Chapter 2: Vineyard Site Selection

2.1 Introduction

Production from a vineyard is dependent on two main factors - the siting of vines and vineyard management. The initial high capital investment required for viticultural production often precludes the relocation or redesign of a vineyard once established. The climatic and environmental factors at a location are often very difficult or impossible to change or control except through initial site selection. Thus the initial site selection and vineyard design is critical in determining the potential wine quality and quantity. Vineyard management and winemaking techniques will also help determine the final wine quality however these can be more easily altered throughout the life time of the vineyard. Thus site selection and vineyard design are the most critical decisions when establishing a new vineyard (Gladstones, 1992).

Stage 1 As early as March in northern Europe and September in the southern hemisphere, the buds left after winter pruning start to swell and the first signs of green can be seen emerging from the gnarled wood. This happens roughly when temperatures reach about 50°F (10°C) although different grape varieties vary.

Stage 2 Within ten days of budbreak, leaves start to separate from the bud and embryonic tendrils begin to be visible, and are all too vulnerable to frost which can strike as late as mid-May or mid-November in cooler districts of northern and southern hemispheres respectively. Late pruning can delay budbreak.

Stage 3 Between six and 13 weeks after budbreak the crucial flowering of the vine begins with the emergence of tiny caps of fused petals. These look very like miniature versions of the grapes that will be formed here once the caps fall, exposing stamens to be fertilized by pollen to create the berries.

Stage 4 The size of the eventual crop depends on the success of pollination. Poor weather during the ten- to 14-day flowering can result in *coulure*, whereby the stalks of an excessive number of very small berries shrivel, causing them to drop off, and also *millerandage*: different-sized berries on the same bunch.

Stage 5 The place of such buds as escape frost and rain is taken by hard, green baby grapes in June/December. These grapes swell during the summer and in August/February undergo *veraison*, whereby they soften and turn reddish or yellow. The ripening process begins and sugars start to build rapidly inside the grape.

Figure 2.1: The stages of development of the grape vine (from Johnson and Robinson, 2001)

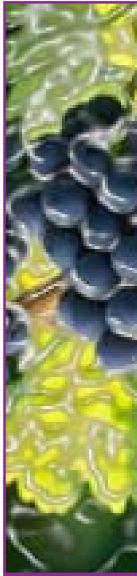
Section 1 of this chapter seeks to outline some of the climatic and environmental factors that need to be considered in site selection. This is followed in Section 2 by a review of current practices used in site selection and vineyard design.

SECTION 1

2.2 Climatic Site Selection Factors

Climatic suitability is perhaps the most important factor in site selection. With the exception of low rainfall (which can be offset by irrigation) most climatic factors such as, temperature, frost, humidity and incident sunshine are impossible or cost prohibitive to control. The susceptibility of winegrape yield and quality to abnormal climatic events differs with the stage of development of the vine. The major phenological events in grape development are bud break, floraison (flowering), veraison (berry colour) and harvest, with climate at veraison the most critical in determining grape quality (Jones and Davis, 2000).

The climate around a grapevine can be considered at different scales; macro-, meso- and micro-climate. Various authors differ on the interpretation of these terms, however, the definitions of Smart (1977) are widely accepted. According to Smart (1977) macro-climate refers to the mean regional climate as measured by one or more weather stations within the region. These measurements are usually available for many years (often >40 years). Meso-climate refers to the climate at a site



and accounts for the local effect of topography and environmental modifications of the macro-climate. Micro-climate defines the climate within and around the vine and accounts for the effect of vine growth and management on the meso-climate. The micro-climate of the grape is perhaps the most important of the three however it is influenced by the macro- and meso-climatic conditions, thus all three are of significance.

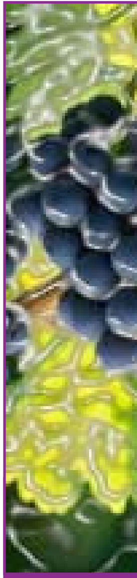
2.2.1 Temperature

Temperature, particularly in the month prior to ripening, plays a large role in the style of wine production, with great wine regions tending to be characterised by low diurnal fluctuations in temperature around harvest (Gladstones, 1992). Generally the lower the variation in temperature around the mean the greater the grape flavour, aroma and pigmentation at a given maturity level. For good table wines the rule of thumb states that the month leading up to harvest needs to be characterised by mean temperature of around 15-21°C (Johnson and Robinson, 2001).

Broadly speaking providing the climate is warm enough to allow grape maturity, quality is generally inversely related to the warmth and length of summer (Jackson and Lombard, 1993). Warmer temperatures usually result in higher soluble sugar content (Jackson and Lombard, 1993) that tend to produce wines high in alcohol and short on taste and aroma (Becker, 1977). Extremely high temperatures (>33°C) however result in reduced sugar assimilation by impeding transpiration and photosynthesis. The optimum temperature for net assimilation is 25°C (Alleweldt *et al.,* 1993) and 90-100% efficiency is achieved between 18-33°C (Kliewer, 1970). Efficiency declines markedly beyond these limits. Jackson and Lombard (1993) report conflicting studies on the importance of temperature at various stages of growth on final sugar content. Some research suggests that temperature during stages I and II are more important while others state that Stage III temperatures are more relevant (re Figure 2.1 for an indication of grape physiology at each stage of development). Gladstones (1992) identifies berry ripening (veraison to harvest) as the critical stage.

The acid and pH content of the must (grapejuice) have also been shown to be temperature dependent and the poorer quality often associated with warmer climates may in part be associated with low acid and pH production (Jackson and Lombard, 1993). Warmer temperatures also tend to increase phenolic content of the must (Herrick and Nagel, 1985) producing harsher wines. Given cooler temperatures at ripening, wines, in particularly white wines, are fresher, more acidic and finer in bouquet and aroma (Jackson and Lombard, 1993). For red wines the situation is complicated by the fact that must/wine colour has also been shown to be partially temperature dependent with anthocyanin production optimised between 17-26°C (Coombe, 1970). Thus warmer average temperatures are preferred for good colour development. However Kliewer and Torres (1972) noted in Pinot Noir and Cabernet Sauvignon that warm night temperatures were more important in determining wine colour and high daytime temperatures (>30°C) during ripening were detrimental.

Vegetative vine growth seems to be optimised by mean temperatures of 23-25°C (Buttrose, 1969) which coincides with optimal net assimilation. Fruitfulness tends to be improved by high temperatures during early bud development in late spring (Gladstones, 1992) and reduced by exposure to cooler temperatures near flowering (Ebadi *et al.,* 1996). Budburst is sensitive to fluctuations in air temperature (Martin and Dunn, 2000). Low temperatures coinciding with budburst have been reported to increase flower numbers but May (2000) indicates that further research is needed to under-



stand this phenomena.

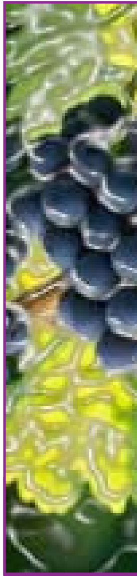
Vineyards in areas with a sustained foliated period post-harvest (such as climates with warm autumn temperatures) are able to re-accumulate carbohydrates prior to defoliation. This improves bud and inflorescence differentiation and supports spring growth in the following year (Shaulis and Pratt, 1965). The effect of temperature on bud initiation is cultivar dependent with Sultana reported as the most sensitive (Sommer *et al.,* 2000).

The use of mean temperatures to describe a localities climate and its effect on growth may produce misleading statistics. Elevated daytime temperatures may actually suppress photosynthesis and net assimilation however the mean daily records may not recognise this (Happ, 1999) resulting in an inflated estimate of grape maturity. Grape productivity is also dependent on actual temperatures, not just mean temperatures, and in particular the frequency and severity of extreme events. While different grape cultivars respond differently to cold temperatures there are many cultivars that are cold hardy. Despite this temperatures below -25°C will kill most cultivars and Prescott (1965) quotes a range of -15 to -18°C as the limit below which vines suffer severe damage. Jordan *et al.* (1980) recommend that any site with two or more occurrences of temperature events below -26°C in a ten-year period are unacceptable for grape production. Often of more concern than absolute lows are sudden temperature drops accompanied by frost after a period of warm weather (Gladstones, 1992). This can occur even in regions of relative high mean temperature. A severe frost after budburst can devastate the seasons production. Cooler temperatures near flowering will reduce fruit set (Ebadi *et al.*, 1996). Similarly extreme heat events, often associated with hot winds and low humidity can cause damage especially around veraison. At most risk are red varieties and berries that are well exposed (Carbonneau, 1985).

2.2.2 Solar Radiation

Wine grapes require a photosynthetic-active radiation (PAR) > 700Em^{-2}s^{-1} for optimum photosynthesis. Below ~30Em^{-2}s^{-1} carbohydrate consumption will outstrip production (Smart, 1973). In Australia solar radiation is usually not limiting and much of Australia's viticulture production is greatly facilitated by high light intensity (Howell, 1999). Clear skies have a PAR of ~2500Em^{-2}s^{-1} and overcast skies between 300-1000Em^{-2}s^{-1} (Jackson and Lombard, 1993). High light intensity favours production throughout the entire season however it appears most beneficial during spring and the period leading up to and at veraison (Gadille, 1967). In general higher levels of radiation, either intensity or duration, result in increases yield and/or sugar content (Jackson and Lombard, 1993). Increased light intensity also reduces the amount of leaf area required to ripen a crop (Howell, 1999). Conversely, in cool climate viticulture, continued overcast conditions have been shown to reduce net photosynthesis (Kliewer 1970; Howell, 1999). Ebadi *et al.* (1996) noted that as shading increased then yield decreased. Shading also promotes decreased sugar content and increased acid content in berries (Smart *et al.*, 1988 and Morrison 1988). From these studies it can be inferred that 100% solar saturation is desirable. While this is true in cooler climates, very sunny climates are often characterised by high temperature variability and low relative humidity. Therefore Gladstones (1992) prefers to describe the influence of solar radiation on production as positive provided temperature variability and relative humidity remain favourable.

As well as influencing yield, sugar and acid content, incident radiation can strongly influence grape



flavour. Sun exposed berries tend to have higher phenolic and anthocyanin concentration however overexposure can produce undesirable wine aromas (Carbonneau, 1985). These undesirable aromas are due to an alteration in phenolic compounds within the grape producing detrimental rather than optimal anthocyanins (Haselgrove *et al.*, 2000). Growers therefore need to properly manage the vine canopy in conjunction with the local meso-climate to ensure that the grapes are not over- or under-exposed to solar radiation.

While temperature rather than solar radiation appears to the determining factor for wine quality, Gladstones (1992) has reported some recommended minimum criteria for solar radiation. For early maturing varieties at least 1200 growing season sunshine hours are required. For cool climate viticulture if the region is warm enough then it is likely that this threshold will be exceeded. Cool climate regions with less than 1600 sunshine hours produce only table wines with the body and alcohol content of the wine usually positively related to temperature units. In warm climates once 1700 effective day degrees is exceeded then temperature is no longer limiting and sunshine hours begin to dominate berry sugar concentration and wine style. In these climates a minimum threshold of 1500 -1600 sunshine hours is needed and below 1750 sunshine hours only table wines are generally produced. From 1750-2000 sunshine hours fortified and low-acid table wines can also be produced. Hot climates with >2000 sunshine hours readily produce raisining and usually poor quality table or fortified wines. There is evidence (Halliday, 1993) to suggest that in warmer climates more sunshine hours to reach optimum maturity. This is attributed to increased respiration consuming higher levels of assimilate at increased temperatures.

2.2.3 Wind

The obvious detrimental effect of wind is the physical damage to the canes which is most serious in spring (Hamilton, 1988) and can lead to reduced shoot growth, leaf size, stomatal density (Takahashi *et al.*, 1976) and lower yield (Kliewer and Gates 1987; Hamilton, 1988). Wind also reduces transpiration (Kobriger *et al.*, 1984) and photosynthesis leading to lower soluble sugar levels (Jackson and Lombard, 1993). Winter winds may serve to reduce the heat budget for a site and thus increase cold injury (Dry and Smart 1988). Cooling winds during the season have been reported to reduce stomatal conductance, transpiration and photosynthesis (Kobriger *et al.*, 1984).

Wind may also have a positive effect on vine growth and grape quality. Light breezes maintain air circulation around the berries stopping the buildup of humidity and maintaining an even temperature within the canopy. Photosynthesis is also enhanced through internal leaves receiving more direct sunlight (Kreidemann *et al.*, 1973) although shaded leaves do not tend to achieve the same level of photosynthesis as unshaded leaves. The hazard of frost damage is also reduced during windy periods (Gladstones, 1992, Trought *et al.*, 1999).

