Hill Slope Viability for Industrial Viticultural Development in the South Island of New Zealand

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A thesis submitted in partial fulfilment of the requirements for the

Degree

of Master of Science

in the University of Canterbury

by D. T. Grose

University of Canterbury

2013

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Acknowledgements

This thesis would not have been possible without the help of many people. I would firstly like to thank my supervisor, Chris Oze, for all the guidance and encouragement throughout the course of my thesis. Secondly, I would like to thank my co-supervisor, David Bell, for looking over my thesis and contributing to it when it was necessary. Thank you to Theo Kritikos who helped me through the GIS process. If it wasn't for you I would still be scratching my head over some of the smallest problems I had. Thank you to the Mason Trust for providing funding for this thesis. James Sturman, my contact at NIWA for providing me with the GIS layers for my thesis. A big thanks to all the people I talked to during the site investigation stage of my research that gave up time and let me wonder around their vineyards. Thanks to the technical staff of the engineering geology department for providing the equipment and software. Thanks to the awesome Masters class of 2012 for the fun times and the help of a friendly ear to discuss all those masters issues. And I would like to thank the Geology Department of the University of Canterbury for providing me with the resources and a great working environment.

I would like to thank my partner Nicola Chamberlain for her support and patience over the last few years. You have made my time through university and my masters awesome! I would also like to acknowledge and thank the support of my family, especially Mum and Dad, not just throughout my Masters, but also through all of my University years. Thanks for always being there for me, encouraging me and believing in me.

Abstract

Hill slopes in wine producing regions of the South Island of New Zealand are rarely developed for viticulture despite having the capability. Viticultural development in these wine producing regions is primarily limited to flat areas despite the benefits of hill slopes that can increase productivity and variability of the grapes grown. The objective of this study is to assess the viability and development of hill slopes in the South Island of New Zealand with regards to industrial viticultural development. Site investigation in combination with background research identified five fundamental characteristics (i.e., elevation, slope angle, aspect, temperature and rainfall) that are required for proper assessment as well as industrial viticultural practices and concerns specific to the South Island. A slope angle of 15° was determined to be suitable for viticultural development as this angle is the maximum angle for machinery to work and operate safely. Additionally, this slope angle encourages the benefits that hill slopes provide and slope stability issues are limited. GIS suitability mapping demonstrates that ~0.7% of the South Island of New Zealand is viable for hill slope viticultural development using elevation, slope angle, aspect, temperature and rainfall characteristics to produce the maps. Temperature and sunlight relationships via data logger analysis support the various benefits that hill slope development provides, including increasing the number of growing degree days (GDD) by 1, increasing air and soil temperature and increasing sunlight exposure by 3,000 Lux. Overall, findings identify the extent and benefits that hill slopes may provide in major grape regions within the South Island of New Zealand.

Chapter 1

1 Introduction

Viticultural development is dependent on selecting a site that has the appropriate characteristics for growing grapes (Kurtural 2002). Site selection is a complex process and is dependent on numerous factors including rainfall, temperature, soil type, proximity to water for irrigation and the history of a site (Smith 2002). One important aspect of site selection is the topography of a site which can produce microclimates, forming a local atmospheric zone where the climate differs from the surrounding area. Hill slopes are known to create microclimates as a result of the slope angle and the direction it is facing (Kurtural 2002). A vineyard positioned on a north facing hill slope in the southern hemisphere can provide various benefits compared to adjacent flat sites. Vineyards located on north facing hill slopes are capable of increasing the number of growing degree days (GDD), receiving more intense sunlight, providing increased air and water drainage, providing a more complex wine as a result of soil type and water exposure, and are potentially warmer due to microclimate establishment (AGG 1989; Bennie *et al.* 2006; Bonan 2002; Rigg 1994; Unwin 1996).

