she has the ability to manipulate the values and include/exclude factors the way they see fit. Thus, it is the tool as a utility and not the maps as a static output, which gives this approach its true power and applicability.

The utility of such a model in helping shape the future landscape of fruit in Virginia will remain to be seen; however, there are other important applications of this study. First, the GIS model approach has great promise in the field of agriculture as a whole: from site analysis, to crop yield prediction, to more accurate pesticide/fertilizer applications--few of which, if any, are currently used in Virginia fruit production. Second, the GIS and GPS approach sets up a standardized database which may serve as a great utility to other researchers and academia. Third, the state and local analyses serve not only to identify areas of viticulture potential, but can also be used to assess areas in terms of risk and profitability--particularly important in the field of crop insurance.

Other utilities for this geographic approach to viticulture potential analysis will certainly arise in the future. For now, county analysis for high potential areas, database establishment for other researchers, and implementation of similar type GIS/GPS systems in agriculture appear to be the most promising applications of this work.

5.3.2 Concluding Remarks

In conclusion, the results of this viticulture suitability study indicate positive capacity for using a viticulture potential model to identify areas most suited for the expansion of the Virginia grape industry. Analysis at the state level is supported by trends in the apple and other tree fruit industries--industries with a much longer evolution into their current areas in the state. At the local analysis, strong correlations exist between current, well established fruit acreage and areas identified as high in potential by the model. This correlation is also supported by the limited climatic data available in the area, specifically for frost events, and by the linkage found between low scoring sites and high frost potential.

Geographic analysis at the state scale, as well as GIS and GPS evaluation procedures, allows us to visually assess the distribution patterns of important climatic and topographic factors, and in turn physically identify and locate areas of viticulture potential created from the combination of those factors. Integrating these technologies into site identification will become even more powerful as more climatic data are collected and introduced into the equation. For now, the most positive employment of this research should be for site assessment at the county scale and for educating current--and future--growers to the importance of site selection.

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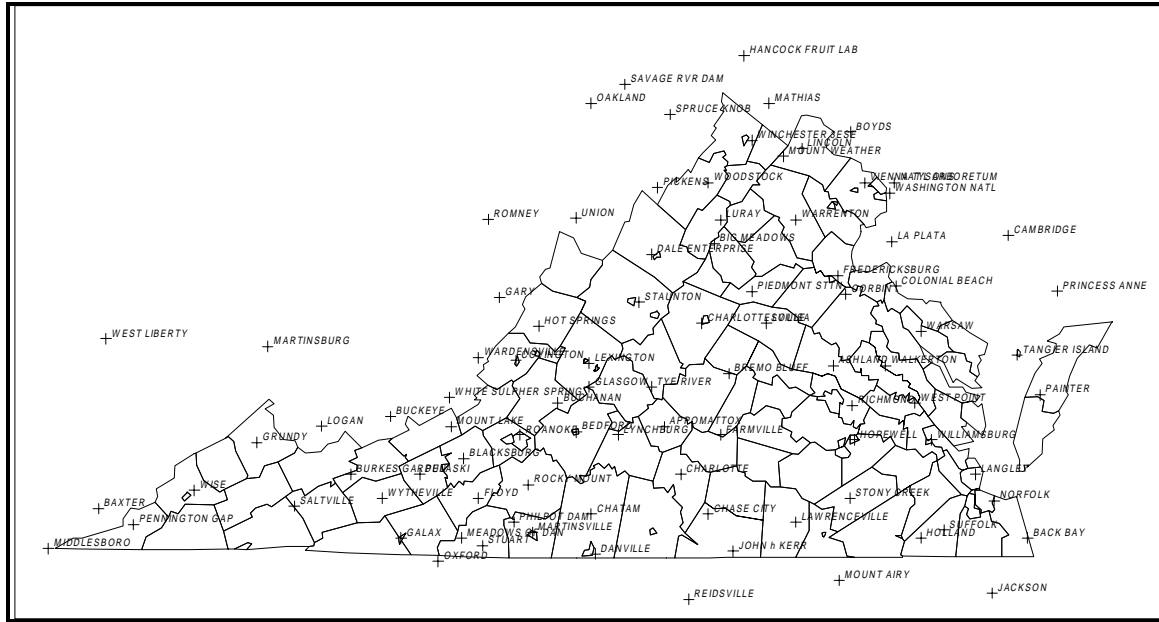
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Appendix B. List of NOAA Weather Stations