2.2.4 Frost

Growing season length is another critical parameter for vineyard site selection. Jordan *et al.* (1980) have defined growing season as the number of consecutive days where the minimum temperatures is above 29°F (-2°C). They classify sites as either unsuitable (< 165 days), marginal (166 - 180 days), preferable (> 180 days). Jorgensen *et al.* (1996) use 31°F (-0.5°C) as a temperature threshold below which frost damage will occur. The actual limit is fuzzy as temperature will differ at different heights in the canopy. However sub zero temperatures will produce frost events. Frost events may be caused by an advection event (horizontal movement of a cold air mass), or a radiation event (loss of heat into the atmosphere) (Jorgensen *et al.*, 1996). Regardless of the cause, frost may impact vine production at any time in the growing cycle (Gladstones, 1992) and the number of frosts per season has been shown to be a significant determinant of final wine quality (Nemani *et al.*, 2001).

Frosts however tend to occur at the start (spring) and end (autumn) of the growing cycle. Spring frosts after the initiation of bud development may severely damage the potential fruiting load for the season (Trought *et al.*, 1999) while autumnal frost will directly damage the canes and maturing berries. Damage to canes and leaves leads to premature senescence and a lack of post harvest assimilate storage to support the following seasons spring growth (Shaulis and Pratt, 1965, Trought *et al.*, 1999).

The best method of avoiding frost damage is by good site selection and vineyard layout (Snyder *et al.*, 1992, Trought *et al.*, 1999). Early season varieties should be planted at higher elevations with an easterly aspect to promote rapid warming in the morning (Snyder *et al.*, 1992). Cultural practices such as maintaining soil moisture, trimming or eliminating inter-row ground cover, using elevated cordons, employing late spur pruning to delay bud break, retaining extra canes as a risk management that can be later pruned and avoiding cultivation will reduce the risk of frost (Snyder, 1992; Trought *et al.*, 1999). Some reports have been published into the chemical delay of bud break (Di Cesare, 1968; Dami *et al.*, 1996; Myers *et al.*, 1996) however the mode of retardation is unclear and the lack of commercialization would indicate that results are unreliable (Trought *et al.*, 1999).

Figure 2.2: Heaters (chaufferettes) in operation in France (top) and overhead sprinklers providing an ice covering for the vines (bottom) (courtesy of Chablis-geoffrey.com).

The likelihood of a frost event has been linked in New Zealand to the daily temperature at 3pm (Trought *et al.*, 1999). If a frost is likely then active measures such as overhead sprinklers or butane heaters may be employed in susceptible vineyards. Overhead irrigation takes advantage of the thermodynamics of water that results in a slight warming as ice is formed. Thus by encasing the buds/florets in ice some protection is afforded (Wilson, 1998; Trought *et al.*, 1999). Heaters work by direct radiation but also by setting up convection currents within the vineyard. The moving airmass retards the development and severity of the frost event (Wilson, 1998; Trought *et al.*, 1999). Wind machines and helicopters have also been used successful to mix warmer upper air strata with the cool air of the vineyard to impede frost development. In areas with low frost risk helicopters are generally preferred to wind machines as they have low labour cost, low operational cost per unit area and require no ongoing maintenance (Trought *et al.*, 1999). It is important to note that wind machines and helicopters are only effective in reradiation frosts and under advection events may actually increase frost damage (Trought *et al.*, 1999)

2.2.5 Humidity

Humidity and relative saturation deficit may play a major role in fruit quality. Very high and very low humidities can adversely influence grape development.

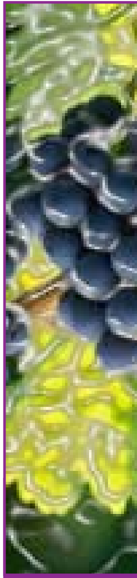
In very arid hot climates, with low humidity, transpiration demands outstrip root water uptake thus even with adequate soil moisture vines will close stomata and cease photosynthesis to conserve moisture (Freeman *et al.*, 1980). As the saturation deficit increases it has also been shown that the moisture:carbon dioxide ratio increases thus growth (yield) per unit of water transpired is decreased (Barber, 1985). This may not necessarily be a problem for moisture stress if adequate irrigation is available however the amount of potassium accumulating in the vine (and fruit) is proportional to the amount of water absorbed from the soil (Barber 1985). Thus low humidity will promote increase potassium content in the grapes (resulting in lower tartaric acid concentration) and decreased must quality, especially in warm to hot climates where must acid is naturally low (Gladstones, 1992).

High relative humidity will promote fungal infection. This is exacerbated with excess rain, low solar radiation and high temperatures. Gladstones (1992) suggest a relative humidity between 50-65% as the ideal level for the ripening of grapes for table wine and slightly lower (40-50%) for fortified wines. Most of the inland wine regions of Australia tend to have insufficient humidity and/or summer/autumn rain for disease propagation.

2.2.6 Rainfall

Lack of rainfall can be a severe influence on grape productivity in the absence of good quality irrigation water. Johnson and Robinson (2001) recommend a minimum level of rainfall/irrigation of 500mm, higher if the growing season is characterised by high evapotranspiration rates. Excess rainfall is also a problem and most quality wines are produced in regions where annual rainfall does not exceed 700-800mm (Jackson and Schuster, 1987). However it is the timing of the excess rainfall that is of more consequence than the amount and examples of successful vineyards in high rainfall areas exist, for example the Galicia region in northern Spain (Johnson and Robinson, 2001).

During the differentiation of fruitful buds in late-spring/early summer the vine is susceptible to moisture stress. Indirectly heavy spring rain can promote vigorous growth which suppresses bud differentiation and fruit setting by monopolizing plant assimilates and causing overshading (Johnson and Robinson, 2001). Flowering and berry set are moisture sensitive and stress at this stage can markedly affect yield. Excess rain at flowering may also suppress yield. Adequate moisture supply up until veraison has been shown to increase yield and lower final sugar content (Alleweldt and Ruehl, 1982). From bud differentiation until the week or two before veraison, moisture stress is well tolerated by the vine. Severe moisture stress in the few weeks up until and after veraison has been shown to inhibit both berry and flavour development (Carbonneau and Hughlin, 1982), however,



moderate stress at this stage appears to be favourable for colour and flavour by limiting berry size, ceasing vegetative growth and redirecting assimilates to the fruit (Ludvigsen, 1987; Mathews and Anderson, 1988). Stress at this stage does not alter the ripening rate (Mathews and Anderson, 1988).

From the period post veraison to harvest it is essential that the vines avoid moisture stress if yield is to be optimised. Stress leading up to ripening reduces photosynthesis and thus the movement of sugar to the berry but may also increase the movement of potassium from the leaves to the fruit. The higher potassium:sugar ratio tends to increase must pH and lower wine quality (Freeman *et al.*, 1982; Iland, 1988). Generally by this stage vegetative growth has been discouraged and the fruit is the dominant sink for assimilates. However in cool wet climates vegetative growth may continue and affect productivity, especially in under cropped vines. Excess rain in this period is also undesirable as it may promote berry splitting, especially in hotter, drier climates (Galdstones, 1992). The presence of moisture may promote fungal diseases, particularly botrytis (Jackson and Lombard, 1993).

The threat of excess rain may also have a secondary detrimental effect by forcing growers to pick the crop while grapes are still immature as a risk management strategy (Jackson and Lombard, 1993). Excessive rainfall (or irrigation) has also been shown to delay ripening even in hot climates (Jackson and Cherry, 1987).

Sufficient moisture from harvest to natural leaf fall is important to maintain root growth, photosynthetic activity and assimilate for the following vintage. A good build up of assimilate post harvest will ensure a vigorous, even budburst and early growth in the following spring (Gladstones, 1992).

In general the best rainfall environments for grapes are either those with an even rainfall distribution and moderate temperatures and sufficient sunshine or Mediterranean climates with dry hot summers and regular winter rainfall coupled with sufficient soil moisture stores or irrigation (Gladstones, 1992). Bohmrich (1993) notes that the majority of the viticultural regions in Europe, Australia, South Africa , USA and Chile are characterised by one or the other of these rainfall patterns.

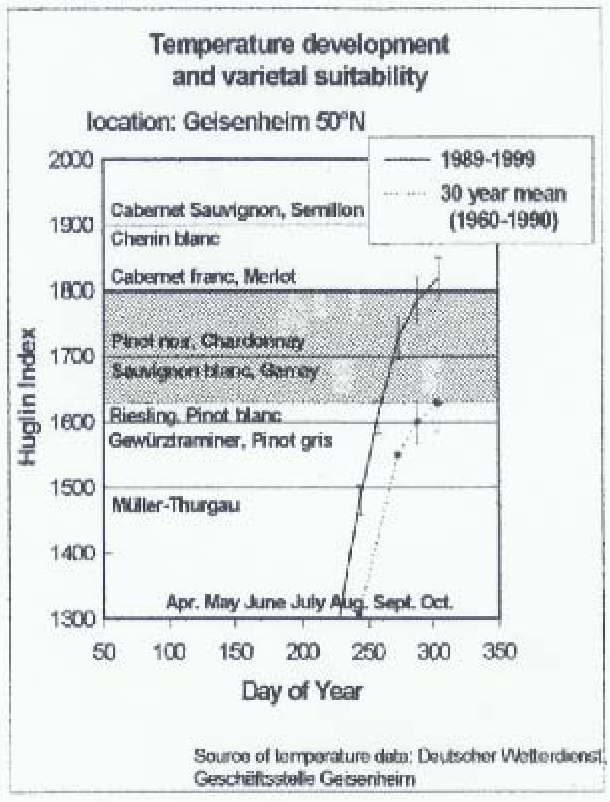
The pattern of rainfall had also been observed to have a significant effect on the influence of soil on wine quality. In Mediterranean climates soil plays a comparatively small role as a wine quality determinant compared to temperature. In regions with considerable rainfall during the season, soil is a major component in determining the terroir of a site (Bohmrich, 1996). This may not be solely due to rainfall, as summer temperatures are often higher in Mediterranean climates, but the observation helps to explain some of the disagreement in terroir between the "new world" (predominantly Mediterranean) and the old world (which includes many famous northerly regions such as Bordeaux, Burgundy and Germany with relatively constant year round precipitation) (Bohmrich, 1996).

2.2.7 Impact of Global Warming

Global warming, with its associated predicted increases mean temperatures, UV radiation and atmospheric CO_2 concentration, is set to have a profound effect on the global wine industry. While the degree of average temperature rise over the next year is open to conjecture there is a consensus that actual warming will be unequally distributed (Tate, 2001). Warming will be greater toward the poles, at night and during winter. This has some serious detrimental as well as beneficial effects on grape production.

The poleward shift of temperature isotherms will make current marginal wine regions more secure and less susceptible to severe winter damage. In Europe the expansion north, estimated at 10-30m per year (Kenny and Harrison, 1993) will not be as simple as shifting isotherms but will depend on local climatic influences (Tate, 2001).

Initial predictions (Kenny and Harrison, 1993) on viticultural production in Europe forecast an expansion of the European viticultural industry eastward into the Ukraine rather than north where sunlight is likely to still be limiting despite increased temperatures. This complements the view of Shultz (2000a) who identifies the increased risk of drought as having a dramatic impact on grape production in the Iberian peninsula and foresees a movement of grape growing eastward. Even in areas where precipitation is not predicted to markedly decrease, an anticipated increase in evapotranspiration rates have lead to predictions of a 20-30% reduction in available soil moisture in the Mediterranean region where water is already scarce (Shultz, 2000b). Warmer winter temperatures may also effect existing viticultural regions where the winter dormancy period is already marginal.



Source of temperature data: Deutscher Wetterdienst, Geschäftsstelle Geisenheim

Figure 2.3: Example of a shift in cultivar suitability in Germany due to climate change (from Shultz 2000b).