The South Island of New Zealand is known worldwide for its award winning wines and wine producing regions. Vineyards on the South Island have traditionally been developed on flat areas with hill slopes being primarily developed in forestry or farmland (Statistics New Zealand 2008). This trend of development continues to occur despite the various inherent benefits of hill slopes. Developing hill slopes for viticulture can increase the productivity and variability of grapes grown in these regions and potentially produce wine, similar, if not better than surrounding flat areas. Hill slope viticultural development is viable, but to achieve it at an industrial scale in New Zealand, the use of mechanised equipment is required to reduce costs, labour, and the time associated with harvesting grapes.

An effective method used to select viable areas for viticultural development is the use of geographic information systems or GIS. A GIS approach allows large amounts of data in the form of layers to be combined and overlain to produce maps and assess areas that may be suitable for viticultural development. GIS provides multiple benefits compared to other conventional methods (i.e., electromagnetic induction and soil resistance and climate models) such as its ability to exclude areas that have unfavourable characteristics for viticultural development and highlight areas suitable for development (Sutton *et al*. 2009). When highlighting suitable areas, a major limitation of GIS is directly associated with the quality of data layers, validation of what is at a site compared with what the GIS has identified as suitable, and it has difficulties when combining layers of a large study area, such as the South Island. These limitations can be addressed by undertaking site visits to an identified site and conducting measurements and interviews with people at the site. Additionally site visits can identify aspects that cannot be determined by GIS such as slope stability. Slope stability is a major concern when developing hill slopes as erosion issues and natural hazards occur and/or arise during vineyard establishment.

In the South Island of New Zealand, the overall viability of hill slopes for industrial viticultural development has not yet been assessed. While there are vineyards positioned on hill slopes, research has not yet been undertaken to assess remaining hill slope sites and the benefits they may provide. Once the viability of these sites is assessed this research and how to approach assessment will provide a beneficial tool for future industrial viticultural development.

Objectives

The objective of this study is to evaluate the viability of hill slopes in grape growing regions of the South Island for industrial viticultural development. This objective will be achieved by using GIS to provide an upper limit of preliminary viable areas where hill slopes can be developed for viticulture. Through the use of ground truthing via interviews and site investigation this upper limit can be decreased and constrain the feasibility of a potential site. During ground truthing, slope stability a major concern for developing hill slopes can be identified, which is not identifiable with GIS. Comparing hill slopes to flat areas using data loggers will aid in identifying whether hill slopes provide better microclimates compared to adjacent flat areas. An assessment for utilizing hill slopes for viticultural development may be provided by combining the factors above.

1.1 Thesis Outline

The structure of this thesis follows an order that addresses the objectives outlined above. **Chapter 2** covers the background information related to this thesis. This includes the factors which make a good viticultural site, the benefits of hill slope development, how to constrain areas of the South Island of New Zealand; and international case studies of hill slope viticultural development. **Chapter 3** describes the methodology used to achieve the objective. **Chapter 4** covers the results gathered during the site investigation, data logging and GIS phase of this research. **Chapter 5** presents a discussion on current hill slope viticultural practices, GIS considerations, hill slope viticultural development compared to flat areas, and other considerations are presented. **Chapter 6** concludes the findings of this research and outlines future research for this field.

Chapter 2

2 Background

2.1 What Makes a Successful Viticultural Site?

Successful viticulture is defined as a vineyard which produces its required grape tonnage at an appropriate quality (Bordelon 2004). Successful viticultural development begins with the selection of a suitable site that has the appropriate characteristics for growing grapes. There are various natural and anthropogenic characteristics, that when combined, constitute a successful site for viticultural development. A viticultural site needs factors such as suitable location, landform, soil, climate, historic land use, proximity to irrigation sources and infrastructure in order for it to be suitable for viticultural development.

2.2 Benefits of Hill Slopes

A site that has suitable characteristics for successful viticultural development and is located on a hill slope has additional benefits compared to flat sites. As noted in the introduction, north facing hill slopes in the southern hemisphere increase the number of growing degree days (GDD), receive more intense sunlight, provide better air and water drainage, provide a more complex wine as a result of soil type and water exposure and are potentially warmer due to the microclimate they generate (AGG 1989; Bennie *et al.* 2006; Bonan 2002; Rigg 1994; Unwin 1996).