<u>Stations</u>	<u>Longitude</u>	<u>Latitude</u>	<u>Elevation</u> (in feet)
<i>Virginia</i>			
APPOMATTOX	-78.81667	37.36667	910
ASHLAND	-77.46667	37.75	220
BACK BAY	-75.91667	36.66667	10
BEDFORD	-79.51667	37.33333	975
BIG MEADOWS	-78.41667	38.51667	3535
BLACKSBURG	-80.41667	37.16667	2000
BREMO BLUFF	-78.3	37.7	300
BUCHANAN	-79.66667	37.51667	975
BURKES GARDEN	-81.31667	37.06667	3300
CHARLOTTE	-78.68333	37.06667	590
CHARLOTTESVILLE	-78.51667	38.01667	870
CHASE CITY	-78.46667	36.81667	510
CHATAM	-79.4	36.81667	640
COLONIAL BEACH	-76.96667	38.25	10
CORBIN	-77.36666	38.2	220
COVINGTON	-80	37.78333	1230
DALE ENTERPRISE	-78.91667	38.45	1400
DANVILLE	-79.36666	36.56667	410
FARMVILLE	-78.36667	37.31667	450
FLOYD	-80.3	36.91667	2600
FREDERICKSBURG	-77.43333	38.31667	90
GALAX	-80.91667	36.66666	2385
GLASGOW	-79.41667	37.61667	1350
GRUNDY	-82.06666	37.26667	1975
HOLLAND	-76.76667	36.66667	80
HOPEWELL	-77.3	37.28333	40
HOT SPRINGS	-79.81667	38	2240
JOHN h KERR	-78.26667	36.58333	250
LANGLEY	-76.33333	37.06667	10
LAWRENCEVILLE	-77.76667	36.76666	300
LEXINGTON	-79.41667	37.76667	1060
LINCOLN	-77.71667	39.11667	500
LOUISA	-78	38.01666	420
LURAY	-78.36667	38.66667	900
LYNCHBURG	-79.18333	37.31667	920
MARTINSVILLE	-79.86666	36.7	900
MEADOWS OF DAN	-80.43333	36.66667	2385
MOUNT LAKE	-80.51667	37.36667	4025
MOUNT WEATHER	-77.86667	39.06667	1720
NORFOLK	-76.18333	36.9	22
PAINTER	-75.81667	37.56667	30
PENNINGTON GAP	-83.05	36.75	1510
PHILPOT DAM	-80.01667	36.76667	1120
PIEDMONT STTN	-78.11667	38.21667	515
PULASKI	-80.76667	37.06667	1850
RICHMOND	-77.31667	37.5	165

ROANOKE	-79.96666	37.31667	1150
ROCKY MOUNT	-79.9	37	1235
SALTVILLE	-81.76667	36.86667	1800
STAUNTON	-79.01667	38.15	1385
STONY CREEK	-77.33333	36.91667	100
STUART	-80.26667	36.61667	1455
SUFFOLK	-76.58333	36.71667	25
TANGIER ISLAND	-76	37.81667	10
TYE RIVER	-78.91667	37.61667	720
VIENNA TYSONS	-77.21667	38.9	418
WALKERTON	-77.05	37.75	50
WARRENTON	-77.76667	38.66667	500
WARSAW	-76.76666	37.96667	140
WASHINGTON NATL	-77.01667	38.83333	10
WEST POINT	-76.81667	37.51667	15
WILLIAMSBURG	-76.68333	37.28333	70
WINCHESTER 3ESE	-78.11667	39.16667	680
WISE	-82.56667	36.96667	2570
WOODSTOCK	-78.46667	38.9	875
WYTHEVILLE	-81.06667	36.91667	2450
<i>Kentucky</i>			
BAXTER	-83.33	36.85	1165
MIDDLESBORO	-83.73	36.6	1175
WEST LIBERTY	-83.27	37.92	765
<i>Maryland</i>			
BOYDS	-77.33	39.22	580
CAMBRIDGE	-76.07	38.57	10
HANCOCK FRUIT LAB	-78.18	39.7	425
LA PLATA	-77	38.53	140
NAT'L ARBORETUM	-76.98	38.9	50
OAKLAND	-79.4	39.4	2420
PRINCESS ANNE	-75.68	38.22	20
SAVAGE RVR DAM	-79.13	39.52	1500
<i>North Carolina</i>			
JACKSON	-76.2	36.32	10
MOUNT AIRY	-77.42	36.4	130
OXFORD	-80.62	36.52	1030
REIDSVILLE	-78.62	36.28	500
<i>West Virginia</i>			
BUCKEYE	-81	37.43	2550
GARY	-80.13	38.18	2100
LOGAN	-81.55	37.37	1430
MARTINSBURG	-81.98	37.87	640
MATHIAS	-77.98	39.4	530
PICKENS	-78.87	38.87	1625
ROMNEY	-80.22	38.67	2770
SPRUCE KNOB	-78.77	39.33	670
UNION	-79.52	38.68	3050
WHITE SULPHUR SPRING	-80.53	37.55	2110
WARDENSVILLE	-80.3	37.8	1920

Appendix C. Location of Weather Stations



Appendix D. Vineyard Factor Survey

I. VARIETIES

1. What varieties do you grow, how many acres of each, and how old-in years-is your *oldest* acreage of that variety? (Please use additional paper if necessary)

Variety	Acres	Age
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

2. Does one variety consistently do better (produces better quality fruit) than the others? If so, which one(s)? If all varieties do equally well, write in SAME.