Studies of predicted temperature rises in Australian viticultural regions at the CSIRO (McInnes *et al.*, 2003) indicate an expected mean temperature increase of between 0.3-1.7C° by 2030 and 0.8-5.2C° by 2070. Increased minimum temperatures will promote earlier budbreak and flowering but also reduce the number of frosts and increase the growing season length producing an overall decrease in frost risk (Nemani *et al.,* 2001). Mean temperatures are expected to increase in all seasons but less so in winter. Annual precipitation is expected to decrease in the south-west and south-east of the continent and some parts of Queensland however the model results for the rest of the continent including much of eastern Australia are uncertain (McInnes *et al.*, 2003). There is a projected general shift for most viticultural areas to lower winter/spring rainfall and higher summer/autumn rainfall. An increase in extreme daily rainfall is also forecast which will result in heavier rainfall events and longer dry spells (McInnes *et al.*, 2003)

Possibly the most contentious problem with rising temperature is a shift in localities that are 'ideal' for particularly varieties. This is particularly relevant to cool climate production where cool night temperatures are required for acidity retention. If mean temperatures rise 5C°, and this increase is weighted toward night-time temperatures will Burgundy still be the ideal location for Pinot Noir? While it may no longer be ideal for Pinot Noir it may well be suitable for a different variety. Shultz (2000b) illustrates that the suitable varieties for Geisenheim in Germany have already shifted from

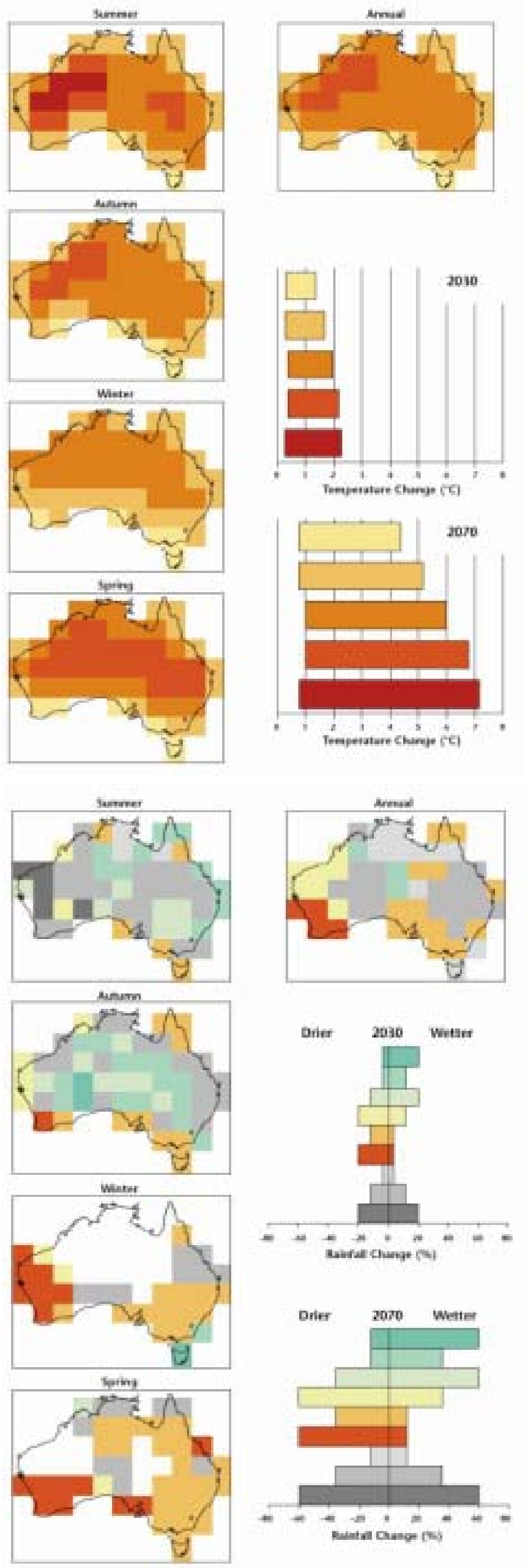


Figure 2.4: Predicted temperature and rainfall changes for Australia for the next 70 years (from McInnes et al, 2003).

Reisling, Pinot Gris and Pinot Noir to Merlot or Cabernet Franc when using the Huglin climate index calculations for the periods 1960-1990 and 1989-1999. This may create serious problems in countries like France where flexibility in grape production is difficult due to industry regulation (Tate, 2001).

As vines are able to move into previously inhospitable areas so too will pests and diseases. Tate (2001) hypothesises that Pierce's disease will move into the Oregon and Washington wine regions where it is currently suppressed by winter temperatures. Trends towards increasing humidity and air temperature indicate a increased future threat from fungal and vector borne diseases for agriculture in general (Watson *et al.*, 1998). Researchers in Australia are also concerned with the potential spread of pests and diseases and are attempting to model the potential spread given current estimates of global warming and knowledge of the lifecycle of pests and diseases (Emmett *et al.*, 2000). As well as a possible increased pest/disease threat, global warming may also nullify or invigorate current integrated pest management strategies and these must also be reassessed with climate change (Emmett *et al.*, 2000). It is unclear how rainfall will be distributed, however, regions that experience increased autumnal rain will suffer from increased disease and pest pressure (Gladstones, 1992)

Rises in sea-level without remedial action may also significantly influence viticulture especially in Europe. Like temperature, the degree of sea-level rise is debatable but the general consensus is that it will occur. For Australia, sea level rise will have little impact on viticulture as the majority of grape growing regions are located inland. Some smaller coastal regions, for example the Swan and Margaret rivers of Western Australia and the Mornington Peninsula in Victoria may be affected (Tate, 2001). From a global perspective the vineyards of Bordeaux which includes some of the most recognisable names in the world would flood if sea level rises in the 3-5m range. This increase may flood a large part of the riverplain between Bordeaux and the Atlantic creating a large waterbody that will further influence the meso-climate of the Bordeaux region (Tate, 2001).

Increased atmospheric CO_2 concentration is usually perceived as beneficial to plant growth but independent studies of the combined effect of higher CO_2 concentrations, temperatures and solar radiation indicate that yield may actually be depressed (Shultz, 2000a). Research is still lacking on the effect of CO_2 on assimilate (sugar and starch) accumulation in the fruit and vine, the timing of budbreak and flowering and the final composition of the fruit (Tate, 2001). Predicted increases in solar radiation especially UV-B radiation are expected to impact on grape composition and flavour by altering secondary metabolites such as flavenoids, amino acids and carotenoids (Shultz, 2000b; Keller, 2000). Keller (2000) also report that vine growth is altered and water use efficiency depressed under increased levels of UV-B radiation

Global warming is predicted to increase the variability of extreme weather events thus viticultural regions should anticipate more drought years and more flood years. Australia already endures a highly variable climate due to the impact of short-term events, such as the El Nino phenomena, and the variability in rainfall is expected to increase even in areas where annual rainfall is predicted to decrease slightly (McInnes *et al.*, 2003) However while globally climatic variability is expected to increase, McInnes *et al.* (2003) predict relatively small changes in future temperature variability for Australia. They forecast that temperature extremes will shift with changes in average maximum and minimum temperatures. Thus more extreme heat events are expected but also less freezing events.

The results of these changes will lead the Australian viticultural industry into a situation where the winter dormancy will be reduced thus the season will begin earlier and thus ripening earlier during the hotter summer months. Higher temperatures at ripening may depress quality and will shorten the harvest window for premium quality wines (McInnes *et al.*, 2003). Less water is likely to be available, due to either or both increased evapotranspiration and lower precipitation, and yield/quality variability is likely to increase creating a higher economic risk for the producer.

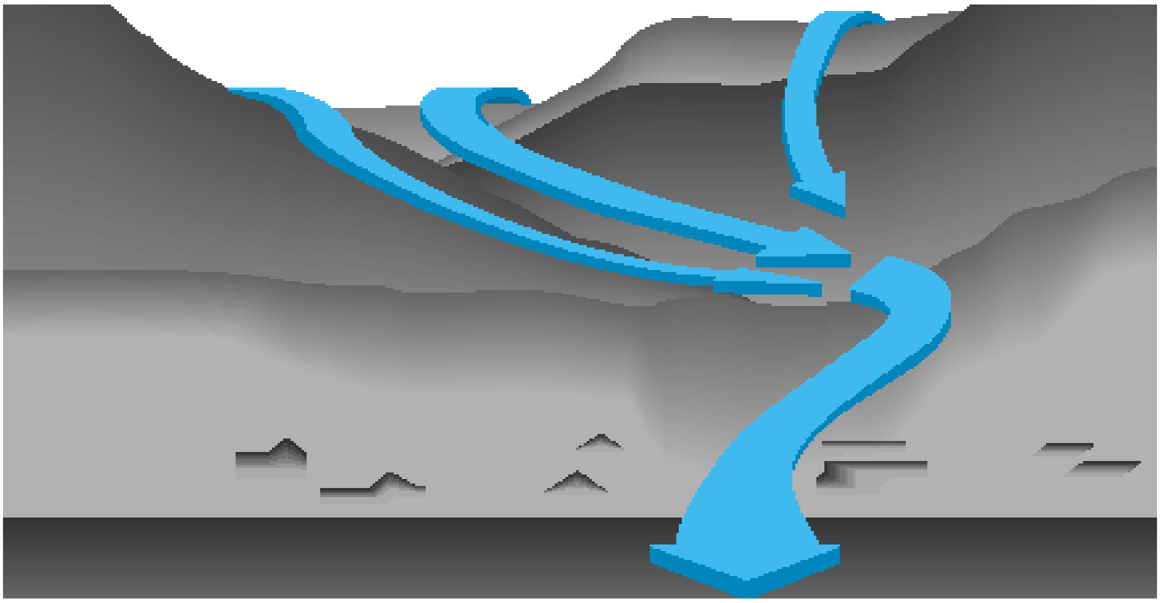
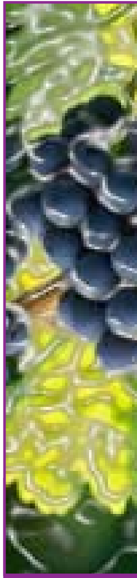


Figure 2.5. Example of katabatic flow over a landscape (courtesy of Environment Canada http://www.ec.gc.ca).



2.3 Topographic Site Selection Factors

The topographic characteristics of a site are recognised as having an affect on vine production by influencing the meso-climate of the site (Gladstones, 1992). Topography can also affect vine production through its influence on the evolution of soil type at a site. From an analysis of premium vineyards from around the globe Gladstones (1976; 1977) found that premium vineyards tended to have a reduced diurnal fluctuation in temperature due to two or more of the following topographic characteristics:

1. Located on slopes with excellent air drainage and situated above the fog level
2. The slopes are on projecting or isolated hills and have outstanding air drainage.
3. Directly face the sun during part of the day (Part easterly aspects are common)
4. Tend to be close to large lakes or rivers if located inland

Therefore the dominant topographic features that influence vine performance appear to be slope, aspect and waterbodies.

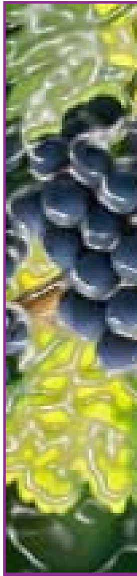
2.3.1 Slope

The location of the vine on a slope is more important that the degree of the slope as location will determine how the vine is affected by the katabatic drainage of air. At night colder denser air tends to settle toward the base of a slope. Directly above this cold layer a 'thermal zone' of warm night air is established on the low- to mid-slope. Higher up the slope the temperatures drops again in response to altitude however the diurnal temperature range is still reduced. This effect is especially pronounced in isolated hills and projecting ranges. Gladstones (1992) identifies this as the dominant topographic effect in Australia and the best approach to trying to minimise diurnal temperature range. Slopes also have the advantage of better drainage and a reduced risk of waterlogging (Bohmrich, 1996).

At higher latitudes the angle of the slope becomes more important as radiation interception becomes more limiting. Steeper slopes will receive more radiation per square metre provided they have a suitable aspect. Steep slopes (greater than 15%), however, can create problems with machinery being difficult, if not dangerous, to operate. The potential for soil erosion is also increased (Wolf, 1997).

2.3.2 Aspect

Aspect is more important in higher latitudes where radiation is weaker, due to the angle of the sun, and light interception may be limiting to growth. With the possible exception of Tasmania, Australian vineyards receive sufficient radiation regardless of aspect. Despite this, research has shown that sun-facing aspects are favourable even in lower latitudes (Gladstones, 1992). In the Northern Hemisphere east, south and west facing slopes are preferred while in the Southern Hemisphere east, west or north facing aspects. Of these east and south or north (dependent on Hemisphere) are preferred (Wilson, 1998). This is partly attributed to westerly winds and storms, in both hemispheres, that can damage vines up until flowering (Gladstones 1992). Easterly aspects also receive the first of the morning radiation warming canopy and soil temperatures fastest when temperatures are generally at their lowest and most limiting (Wilson 1998, Gladstones 1992). Conversely they are less exposed



during the hottest part of the day (early-mid afternoon) when westerly slopes bear the brunt of both wind and sun exposure. Sun-facing aspects can also be problematic in areas where late frost events are common. Increased warming during winter will promote advanced budbreak, increasing the risk of frost damage. In colder climes heating during the day followed by sudden severe drops in temperature at night can also lead to bark splitting and cold damage (Wolf, 1997).