North facing hill slopes in the southern hemisphere are oriented towards the sun which results in greater sunlight intensity compared to flat adjacent sites. Increased sunlight on slopes results in warmer conditions as they are receiving more energy (Bennie *et al.* 2006). Increases in energy results in an increase in temperature, thereby, increasing the number of growing degree days (GDD) experienced on a sloping site compared to a flat site (AGG

1984). Sloping topography allows air and water to drain freely, provided that the slope is relatively smooth and free of obstacles. At night cool air drains down slope and displaces warmer air up to higher elevations, resulting in slopes at higher elevation to become warmer and protected from frosts (Trought *et al.* 1999). If one or all of these are occurring at a site it initiates a climate shift, which results in the establishment of a microclimate on the hill slope (Bonan 2002). The establishment of this microclimate provides more favourable conditions for growing grapes (De Blij 1983).

2.3 Application of Viticultural Site Selection Characteristics

The South Island of New Zealand has many well established wine regions (Figure 2.1). The regions of Marlborough, Canterbury and Central Otago have a continued history of producing vast amounts of grapes which have been made into many high quality wines (Schamel & Anderson 2001). The wines winning success are largely related to the specific characteristics of their region compared with other regions of the South Island. When identifying viable hill slope sites for viticultural development, the regions characteristics should be used as a template because they are known to produce award winning wines.

Figure 2.1 South Island of New Zealand major wine growing regions. Yellow indicates the major wine growing regions and black indicates the other regions on the South Island of New Zealand.

Within these wine producing regions, hill slope sites with the appropriate characteristics for growing grapes need to be constrained to allow specific selection of the most viable sites for viticultural development. The characteristics that constitute a successful viticultural site allow us to constrain these areas, but some of the characteristics are considered more important when initially identifying viable viticultural sites. These more important characteristics have a greater influence on the overall success of site and, therefore, need to be identified to constrain sites that are viable for hill slope viticultural development.

2.3.1 Applicability of Characteristics to the South Island of New Zealand

The characteristics that constitute a successful viticultural site, as mentioned above are location, landform, soils, climate, historic land use and proximity to irrigation sources and infrastructure (Smith 2002). When looking at these characteristics in relation to the South Island of New Zealand it highlights certain factors within these characteristics that are more important when initially selecting a viable site for viticultural development and that will determine the success of the development.

Location

The location is the latitude, maritime or continental location of a site. The South Island of New Zealand sits between 30 – 50° south of the equator and has a mixture of maritime and continental locations. These locations are considered most favourable for viticultural development and compare to famous wine growing regions in France, Italy and places in the United States of America (Unwin 1996).

Landform

Landform is the elevation, shape, slope and aspect of the site. At high elevations issues such as cold temperatures and increased humidity can affect grape development. Therefore, the ideal elevation of hill slope vineyards is below 450m above mean sea level (Kurtural

2002). The ideal shape of the landscape on hill slopes is smooth to limit shading effects and improve air drainage to reduce effects from frosts (Kurtural 2002). A slope of 5 – 15° is ideal for viticultural development as it allows drainage of air and water and is safe for machinery (Bergmeier & Striegler 2011). On steeper hill slopes, a slope of up to 40° can be used, but it is not recommended due to an increase in slope stability issues (Kurtural 2007). As New Zealand is in the southern hemisphere, the ideal aspect of slopes for viticultural development would be north facing to capture the maximum amount of sunlight. Smith (2002) indicates that features of topography, landform in particular are fundamental for selecting a successful viticultural site.