3. Do some varieties consistently have more problems than others? If so, which one(s) and briefly what problems? i.e. Merlot--fungal, Pinot Noir--cold damage
If all varieties are equally effected by adverse conditions, write in SAME.

4. Does one variety consistently yield more fruit than others? If so, please name or write in SAME.

5. Do some varieties consistently yield less than others? If so, please name, if not, write in SAME.

OVER

II. CLIMATE

1. Please rate the following climate factors in the left column using list 1-6 on the right.

- | | |
|--|--|
| ___ Late spring frosts damage | 1=Has been a problem every year |
| ___ Early fall frosts damage | 2=Has been a problem 50% of the time
(Generally once every 2 years) |
| ___ Cold winter temperatures damage | 3=Has been a problem once every 3 years |
| ___ Hot summer temperatures damage | 4=Has been a problem once every 5 years |
| ___ Excessive humidity (promoting fungus) | 5=Has been a problem once a decade |
| ___ Excessive precipitation | 6=Has never been a problem |
| ___ Lack of precipitation(if irrigation used, leave blank) | |

III. TOPOGRAPHY

1. What is the change in elevation among all vineyard acreage? (Highest point of highest vineyard subtract lowest point of lowest vineyard--if you know the actual elevations, please write in.)

_____ feet

2. What is the average slope of your vineyards?

(A 0 to 2% slope is relatively flat, a 15% slope or higher is very steep: 15% slope means a 15 foot drop in elevation over a 100 foot plane.)

_____ % on average

3. Generally, what aspect(s) does your vineyard(s) face? Circle all that apply.

North NE East SE South SW West NW Flat Land-No Aspect

4. Do any varieties appear to produce more/better fruit when planted on certain aspects? If so, which varieties and on what aspect? i.e.Chardonnay on NE, Vidal Blanc on East, etc.

IV. GENERAL

1. What is the average growing season at your site? _____ days

2. Do you keep temperature and precipitation records on your vineyard? _____
 If yes, how many years have you collected such data? _____years

3. How would you characterize your soil?

4. What would you consider to be the single biggest climatic or topographic challenge to your vineyard? In other words, what do you spend the most time worrying about or dealing with? i.e. humidity, early frosts, excess precip., etc.

5. Conversely, what do you consider to be the best characteristic of your site? List several if desired.

6. Please rate the following problems using the list on the right.

- | | |
|---|--|
| <input type="checkbox"/> Poor soil type | 1=Never a problem |
| <input type="checkbox"/> Poor soil drainage | 2=Sometimes a problem |
| <input type="checkbox"/> Soil erosion | 3=Typically a problem (Dealt with routinely) |
| <input type="checkbox"/> Fungi/rot/mildew | 4=A bigger than average problem |
| <input type="checkbox"/> Disease/virus | 5=BIG problem |
| <input type="checkbox"/> Insects | |
| <input type="checkbox"/> Cold damage (winter) | |
| <input type="checkbox"/> Frost damage (spring & fall) | |
| <input type="checkbox"/> Late harvest precipitation | |
| <input type="checkbox"/> Surplus precipitation | |
| <input type="checkbox"/> Insufficient growing season | |

7. Briefly describe the site selection process that you went through when selecting your current vineyard location. Please list any predominant literature/sources you referred to or sought advice from.

8. To expedite my vineyard location process, could you please give me directions to your vineyard, referencing at least 2 state route numbers? (Vineyards attached to wineries need not fill out.)

Please feel free to make any additional comments that you feel are pertinent to this research on the back of this sheet, and once again thank you for your time and effort.

Vita

John D. Boyer was born on May 19th, 1969 in Roanoke, Virginia. He served three years as a quartermaster (navigator) in the US Coast Guard from 1988 to 1991. This service was aboard the USCGC Polar Sea, one of two icebreakers operated by the United States government. He graduated in May of 1996 with a Bachelor of Arts Degree in Geography from Virginia Polytechnic Institute and State University. He earned his Master of Science Degree in Geography in September of 1998, also from VPI&SU. Upon graduation, he accepted a teaching position in the Geography Department of Virginia Tech, and plans on entering a Ph.D. program in the following academic year.

John D. Boyer