2.3.3 Water bodies

A waterbody can have a large effect on the local climate due to its relative temperature inertia compared with the surrounding land masses (Magarey *et al.*, 2000). While reduced temperature variability is pronounced near the ocean, large inland waterbodies such as lakes and rivers, can influence temperature up to a few kilometres away. This provides protection against frost and high afternoon temperatures (Gladstones, 1992). The Finger Lakes and Lake Erie Belt regions of New York State, USA, is a prime example of a region where grape production is only possible due to the influence of the lakes (Magarey *et al.*, 1995). This phenomenon is rare in Australia due to the lack of permanent inland waterbodies. Maritime influences are more common in coastal regions, like the Hunter Valley and Margaret River regions, however the majority of Australian vineyards are located inland away from maritime influences.

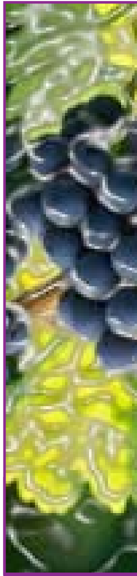
2.4 Soil Site Selection Factors

The debate on the influence of soil on wine quality is a long and at times colourful one, often centred around the concept of terroir and the influence of soil chemistry on grape quality. The importance of soil type on the quality of wine has long been appreciated. Gladstones (1992) documents several 19th and early 20th reports of soil influence on wine. These reports comment on the production of delicate, light wines from sandy soils that are often lacking in strength and colour but perfumed and lively. Wines from limestone soils have increased alcoholic strength while clay soils tend to acidic, less delicate grapes, high in tannins that produce deep, rich red wines. All 19th century reports found by Gladstones quoted that rocky, stony or chalky soils gave the best wines. However all these reports focus on the physical characteristics of the soil.

In a study of 54 experimental sites in Italy, Poni *et al.*, (1996) found that the most fertile soils resulted in overproduction and the worst viticultural and oenological results. The best results were reported on moderately fertile soils with some pedological limitations. The poorest soils produced the most variable results and were heavily dependent on climatic influences. Despite these general trends, Winkler *et al.*, (1974) note that good to excellent quality grapes have been produced for numerous varieties on practically all soil types, except very heavily textured soils.

2.4.1 Chemical Properties

While soil type has long been appreciated as a wine quality determinant the direct influence of soil chemical properties on must and wine quality is a contentious area. Traditionally vineyard sites are picked on soil physical properties rather than chemical ones. Good viticulture soils are often infertile leading to a belief that soil chemicals are not important for good grape production. Certainly the concentration of certain ions in the must is important in determining must quality however the relationship between chemical concentrations in the soil and the must have not been well under-



stood. Halliday (1993) observes that from his experience, Australian viticulturists tend to disbelieve in a relationship between soil mineral composition and must and wine quality. Seguin (1986) also notes that knowledge on the relationship is lacking and if the knowledge did exist it would be possible to produce great wines with chemical additives.

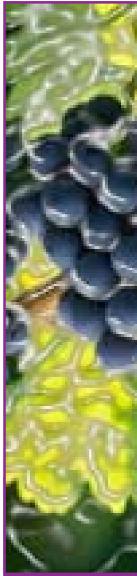
The exceptions to this general lack of chemical knowledge are potassium and nitrogen which have been documented as influential on wine quality. In the past 10 years researchers have started to fill this knowledge gap and investigate the effect of other ions on grape production. However the correlation of organoleptic wine qualities with soil chemistry is still considered circumstantial by most in the industry and little credence has been given to the research (Bohmrich, 1996). Despite this many prominent industry figures in Australia and internationally have not discounted the possible contribution of soil minerals to wine flavours and aromas (Robinson, 1994).

Potassium is a dominant element in the determination of must quality. Its concentration in the fruit is dependent on several climatic factors. In cool climates excess soil potassium is tolerable as the climatic conditions are not favourable for uptake by the vine. However K deficiency may be a problem as it reduces vegetative growth and yield and increases the vines susceptibility to fungal and bacterial infection (Huber and Arny, 1985, Baveresco, 1989). Cool climates, often associated with low light intensity, are already susceptible to fungal attack. Robinson (2000) notes that most soils in Australian viticultural regions supply adequate K. In hot climates excess K is a problem as it can be hyperaccumulated by the vine, especially if there is a large flow of water through the plant (Ruhl, 2000). Research has shown that the correct choice of rootstock can minimise the uptake of K (Ruhl and Walker, 1990; Ruhl, 2000).

An excess availability of nitrogen is generally detrimental as it promotes excessive vegetative growth. This in turn promotes disease by increasing shading and canopy humidity and may also create deficiencies by increasing the vegetative demand for micro-nutrients (Bavaresco, 1989). Nitrogen deficiency is also undesirable and leads to reduced grape sugar and wine quality (Gladstones, 1992, Keller *et al.*, 2001). Increasing nitrogen supply to grapevines (cv Muller-Thurgau) has been shown to improve fruit set and decrease inflorescence necrosis, however increased bunch-stem necrosis and *Botrytis cinerea* bunch rot were also observed (Keller *et al.*, 2001). This study highlights the need to for viticulturists to understand the vines response to the soil in their vineyard. Of particular importance is the ability to match nitrogen inputs to vine response to achieve the desired level of vegetative growth for the trellising system used (A case for PV and VRT!). Both nitrogen and potassium are most actively taken up prior to veraison and uptake is reduced from veraison to full ripeness when translocation of ions from vegetative to reproductive organs is more common (Schaller, 1999).

Calcium and magnesium inhibit the translocation and uptake of potassium in the plant. In cool climates where this may be a problem the advantages of calcareous soils are actually preferred as their other advantages, good structure, drainage, moisture supply and thermal conductivity, outweigh this disadvantage (Winkler, 1962). Experiments with phosphorous fertigation have shown increased cluster numbers, must free monoterpene content, and higher scores in sensory evaluation (Bravdo, 2000; 2001)

Trace elements are required for enzyme reactions in the plant and deficiency may limit production however excess levels do not appear detrimental (Robinson, 2000). The grapevine is very tolerant of



soil pH and the main influence of pH may be its influence on the availability of trace elements (Gladstones, 1992). Heavy metal concentration in vine organs is not related to soil concentrations (Stockley *et al.*, 1997) and the majority of heavy metals taken up by the roots are immobilised within young feeder roots (Angelova *et al.*, 1999). Heavy metal concentration in the vine appears more closely related to atmospheric aerosol concentrations (Angelova *et al.*, 1999). In general most viticultural soils in Australia supply adequate levels of trace elements although alkaline soils may be Zn or Mn deficient and acidic soils low in Cu and Zn (Robinson, 2000).

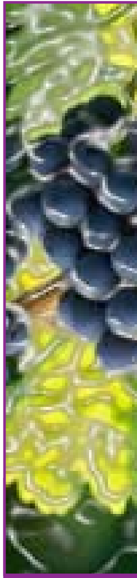
Organic matter in the soil plays several key roles including nutrient supply, improving soil moisture storage and improving soil structure. Fresh material may over supply nitrogen and weathered material is preferable (Gladstones, 1992). Porter (1999) reports that organic matter applied as mulch can be effectively used to protect vines against fungal pathogens, loosen heavy soils, weed and pest control, improve nutrients and increase yield.

Salt is perhaps the largest soil chemical problem in Australian agriculture. Salt-affected soils are a major threat to production in many Australian viticultural regions, particularly through the Victoria/ South Australian riverlands and the irrigation districts in Southern NSW (Cass *et al.*, 1995). Salt can impact on viticultural production systems through salinity (overall concentration of soluble salts) or sodicity (the relative concentration of sodium to magnesium and calcium) (Cass *et al.*, 1995). Many of Australia's viticultural soils are naturally sodic but naturally saline soils are rarer and generally associated with inland salt lakes and estuarine conditions (Fitzpatrick *et al.*, 1992). The current problems of salinity threatening Australian agricultural land are more closely associated with sodic soils that have become saline as a result of land clearing and irrigation practices (Fitzpatrick *et al.*, 1995).

General threshold values for the influence of EC_{se} on plant yield are given in Table 2.1 (after Cass *et al.*, 1995 and Finnigan, 1999). The generally accepted threshold at which salinity begins to impact on vegetative growth and yield is 2 dS/m (EC_{se}) however reports have shown that this figure may be around 1.5 for own rooted vines on heavier textured soils (Cass *et al.*, 1995). In general vines on heavier textured soils have been shown to be more susceptible to salinity (Stevens, 1996).

Salinity affects vine production by lowering bunch numbers and berry weigh thus reducing yield. It also impacts on quality by increasing the chloride concentration and pH of the must but does not appear to affect sugar levels (Prior *et al.*, 1992). In measuring the terpene concentration of Cabernet Sauvignon grapes grown in moderately saline and non-saline treatment plots, Bravdo (2001) reported a significant difference in 16 of 36 terpenes measured. A sensory analysis noted a distinct character in the wine from the saline plots but did not find a significantly different quality score.

Stevens and Harvey (1994) experimented with different salt concentration in irrigation water for an entire season. They found that as the salt concentration increased from 2mM to 60mM, yield was decreased by 51%. Experiments with transient soil salinisation through irrigation water did not impact on growth or yield but did increase leaf petiole sodium and chloride contents (Stevens and Harvey, 1990). However sustained irrigation with saline water between veraison and harvest impacted on yield (Stevens *et al.*, 1995) but the influence of saline irrigation water is minimal when used pre-veraison or post-harvest (Stevens *et al.*, 1995, Stevens, 1996). This may have serious con-



sequences for irrigation management if a growers irrigation supply is supplied from multiple sources with different levels of contamination.

Salinity Hazard	EC_{se} (dS/m)	Effect on Plant yield	Effect on vines
Non-saline	<2	Negligible effect	Negligible effect*
Slightly saline	2-4	Very sensitive plants affected	Own rooted vines affected
Moderately saline	4-8	Many plants affected	Own rooted vines severely affected. Rootstocks affected to varying degrees
Very saline	8-16	Salt tolerant plants unaffected	Vines non productive
Highly saline	>16	Salt tolerant plants affected	Grapevines cannot survive

Table 2.1: Effect of soil salinity (EC_{se})on plant and vine performance (adapted from Cass *et al.*, 1995 and Finnigan, 1999).

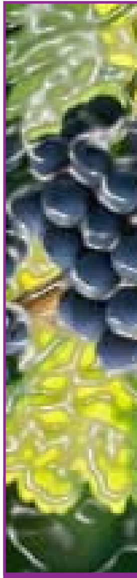
Grapes are able to more readily absorb sodium through leaf tissue than the root system. Therefore the impact of overhead irrigation with saline water on yield loss compared with drip irrigation has been reported as 6 fold and the uptake of salt into must and leaf tissue is 5-15 times greater (Stevens *et al.*, 1995). The impact of salinity is much more serious when it is combined with even mild cyclic waterlogging from irrigation (Stevens, 1996). Judicious use of rootstocks in saline areas can help minimise the uptake of salt into a vine (Stevens *et al.*, 1995)

The effect of excess sodium in a soil promotes soil dispersion resulting in reduced water infiltration, reduced soil hydraulic conductivity (increased waterlogging) and surface crusting. Thus sodicity tends to create problems with vineyard water management (Fitzpatrick *et al.*, 1992). However salinity in a soil will negate the adverse effects of sodicity (Cass *et al.*, 1995). Thus when considering the sodicity of the soil the salinity of the soil must also be considered. Strongly sodic soils which are also highly saline will return reasonable soil structure however the saline situation is likely to make them unusable.

2.4.2 Physical Properties

Viticultural soils have traditionally been chosen by their physical properties. Moisture storage and drainage are considered important for good grape production, especially in areas where irrigation is unavailable or not permitted. Shallow, poorly drained soils tend to be susceptible to waterlogging and moisture deficiency with only average fluctuations in rainfall (Gladstones 1992). Waterlogging has been linked to high must acidity and low phenolic constituents while sudden dramatic increases in soil moisture promotes berry splitting (Seguin 1983, 1986, Johnson, 1971). By contrast, deep soils allow the development of an extensive root system. This buffers the plant against fluctuations in rainfall allowing for a more consistent grape quality from year to year. In Mediterranean type environments the ability of the soil to maintain moisture is crucial for good grape production especially in the absence of irrigation (Gladstones, 1992). Waterlogging, even for brief periods (1-2 days) following irrigation has been shown to depress yield (Stevens and Harvey 1994) and inhibit the plants ability to moderate salt uptake in saline soils (Stevens, 1996).