Soils

Soil is considered to play an important role in the success of a vineyard because soils provide the nutrients; water and rooting potential that a grape vine needs to grow and produce grapes. A soil in its full context is characterised by physical, chemical and biological properties (Coombes & Dry 1992; Huggett 2006). These properties need consideration when looking at developing vineyards on hill slopes because there are various stability issues associated with disturbing the ground before planting the vines. Once the soil is disturbed and is exposed to wind and water it can become susceptible to erosion. These issues can be mitigated through correct vineyard management and engineering practices. In the South Island of New Zealand soils can be addressed later as they are not considered an important characteristic when initially selecting viable sites for viticultural development.

Climate

In New Zealand there are several climate regimes for growing grapes, ranging from sub-tropical in the North Island to semi-continental in the South Island (Fitzharris &

Endlicher 1996). The climate of a site is characterised by temperature, rainfall, sun exposure, wind exposure, humidity and frosts.

Temperature and rainfall are the two climatic factors that have the largest impact on successful viticultural development (Watkins 1997). The temperature must be high enough all year round to sustain vine growth, with limited rainfall. Four regions in the South Island have appropriate temperatures and rainfall for viticultural development; Marlborough, Nelson, Canterbury and Central Otago. When selecting a suitable site, areas can be ignored based on the climate because of the climates importance in grape production. Areas with high rainfall and low temperatures can be ignored from the start of an investigation because they are unsuitable for grape production. In the South Island of New Zealand, these areas include Southland and the West Coast.

Historic Land Use

Historic and/or current land use at a site can determine what practices have been successful. Many land uses can affect the ground and leave residual deposits which can reduce the production capacity of the land. These areas can be avoided through the use of buffer zones that are used to avoid specific areas. Based on New Zealand's history of hill slope development, the historic uses of hill slopes have been farming and forestry which would not inhibit vineyard development.

Proximity to Irrigation and Infrastructure

To establish a vineyard, irrigation and infrastructure need to be installed and operational to cater for the needs of the vineyard. Within the South Island of New Zealand there is an abundance of irrigation sources available, whether it is from rainfall, groundwater or streams/rivers. Infrastructure refers to roading, water supply, shelter belts, fences, buildings, tracks, irrigation channels and structures. The South Island of New Zealand has several networks of roads and tracks. This allows built features and infrastructure to extend from or around these roads. For these reasons, proximity to irrigation and infrastructure are not important characteristics when selecting a site for viticultural development.

2.4 Hill Slope Industrial Viticultural Development Fundamental Considerations

A fundamental aspect of industrial hill slope viticultural development is selecting a slope that allows machinery to work and slope stability to be controlled, but is not too flat to reduce benefits that hill slopes provide. When determining hill slopes on the South Island of New Zealand viability for industrial viticultural development the above fundamental aspects need to be considered in conjunction with the characteristics that make a suitable site for viticultural development.

2.4.1 Mechanisation

The use of machinery on hill slopes throughout New Zealand for viticultural purposes is common but usually limited to maintenance machinery such as tractors, trucks or motor bikes. The use of harvesting machinery on hill slopes is rarely used because of the common pinot noir variety planted on the slopes which is traditionally picked by hand. In order for industrial viticultural development on the hill slopes to be economical, machinery use is needed to reduce costs and time spent on jobs in the hill slope vineyards.

Research of viticultural machinery used in vineyards allows an understanding of the machineries capability on hill slopes to be assessed. Table 2.1 below displays the specifications of common viticulture machinery used in a vineyard (Worksafe 2009; New Holland 2001; Pellenc 2011). The performance of each type of machinery varies on the hill slopes, as a result of each piece of machinery having its own specific job.

Table 2.1 Machinery specifications for operation on hill slope vineyards.

	Specifications					
	Minimum Row Width (m)	**Minimum Operational Height (m)**	**Maximum Slope (°)**	**Maximum Lateral Slope (°)**	**Maximum Vertical Wheel Offset (m)**	**Minimum Headland (m)**
Tractor	2	Ground	35	30	N/A	5
4x4 Motorbike	1.5	Ground	45	40	N/A	3
Truck	2	Ground	40	35	N/A	5
Harvester	2	0.5	30	15	0.4	6

When using machinery on a hill slope it is important to understand the machineries capability to ensure that a site is not selected where machinery cannot be used. All machinery can function up to 30° parallel to slope but use up to 25° is recommended (New Holland 2001; Pellenc 2011). The harvesters are limited to 15° across slope because of their top heavy structure. For industrial purposes, this limits a sites slope angle up to 15° for viticultural development. Some of the machinery is capable of being used at greater slopes but the hazard risk greatly increases (John Deere 1983; Erlich *et al.* 1993).