The primary soil property that determines a soil's moisture holding capacity is texture. Estimates of

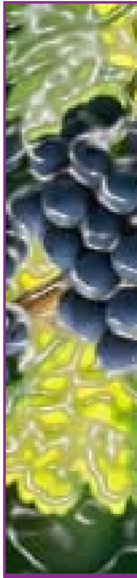


soil moisture can be obtained by accounting for the texture and depth of horizons in a soil profile (Wetherby, 2000; Cass, 1999). Secondary soil properties that influence moisture holding capacity, but are seldom considered in moisture holding capacity calculations (Cass, 1999), include aggregate structure, ped structure, bulk density (air filled porosity), soil strength, chemical toxins and rooting distribution (depth). These secondary factors mainly determine the accessibility of soil water to the plant rather than moisture holding capacity (Cass, 1999). Stevens and Cole (1987) studied the effect of different soil matrix moisture regimmes, ranging from 740 to 1342mm over the season, on yield and must composition in vineyards in the Riverland region of South Australia.. They showed that increased moisture stress depressed yield and berry weight but had no significant effect on must Brix°, pH, TA, tartrate and potassium concentration in the berries (Stevens and Cole, 1987). The implication from this study is that irrigation management is not really affecting grape quality but is impacting on yield. It is not indicated how large the yields were, however this study runs contrary to popular opinion especially in traditional wine producing countries.

Regardless of whether water is supplied through rainfall or irrigation the need for good drainage is a constant for vineyard selection. For optimal production roots require at least 15% air filled porosity (Cass, 1998, 1999). This is particular important in areas of high and late winter to spring rainfall where waterlogging can affect the early growth period. Brown *et al.* (2001) found that in heavy clay soils excessive water logging from a wet year can cause cane dieback and result in poor vine growth for several years after the event. This can be remedied by tiling and improved drainage (Brown *et al.*, 2001). Soil colour can provide a guide to the drainage regime of the soil when designing vineyards (Cass, 1998).

There are a wide range of soil profiles with diverse pedological origins that are capable of fulfilling the moisture requirements of the vine. These include gravelly alluvial soils, limestone based soils and even clays if they are well structured and well drained (Gladstones, 1992). Unless large quantities of irrigation or rainfall are available sands are not particularly suited due to their poor moisture retention. Vines also perform poorly in soils that have a wet soil strength of >2MPa as measured by a penetrometer (Cass, 1999)

The preference for stony or rocky soil surfaces has long been recognised as a favourable characteristic for viticulture. Soil infertility is often lower in these soils and they have advantages with soil infiltration due to their uneven surface which inhibits runoff. This permits greater infiltration and reduces the loss of topsoil through erosion. The thermal properties of stony soils are also recognised as being beneficial. Stony soils often have good thermal conductance thus heat absorbed during the day is radiated deep into the profile. At night this heat is re-radiated, decreasing the diurnal temperature variability around the vine and prolonging the period at which enzymic process occur (Gladstones 1992). Even in hot climates stony soils are preferable. Day temperatures are often above optimum and nights may be suboptimum. In these conditions physiological ripening at night may be important. Good thermal conductance also allows earlier subsoil warming in spring. This promotes root growth, an earlier, more even budburst and rapid early growth culminating in more fruitfulness (Gladstones, 1992). Continued deeper subsoil warming through summer coupled with lower temperature extremes tends to promote better vine balance and cytokinin supply to the fruit (Gladstones 1992). The presence of ground cover acts as an insulating layer inhibiting exchanges between the atmosphere and soil (Pradel and Pieri, 2000).



2.4.3 Classifying Australian vineyard soils

A wide variety of soil classification systems exist in Australia and worldwide (Stace *et al.*, 1968; Northcote 1979; Isbell 1996; FAO World Reference Base for Soil Resources 1998; USDA Soil Taxonomy and Soil Classification Working Group 1991) and many of these have been applied at different stages to wine producing regions (Maschmedt *et al.*, 2002). These formal soil classification systems are complex and/or technically orientated and not user-friendly for people without a soil science background. This led to a call from the Australian viticulture industry for a soil key that was applicable and accessible by Australian viticulturists (May, 1994).

The result has been a bifurcating key that focuses on viticulturally important and visually diagnostic features (Maschmedt *et al.*, 2002). General soil characteristics such as waterlogging, depth to restrictive layers, presence of cracking, texture trends and calcareousness are used to group soils into 9 broad classes after which further classification is based on consistency, colour and structure into one of 36 subclasses. The terminology used reflects common terminology rather than that of a particularly classification system and the key contains a glossary of terms. The final soil subclasses from the key have also been classified as near as possible in the main classification systems used in Australia and a comparative table is provided with the key (Maschmedt *et al.*, 2002).

SECTION 2

In Section 1 the climatic, edaphic and topographic needs of the grapevine were discussed. This section reviews methods developed to put this knowledge into practice. Planting a vineyard is a two step process. 1) The identification of a suitable climate and 2) matching local soil and meso-climatic conditions to suitable varieties. The first looks at site selection and is mainly an exercise in broad-scale mapping of climatic variables. The second deals with vineyard design and varietal layout once a suitable site has been found.

2.5 Vineyard Site Selection

2.5.1 A Brief History of Australian Production.

Grapevines were introduced to Australia with the early settlers and due to the efforts of James Busby and William Macarthur a large variety of cultivars were grown (Halliday, 1993). These early vines were used as much for fresh and dried fruit as wine and the quality issue was secondary. As the population increased commercial production became viable and pioneering viticulturists found the premium areas for grape production essentially by trial and error (Halliday, 1991). While Australian wine producers have had success internationally with noble varieties in cool climates, it was mainly warm climate cultivars that dominated in the early 20th century. Most of the production at this time was based on high-yielding varieties along the Murray and Murrumbidgee rivers for modest quality fortified wines and low yielding crops for table and fortified wines in dryland areas such as the Barossa, Clare and Hunter Valleys (Halliday 1993).

Despite the availability of land, up until the 1950s, viticulture remained essentially a small-scale enterprise due to the influence of European settlers, particularly Silesians, Germans, Italians and Dalmatians. These settlers brought the traditional small family approach to viticulture when they immigrated (Halliday 1993). Wine production up to this stage was also dominated by fortified wines

with only 30% of the bottled wine produced in the 1950s being table wines (Halliday 1993). In the 1950s, 1960s and 1970s wine consumption increased in Australia, due partly to a rationing of beer post World War II. The 1980s saw domestic consumption plateau and even dip in the middle of the decade. At this stage vines were actually removed and the overall area under production decreased. However this proved to be a "lull before the storm" with viticultural production under going a revolution in the late 1980s and 1990s towards large scale commercial production. This expansion, which has seen the industry almost triple in 15 years has been driven almost solely by the development of an export market. Domestic consumption has varied little over the past 20 years (Figure 2.6)

2.5.2 The Appellation system - a traditional classification system

The delineation of regions based on wine quality is not a new concept and was practised during the Roman Empire and again by Benedictines and Cistercians who revived the wine culture during the middle ages (Bohmrich, 1996). In the early 19th century the vineyards and wineries of Bordeaux were classified mainly on market value, hence the classification was skewed toward the most famous estates (Bohmrich 1996).

However the marriage of varieties and terroir really came to fruition in the 1930s with the development of the *Appellation d'Origine Controlée* (AOC) system. Based on the notion of identifying and isolating unique terroirs these laws quantified the centuries of experience gained by trial and error in French viticulture. The AOC was established following the devastation of the French winegrape industry by phylloxera and the following widespread fraud and surplus production that threatened many of the best known wines (Bohmrich, 1996). The AOC not only delineated wine regions but also determined the varieties, densities, pruning, yield and alcoholic strength that can be grown.

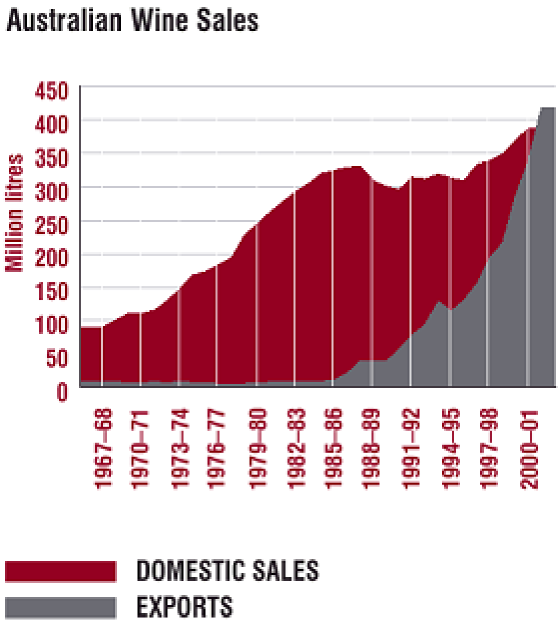
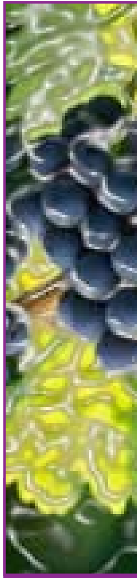


Figure 2.6: Compaison of Domestic and Export wine sales for Australia for the past 35 years (courtesy of the Australian Wine and Brandy Corporation. www.awbc.com.au).

The AOC has provided the French wine industry with a powerful marketing tool for the sale of their wines (Celine, 1998). The AOC system provides consumers with information on the raw materials and methods of production of the wine thus consumers are able to make a decision not only on the end product but also the whole process. This marketing advantage has made certification and labelling with AOC information more common in French wines over the past 25 years (Celine, 1998). The AOC tends to be viewed as an environmentally friendly approach to wine making. Since the terroir is so fundamental to the AOC system the "*cahier des charges*" or guidelines for production tend towards environmental protection (Celine, 1998). Traditionally vineyards outside the AOC areas were referred to as *Vin de Table* and had no restrictions on production but likewise commanded no premiums. In recent years two additional classifications have been added. *Vins Delimites de Qualite Superieure* (VDQS)



which are areas that may be promoted to AOC status and *Vin de Pays* or "country wine" which is a level above the *Vin de Table*. *Vin de Pays* wines are essentially superior table wines that have excelled enough to earn a geographical context without impinging on the AOC or VDQS classification (Johnson and Robinson, 2001)

The AOC system however does have additional costs in production. The "cahier des charges" usually increase production costs and producers must conform to standardized norms for packaging and retail. The adoption of new technology or production practices is also restricted until such practices are incorporated into the "*cahier des charges*" (Celine, 1998).

2.5.3 Climatic Classification and Modelling for Viticulture

As has been pointed out in the previous section the dominant determinant for grape production is climate. The climate of a site will not only determine which grapes can be grown there but also what management strategies are required to maximise grape potential. The first step in determine a vineyard site therefore must be the selection of a location with a suitable climate.

Plants need warmth and sunlight to grow and as early as 1855 the threshold limit of 10°C had been established as the point below which grapes do not actively grow (Halliday 2000). However despite this knowledge it was not until the landmark paper of Amerine and Winkler (1944) that a quantitative index for temperature was developed for viticultural production. Amerine and Winkler (1944) summed the degrees above 10°C (50°F) for an assumed growing season length as an indication of the available heat for production. A set of cutoff temperature sums were established and linked to wine styles (Table 2.2).

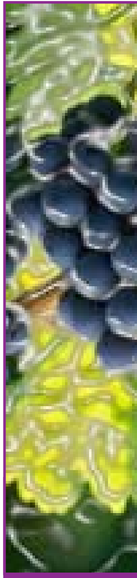
Region	**day degrees (C)**	**Wine Style**
Region I	>1389	Best table wines, light to medium body and good balance
Region I	1389 - 1667	Best table wines, light to medium body and good balance
Region II	1667 - 1944	Full-bodied dry and sweet table wines lighter bodied dessert wines
Region IV	1944 - 2222	Dessert wines and low quality table wines
Region V	2222 - 2500	Bulk wines and fortified wines. Fresh and dried grapes

Table 2.2: Temperature Summation (day degrees) and associated winestyles for California (after Amerine and Winkler, 1944).

The method of Amerine and Winkler (1944), although designed for California has been used to classify Australian (Gladstones, 1992) and South African (Carey *et al., pers. comm.*) viticultural areas. However the approach is simplistic and its reliance on heat summation without adjustment for extremely high temperatures has been criticised (Bentryn, 1988; Due, 1995). As a result in the past 20 years a variety of universal and regional specific climatic indices have been developed.

2.5.3.1 Universal classification systems

For generic classification of regions for viticulture, Jackson (1987) has proposed a 2 zone classification, alpha and beta, based on temperature at ripening. Alpha regions are classed as those where maturation occurs under cool nights and moderate days, and where the mean temperature at ripen-



ing is 9-15°C. Beta zones are characterised by areas where maturation occurs well before temperatures drop below 10°C and have a mean temperature of 16°C and above during maturation.

Production in alpha zones (cool climates) is advantaged by warm seasons or mesoclimates. Warmer day temperatures ensure good sugar content in the must while cool nights are optimum for pH, acid, colour and flavour compounds. In beta zones warm seasons or mesoclimates offer no advantage as temperature is not a limiting factor.

The determination of a region as either alpha or beta is often dependent on the variety. For example, for short growing season varieties such as Pinot Noir, the Barossa Valley would be considered a beta zone. However the Barossa could also be considered an alpha zone for late ripening varieties such as Cabernet Franc. Many short to medium growing season varieties are suitable for production in both zones. However the resultant wine style will differ.

Another method of characterising climate is through the use of a latitude-temperature index (LTI). Jackson and Cherry (1988) compared a variety of climatic indices and found it to be the best at differentiating selected sites from around the world according to their grape ripening capacity especially for cooler climate areas. Jackson and Cherry initially suggested the use of

$$\text{LTI} = \text{MTWM} * (75 - \text{latitude}) \qquad \text{Equation 2.1}$$

where MTWM = Mean Temperature of warmest month

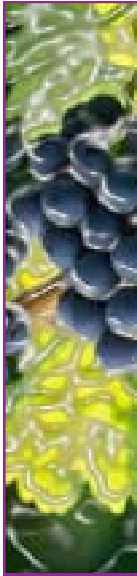
Jackson and Cherry (1988) used the LTI to delineate four climatic zones (Table 2.3). However it should be noted that warmer climates may be suited to cool climate cultivars as well.

Kenny and Shao (1992) mapped LTI (equation 2.1) across Europe using 30 year mean climatic data. This map was adjusted by Kenny and Harrison (1992) to include a winter severity constraint to exclude areas where winters are too harsh for vines. Regions with a mean minimum temperature less than -3°C were considered unsuitable regardless of MTWM.

Group	LTI	Cultivars
Unsuitable	0 - 380	No suitable cultivars
Group A	380 - 460	Cool climate cultivars e.g. Gewurztraminer, Pinot Noir, Chardonnay, Mullar Thurgau
Group B	460 - 575	Warmer climate cultivars e.g. Riesling, Pinot Noir (full bodied)
Group C	575 - 700	Warm climate cultivars e.g. Cab. Sauvignon, Semillon, Sauvignon Blanc
Group D	> 700	Hot climate cultivars e.g. Grenache, Shiraz, Sultana, Zinfandel

Table 2.3: Climatic zones after Jackson and Cherry (1988) indicating LTI thresholds and cultivar suitability.

Kenny and Harrison (1992) found that the LTI gave an adequate reflection of wine cultivar in Europe based on ripening capacity. Some problems occur due to the coarse resolution of the data and the use of average climatic data. By using yearly data rather than 30 year means Kenny and Harrison



(1992) calculated the LTI from 1951 - 1980. This allows for climatic risk assessment and areas of high climatic variability which Gladstones (1992) considers the most important climatic criteria. Interestingly Kenny and Harrison (1992) note the predominance of France to have a high frequency of years climatically suitable for a wide range of cultivars. Spain, Portugal and Italy, powerhouses of 'old world' viticulture are also identified as suitable.

Like Jackson and Cherry (1988) who were critical of heat summation indices, Bentryn (1988) proposed an index based the mean low temperature of the coldest month, mean high temperature of the hottest month, diurnal temperature ranges, annual rainfall and hottest month rainfall. This index is based on identifying areas where the heat summation is slow and even rather than total eat summation. Bentryn argues that slow, even maturity produces the best wines.

2.5.3.2 Climate Classification in Australia

Gladstones (1992) attributes the visitation by Professor Harold Olmo of the University of California as the first step forward for Australian viticulture in accepting climate as a major criterion. Since then a variety of classifications have been developed.

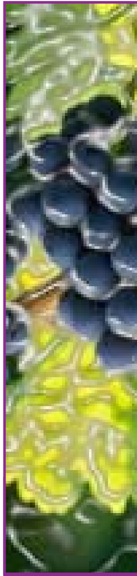
A simple approach to climate classification is a homoclime comparison. Since viticultural regions (appellations) are well defined in Europe and have evolved over several centuries, Smart (1977) and Dry and Smart (1987) have tried to match Australian climates to those of established European viticultural regions. By finding similar environs they hoped to identify premium viticultural regions in Australia. Despite using several different climate indicators this approach was only marginally successful.

The failure of the homoclime approach led Smart and Dry (1980) and Dry and Smart (1988) to develop a classification for viticultural production in Australia based on five climatic indices: average mean temperature of the hottest month, continentality (difference in average mean temperatures for January and July), total sunshine hours for October -March, aridity (total rainfall minus 0.5 of pan evaporation from October-March) and average relative humidity at 0900 for the period October-March.

Gladstones (1992) has suggested a biologically effective day degree summation that is a combination of heat summation with adjustments for mean temperatures above 19°C, latitude, day length and diurnal temperature range. Like Bentryn's index Gladstones (1992) index aims at locating areas with low temperature variability; a criteria they consider the most important during ripening. Anecdotal evidence in warm climates shows that the best vintages are in cooler years. This has lead to the traditional belief that long cool ripening periods are preferable (Halliday, 1993). However in cooler years, temperature variability is reduced and Gladstones (1992) argues that warm temperatures are as preferable provided the variability is low. Halliday (1993) considers Gladstones approach to be the most complete and convincing index for Australian conditions.

2.5.4 Alternative approaches to climate classification

All of the classifications discussed so far have relied on mean or summed climatic parameters; however, day-to-day weather events, especially extreme ones, can have a significant impact on quality and quantity of the harvest. To incorporate this daily variability, Jones and Davis (2000) have used



synoptic climatic techniques to examine the climate-vine interaction in the Bordeaux region of France. They argue that by using air mass based approaches they are eliminating any *a priori* decisions about which variables are the important determinants in production. By dividing the growing season into four distinct phenological stages Jones and Davis (2000) have correlated air mass circulations to grape production. This not only identifies how the climate affects the timing and duration of phenological stages but also which air masses are most influential on yield and quality. While this is not strictly a classification system, this approach could be used in the future to help classify regional climates.

In a similar vein, studies into the influence of global-scale climatic anomalies on overall vintage quality have been recently carried out. Rodo and Comin (2000) in a 30-year study show a high probability of high-quality harvests in Spain being linked with an El Nino event in the same or previous year. Studies in California (Nemani *et al.*, 2000; Nemani *et al.*, 2001) have also linked the winter Pacific sea surface temperature to wine quality in the following vintage. These studies demonstrate that the macro-climate is impacting on year-to-year quality variations.

2.5.5 Broad-scale Digital Terroir Prediction

Site selection has traditionally been empirically based or influenced by climatic suitability. In more recent times the influence of the soil-climate interaction on wine style and to a lesser extent wine quality has been more widely accepted (Iacono, 2000). As a consequence more focus has been placed on soil parameters, particularly soil moisture, in recent times. This has resulted in a more systematic approach to vineyard selection that accounts for environmental and climatic factors as well as managerial factors (Iacono *et al.*, 2000). This approach is now gaining wide acceptance in European viticulture (Iacono *et al.*, 2000) although the majority of work on this area is being done outside of Europe.

The push towards a more systematic approach has been facilitated by the increased availability of broad-scale digital elevation and digital soil surveys. Having digitised data has allowed the integration of landform and soil data with the climatic data to produce a predicted “digital terroir” classification. Digital terroirs can be predicted at different scales. In this section the prediction of digital terroir at the macro-climate scale is discussed. Meso-climatic scale digital terroirs are discussed in Vineyard design. The micro-climatic scale, as defined previously, is too small for digital terroir prediction and precision management.

Researchers (Carey *et al.*, *pers. comm.*) at the University of Stellenbosch have adapted the “land-type” classification of MacVicar *et al.,* (1974) to derive a predicted digital terroir map for the South Western Cape region of South Africa. MacVicar *et al.*, (1974) define a land type as a class of land, that may or may not be contiguous, where the macroclimate, terrain form and soil patterns display a marked degree of uniformity. I would argue that it is the meso- rather than macroclimate that is important however Mac Vicar *et al.* (1974) do not make it clear what they consider to be meso- and macro-climates. The land-type classification was developed to ascertain the potential for any agricultural production. When it is applied specifically to viticulture it can be considered a digital terroir prediction.

The main data sources Carey *et al.* (*pers. comm.*) used are growing degree day maps, a soil map with derived soil characteristics (soil depth, clay content, moisture holding capacity and degree of wetness) and a 50m digital elevation model with derived secondary topographic parameters (slope, aspect, drainage, profile type and percentage level land). Historical records for yield were matched to known land types and an algorithm developed to predict yield potential across the South western Cape. Attempts are under way to model the climate-cultivar interaction to predict wine quality (Carey *et al.*, *pers. comm.*).

A similar approach has been adopted by researchers at Cornell University to map agricultural and vineyard suitability in New York State on a 1km square grid (Magarey *et al.*, 1996). Magarey *et al.* (1996) produced a series of suitability maps for land use, climate and soil based on a range of attributes. Threshold values for attributes were used to determine if a location was suitable for each of the maps. The results were weighted and rescaled according to the importance of the particular attribute to produce a final prediction map (Figure 2.7).

In France the majority of research into terroir, at both macro- and meso-scales, is occurring at Institut National de la Recherche Agronomique - Unité Vigne et Vin (INRA-UVV), Angers. While their approach is again systematic there is a lot more physical sampling and data collection used in their studies. There is also a real consideration of the human factors of terroir (Rioux *et al.*, *pers. comm.*). The approaches of Carey *et al.* (*pers. comm.*) and Magarey *et al.* (1996) rely on existing digital data rather than new surveys and ignore the social aspect of terroir. Given the importance of the terroir concept in French viticulture it is not surprising that more effort and expense is made to accurately delineate terroirs. The work at Angers focuses on identifying *d'Unite Terroir de Base* (Basic Terroir

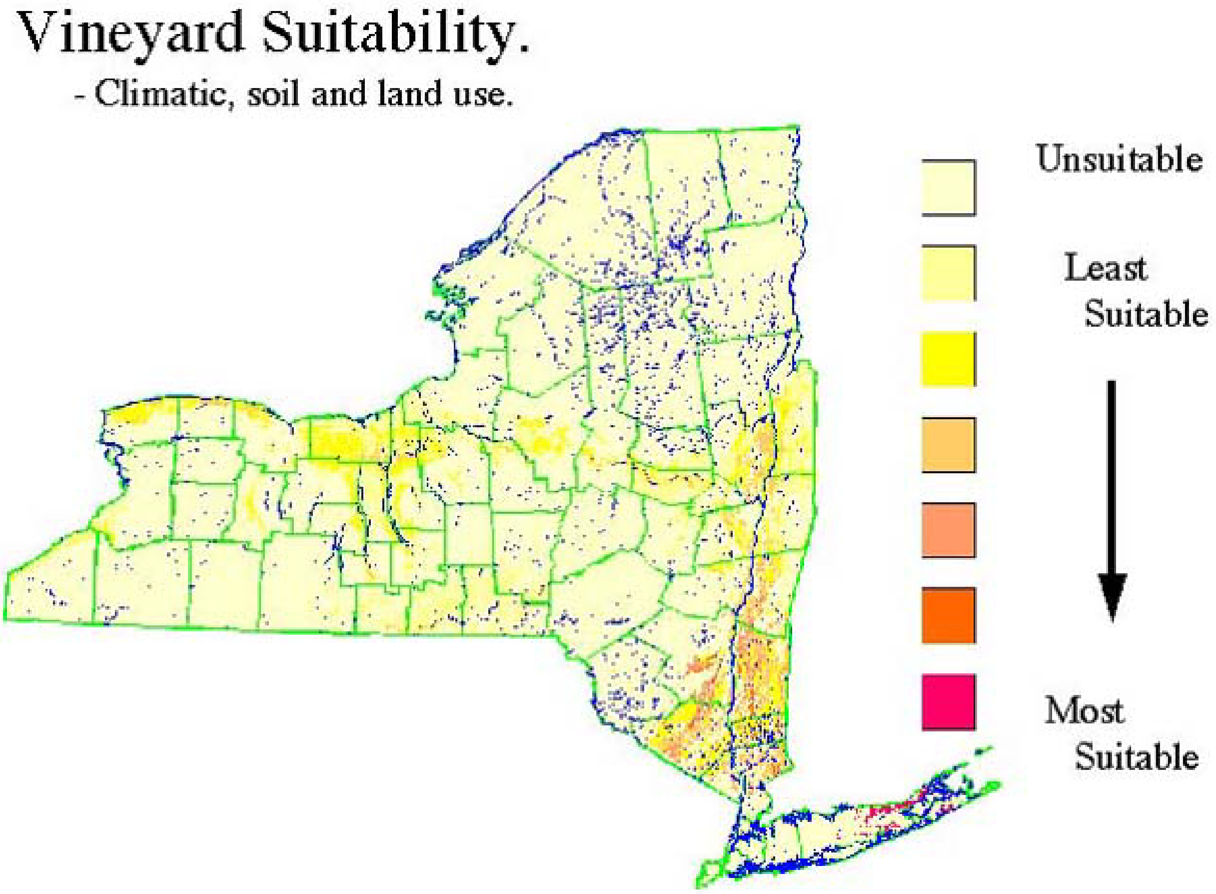
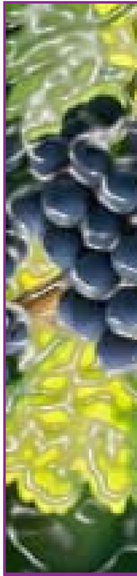


Figure 2.7: Map of Vineyard suitability in New York State, USA (from Magarey *et al.*, 1996).