2.4.2 Stability

Hill slopes are dipping areas of land with soil, underlain by a certain type of bedrock. Because of the slopping nature of the land, hill slopes have various forces acting on them that make them more susceptible to slope stability issues. Stability issues that arise are associated with the soils, geology, geomorphology, slope angle and water on a hill slope (Townsend 2011). Stability issues need to be considered when developing vineyards on hill slopes to ensure the vineyard is safe to work on and has a long life. Slope stability of soils and geology on a sloping site are a function of erosion, slope angle, water and vegetation cover (Martinson 2006).

Erosion

Erosion is mainly limited to the soil profile and exposed outcrops where water or wind can breakdown the soil structure and cause it to fail or gradually move down slope under the influence of gravity. There are two primary types of erosion to consider, the first is gully, and the second is sheet and rill erosion. Gully erosion involves the mass movement of soil from an area of concentrated flow, often following heavy rainfall (Gregg 2010). Sheet and rill erosion involves more subtle loss of soil across an entire area and involves a small layer of soil. If a slope is un-vegetated then the likelihood of erosion is greatly increased (Gregg 2010).

Slope Angle

The steeper a slope angle at a site, the higher the chance of slope stability issues occurring. With this in mind a slope angle of approximately 15° is considered the steepest slope angle before mechanisation and stability issues arise. If viticultural development occurs on slopes >15°, engineering methods will need to be utilized to mitigate potential slope stability issues (Cathcart *et al.* 2001).

Water

Water can influence stability by way of erosion, pore pressures and lubrication. Water can be supplied to a slope naturally by rainfall or by irrigation once a vineyard has been established. Introducing excess water to a sloping site can mobilise the topsoil and saturate the slope. This reduces slope stability and can lead to on-going or future problems. If a slope is vegetated, excess water on the slope surface can be absorbed by the vegetation's root system, mitigating slope stability issues. The stability issues highlighted above have the potential to lead to natural hazards occurring on a hill slope (Cathcart *et al.* 2001; Hoek 2007; Varnes 1978).

2.4.3 Benefits of Hill Slopes for Viticultural Development

The benefits hill slopes provide over flat areas have been outlined above. These benefits are of importance if a viticultural development is positioned on a hill slope. The main benefits hill slopes provide for a viticultural development is the establishment of a microclimate, greater number of growing degree days (GDD) and drainage.

Microclimate

Climate on hill slopes can differ from that on flat adjacent land and can mitigate or contain some of the climatic issues that may affect viticultural success. Depending on where the vineyard is positioned on the slope, the elevation, the shape of the slope and the direction it faces are all factors that can affect the microclimate (Bonan 2002). Microclimate can protect against prevailing winds, frosts and provide a warmer growing environment. The formation of an inversion layer or thermal belt during the night and cold days is an aspect of microclimate that can occur in hill slope areas. Cold air is much denser than warm air, and will begin to flow like a viscous fluid downhill from higher, cooler elevations to lower elevations, providing there are no obstacles on the slope. This in turn displaces the warmer air upwards, creating a temperature inversion or a thermal belt (Figure 2.2) (Bergen 1969). This temperature inversion layer or thermal belt provides warmer growing conditions for grapes at all times of the year compared to the surrounding flat areas.