Units or UTB) in the Loire Valley from landform attributes, soil information and geology (Rioux *et al.*, *pers. comm.*; Guilbault *et al.*, 1998). Climatic data was not incorporated into the UTB predictions.. The resultant UTB maps have been used to match suitable rootstocks to terroirs and optimise management (Rioux *et al.*, Guilbault *et al.*, 1998). By intensively studying the terroirs around Angers they hope to establish a protocol to facilitate the mapping of other viticultural 'communes' in France. While climatic indices are not part of the current classification process a series of precocity indices have been developed at Angers to time the phenological development of the vine (Barbeau *et al.*, 1998).

In Australia there have also been attempts to classify areas for viticultural production. Geographic Indications (GIs) have been established by the Australian Wine and Brandy Corporation in 1993 along the same principle as the AOC in France. However GIs are much less restrictive in terms of vineyard management and exist mainly to protect the regional name under international law. Any wine label with a particular GI must source at least 85% of the fruit from that GI (www.awbc.com.au). GIs can be defined (www.awbc.com.au) as either:

i) Zones - area of land, without any particular qualifying attributes

ii) Region - A region must be a single tract of land, comprising at least five independently owned wine grape vineyards of at least five hectares each and usually produce five hundred tonnes of wine grapes in a year. A region is required to be measurably discrete from adjoining regions and have measurable homogeneity in grape growing attributes over its area

iii) Sub-region - A sub-region must also be a single tract of land, comprising at least five independently owned wine grape vineyards of at least five hectares each and usually produce five hundred tonnes of wine grapes in a year. However, a sub-region is required to be substantially discrete within the region and have substantial homogeneity in grape growing attributes over the area.

Regional and sub-regional GIs may be registered as trademarks for marketing purposes. New GIs are determined by a Geographic Indications Committee primarily as a result of applications from growers/grower groups. Criteria for selection includes history, geology, climate, harvest dates, drainage, water availability, elevation and the traditional use of the area and proposed name (www.awbc.com.au). These criteria and GI definitions require a clarification of uniformity or distinctiveness however methodologies to provide this information are generally lacking in Australia (Tesic, 2003). Published maps of wine zones and regions in Australia are shown in Figures 2.8 and 2.9.

Tesic *et al.*, (2002) has used results of previous studies in the Hawkes Bay region of New Zealand to develop a Site Index (SI) for vineyard selection. (Equation 2.2). This SI together with the percocity indices of Barbeau have been applied in a recent study to vineyards within the Cowra and Mornington Peninsula grape-growing regions (Tesic, 2003). The results show that the Mornington Peninsula is highly variable and would benefit from further classification into specific sub-regions. Cowra showed less variability, particularly in the SI due to its more uniform elevation and climate. Tesic (2003) suggests that the SI and indices of Barbeau (1998) can be useful in segregating sites within a region. While he cautions against the heavy regulation enforced in the AOC, Tesic (2003) observes that a similar level of classification in Australia would provide an advantage in branding certain wine styles particularly in the European market. This would provide Australia with a culture of "vineyard

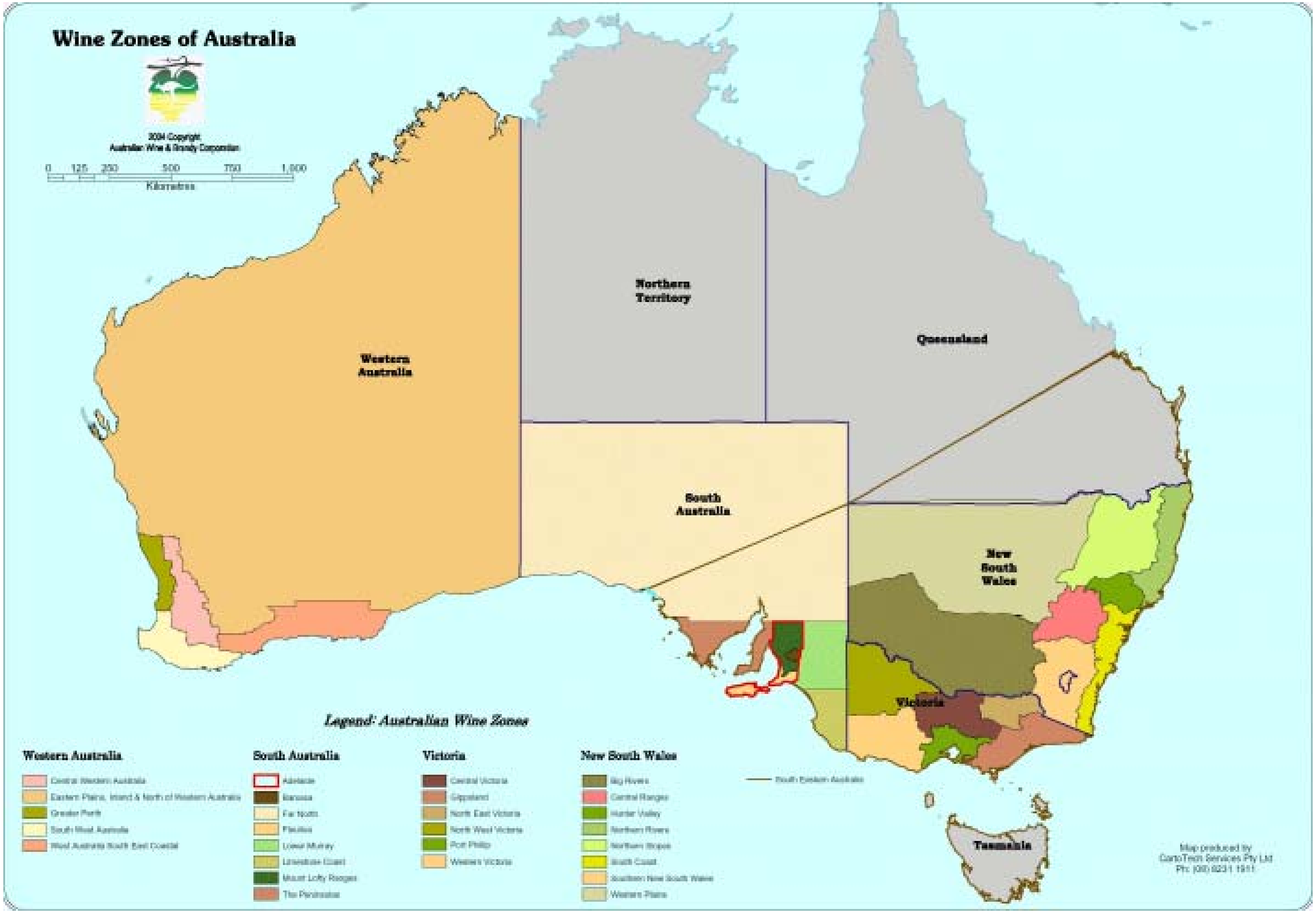


Figure 2.8: Wine Zones in Australia (published by AWBC, www.awbc.com.au).

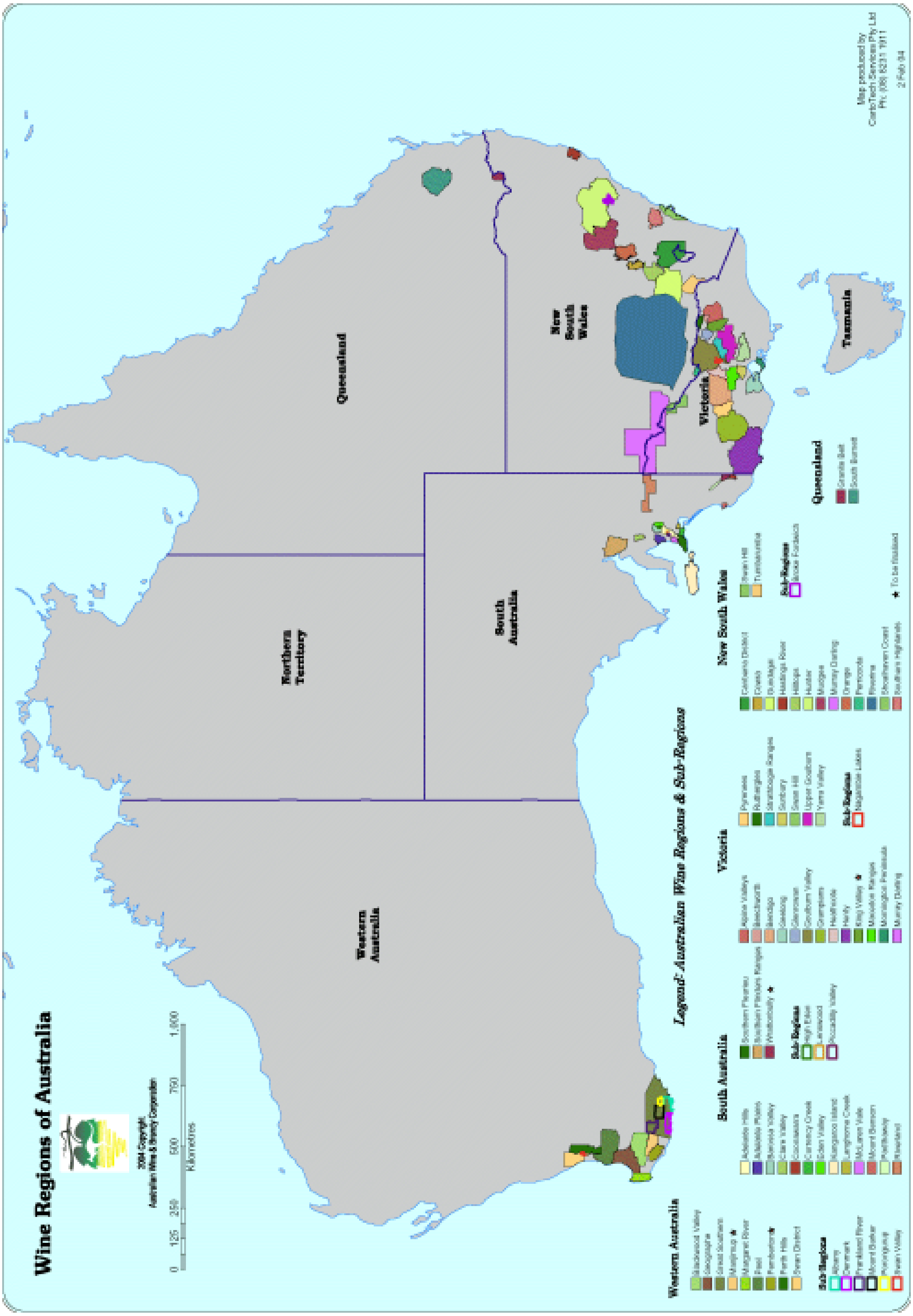


Figure 2.9: Geographic Indications for viticulture in Australia (published by AWBC. www.awbc.com.au).

wines” as well as “brand” wines to sell in export markets. Australia also has an opportunity to base these sub-regions on scientific relationships rather than the whims of individuals (Tesic, 2003).

$$SI = \frac{(t_o + t_j)^2 \bullet (1 + \frac{G_p}{100})}{R_S \bullet \sqrt{1 + C_S} \bullet RD} \qquad \text{Equation 2.2}$$

where t_o = mean air temperature in October (°C)
t_j = mean air temperature January (°C)
G_p = gravel percentage in topsoil
R_S = seasonal rainfall (October to April in mm)
C_S = ratio of clay percent to silt percent in the 35-70cm zone
R_D = maximum depth of rooting zone.

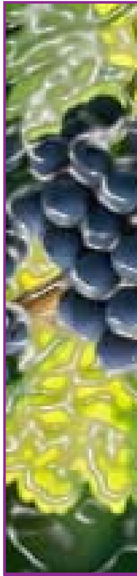
A separate study in the wine-growing region of West-Gippsland has been performed by researchers at University of Melbourne and Department of Natural Resources and Environment, Victoria (Itami *et al.*, 2000). Their approach mirrors that of Magarey *et al.* (1996), where climate, soil and terrain maps have been derived from a combination of digital sources using an Analytical Hierarchy Process (AHP). These maps were then analysed in Catchment Decision Assistant (CDA) (Itami *et al.*, 1999) to determine suitability for viticultural production. Interestingly the CDA output showed a strong soil effect on landscape suitability possibly due to a relatively uniform climate and /or much coarser resolution in the climatic data (Itami *et al.*, 2000). This study was done primarily as a case study on the use of AHP in determining landscape suitability rather than an attempt to define regional or sub-regional GIs. The resultant maps have yet to be ground-truthed.

Figure 2.10: NSW homoclimes of Montpellier in Southern France. Red = most similar, Yellow = similar (Adapted from Tunstall and Sparks, 2001).

A commercial service for selecting vineyard sites was offered by Environmental Research and Information Consortium (ERIC) based in the ACT (Tunstall and Sparks, 2001). This was based on analysing climatic data, terrain attributes and frost risk to identify homoclimes within Australia that are similar to established districts in Europe (Figure 2.10). Detailed mapping of local frost risk was performed using DEMs and night-time thermal imagery (Tunstall and Sparks, 2001). The homoclime approach has already been discredited (Gladstones, 1992, Smart and Dry, 1980, Dry and Smart, 1988) and this service appears no longer to be available.

2.6 Vineyard design

Once a site has been selected a suitable layout is needed for the vineyard. While site selection is determined from the disaggregation of broad-scale data, vineyard design is usually made on fine-scale data that is aggregated to the vineyard size. The manner in which vineyard design is achieved



is ever changing as technology improves.

2.6.1 *Traditional approach*

As mentioned earlier vineyards were traditionally established by trial and error. The climate and soils of Australia are very different to European conditions that were familiar to early viticulturists. As growers came to understand the environment and its influence on wine grape quality they became more adept at designing vineyards. However vineyard site selection was still subjective, thus, as new viticultural regions were colonised this knowledge had to be re-learnt. Soil evaluation for vine growth was also often overlooked and if soil tests were taken they usually ignored the rigours of soil science (Cass, 1998). At this stage an established protocol for soil description in the vineyard did not exist.

2.6.2 *The Wetherby-ICMS system*

In the late 1980s and early 1990s Ken Wetherby in conjunction with Irrigated Crop Management Services (ICMS) developed an industry protocol for soil survey and description for the establishment of vineyards. The survey was based initially on soil pits, generally dug with a back-hoe, on a 75m grid (this has recently been expanded to a 100m grid for larger vineyards for economic reasons although Wetherby (2000) advises against that). The following characteristics of each horizon observed in the pit are recorded (Wetherby 2000). These measurements, listed below, are based on the methodology in the Australian Soil and Land Survey Field Handbook (1990) and modifications by Wetherby (2000a).

Horizon thickness (cm)
pH (Raupach method)
Soil texture
Percentage of coarse fragments (gravel)
Pedality (Structure and aggregation)
Potential vine rootzone depth
Depth and salinity of watertable
Presence of soil carbonate (1M HCl test)
Carbonate layer class
Topsoil depth (cm)
Geology
Soil moisture status
Rootzone Readily Available Waterholding capacity

Other variables of note may also be recorded according to the surveyors discretion.

The main emphasis of the Wetherby-ICMS system is the estimation of the moisture holding capacity in the soil. Map units derived from the Wetherby method are heavily weighted toward readily available water (RAW) values. In the field, the RAW is derived by multiplying the thickness of a horizon by a moisture holding coefficient based on the horizon soil texture. This is summed for all horizons/depths up to the identified root zone depth. In the laboratory the RAW for a horizon can be determined by:

$$RAW = (\theta_{FC} - \theta_{60kPa})*D \quad (mm) \qquad \text{Equation 2.3}$$

where θ_{FC} = field capacity water content (mm of water/m of soil)
θ_{60kPa} = 60kPa soil matrix suction water content (mm of water/m of soil)
D = Depth of horizon or effective depth of rootzone (m)

The coefficients used for the calculations were empirically derived from 360 samples taken from the Murray, Mallee and Barossa valleys in South Australia. Over the past 10 years the concept of RAW

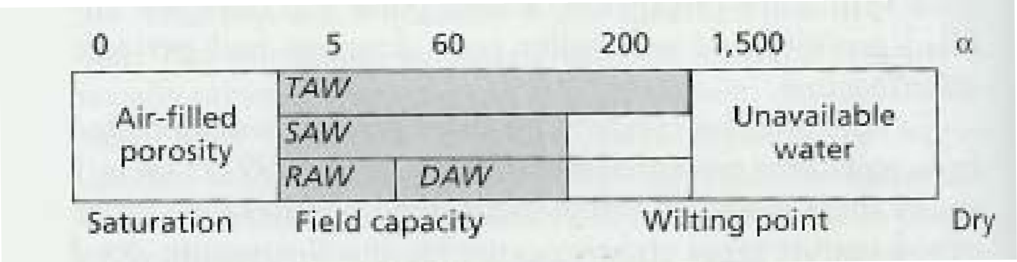


Figure 2.11: Comparison of RAW, TAW, DAW and SAW with traditional measurements in kPa of soil moisture (from Cass, 1999).

has been adopted globally, particularly in 'new world' viticulture. It has also given rise to a variety of associated indices, total available water (TAW), stress available water (SAW) and deficit available water (DAW) that are illustrated in Figure 2.11 (Cass, 1998 and 1999). Improvements have also been made to the initial values to account for carbonate layers and to better define the rootzone depth (Brooker *et al.*, 1995)

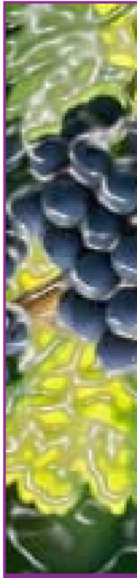
Rapid adoption of the protocol by the viticulture community provided the industry with a good platform for vineyard design for the rapid expansion of the industry that occurred during the 1990s. It is undoubtedly one of the contributing factors to the export success Australian wine is currently enjoying.

While this preliminary survey has given the Australian wine industry a major advantage, concerns over the use of a fixed 75m x 75m grid have been identified (Brooker *et al.*, 1995, Brooker and Warren, 1997). Fixed grids do not account for any anisotropic variation (Brooker *et al.*, 1995). The choice of optimal grid size was determined using soil from a viticultural region in South Australia (Wetherby 2000). It is unreasonable to assume that all viticultural soils in Australia exhibit the same level of variation. Grid systems do not maximise the value of data collected by failing to account for the intrinsic variability in the soil system. In studies in South Australia Brooker and Warren (1997) found that the vineyards were oversampled and the same level of information could be derived by optimal location of the soil pits. Extensive research in the area of Precision Agriculture has also shown that grid systems poorly identify boundaries in the soil system compared to site directed soil surveys with ancillary information (Pocknee, 2000). The coefficients for RAW determination are also based on South Australian soils and may not be correct for other regions. A further disadvantage is the use of hand texturing which is subjective on the surveyor.

In the past 3-5 years many vineyards have also been surveyed with Electro-magnetic Induction (EMI) instruments (such as the Geonic EM38) to provide a finer scale picture of soil variability and help to identify the location of soil boundaries. However there is no industry protocol for the use of EMI data and the information is usually not properly ground-truthed and used sparingly. The data is not directly used in the determination of soil maps which are still derived solely from the soil survey but may be used in vineyard layout. The addition of ancillary data with soil survey data to improve soil maps will be discussed in later chapters.

2.6.3 Meso-climate Modelling

Considering the emphasis placed on climate very little was found in the literature on modelling and measuring climate at the meso-climatic (vineyard) scale for viticulture. The collection of meso- and



micro-scale climatic data is probably the biggest constraint to identifying suitable vineyard sites (Magarey, 2000).

Trambouze and Voltz (2001) measured transpiration across a vineyard. They found that the intensity of transpiration varies greatly between vines and the pattern of variation is strongly linked with soil water storage whereas the magnitude of the variation was linked to light interception, a function of the pruning strategy. However it was noted that seasonal variation of transpiration is predominantly uniform across the vineyard (Trambouze and Voltz, 2001).

Magarey *et al.*, (1996) identified the coarseness of climatic data as a major limitation to their prediction of vineyard suitability in New York State (Figure 2.7). To rectify this they have used a high resolution atmospheric model called Local-area Agricultural Weather Simulation System (LAWSS) to map climate at 25-100ha scales. LAWSS was found to be superior to interpolation methods for prediction of local temperatures and significantly improved the predicted map of vineyard suitability in respect to areas prone to severe frost damage (Magarey, 2000).

2.6.4 Vineyard-scale Digital Terroir Prediction

Most attempts to produce meso- or vineyard-scale “terroir” maps have focused on a “top-down” approach (Tesic 200, Magarey *et al.*, 1996, Itami *et al.*, 2000, Guilbault *et al.*, 1998). Despite the uptake of proximal and remote soil and crop sensors in viticulture in the past 5 years (Hall *et al.*, 2002, Lamb, 2000, Ortega, 2003) and the proliferation of soil surveys no reports on a “bottom up” approach to “digital terroir” prediction were found in the literature. Vineyard design in Australia is still being driven primarily by expert knowledge rather than quantitative modelling.

The intensive studies around Angers by researchers at the UVV (Guilbault *et al.*, 1998, Rioux *et al.*, *pers. comm.*) is the finest-scale study that has been found cited in the literature. This work however is targeted at differentiating sub-regions or “communes” to classify a production region rather than specifically for the design of a vineyard.

2.7 Summary and Conclusions

Whether it is due to climatic, soil chemical or soil physical properties or a combination of the three there is no doubt that different regions (terroirs) produce different flavours in identical varieties. These differences are often unique enough for professional tasters to identify the region of production by taste and the majority of the great wines of the world are produced from distinct terroirs. However great wines can also be produced from a blend of grapes produced on differing soil types rather than grapes from a single vineyard or terroir (Bohmrich 1996). Grange Hermitage is a classic example of a premium blended Australian wine that is produced from grapes sourced from vineyards over a wide geographical area (Bohmrich, 1996).

When selecting a vineyard location it is important to ensure that any limiting factor is not above or below a threshold value that will impede production. If the environment or climate is not limiting then ultimately it is up to the grower to ensure that the vineyard management is tailored to produce the desired grape quality.

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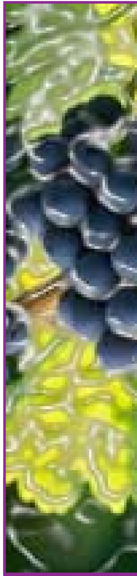

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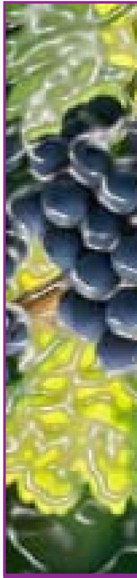

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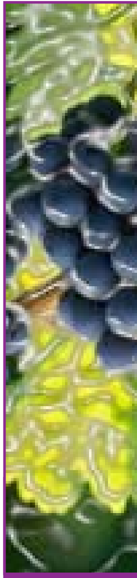

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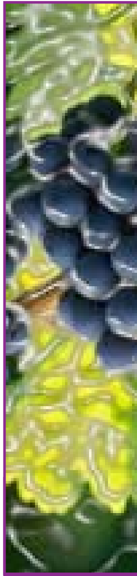

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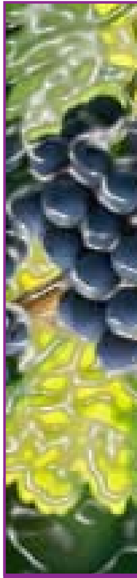

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