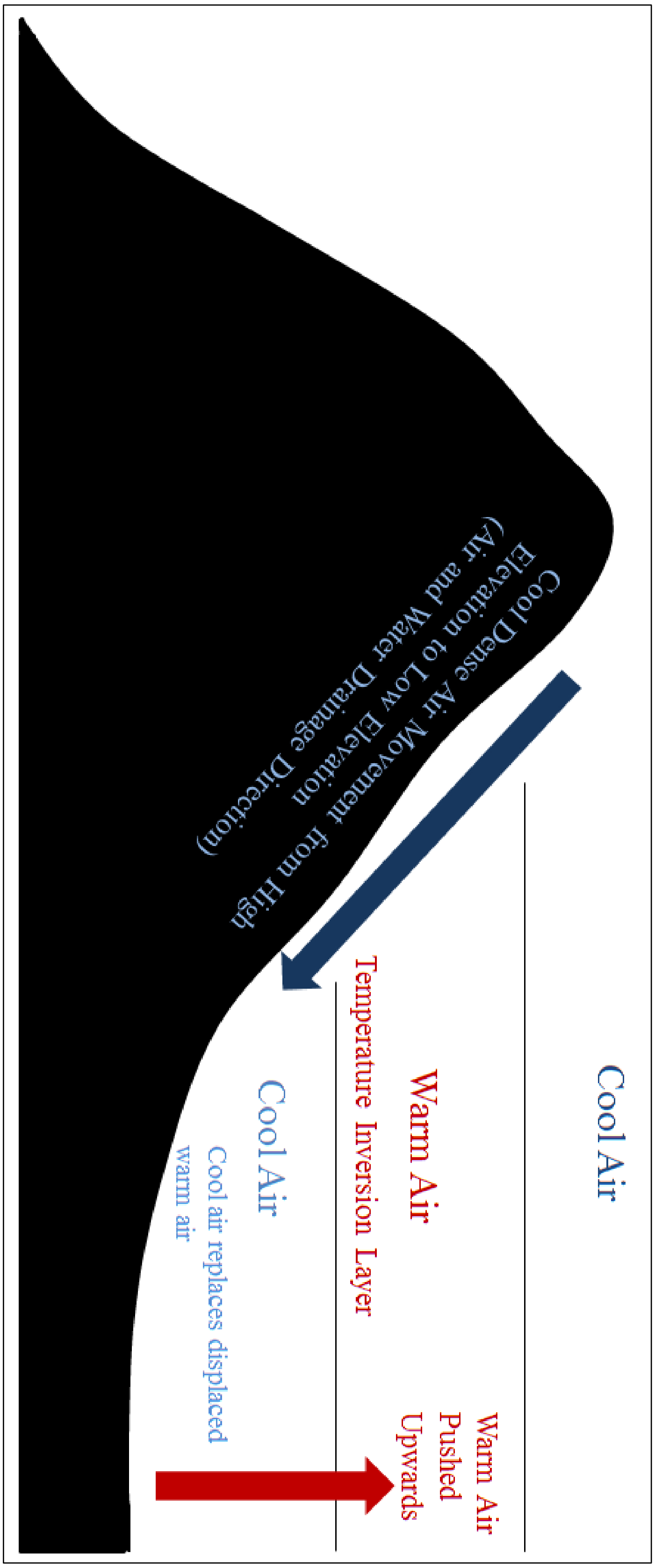

Figure 2.2 Formation of a temperature inversion layer or thermal belt and air/water drainage direction.

Growing Degree Days (GDD)

Vineyard vines require energy to grow and develop, and some of this energy is in the form of heat. Many climatic factors influence the wellbeing of a vine but temperature is the most important factor contributing to vine response (Trought *et al*. 1999). Hill slopes increase the number of growing degree days (GDD) compared to flat surrounding land because they receive more sunlight, which results in slightly higher temperatures. From a viticultural perspective, this increase in GDD allows an increased growth rate and ripening of grapes.

Drainage

A vineyard positioned on a hill slope provides increased air and water drainage (Figure 2.2). Previous studies (e.g. Richards & Baumgarten 2003; Snyder 2000; Bergen 1969) have stated that hill slopes are less susceptible to frosts providing they are free of obstacles as the hill slope does not allow cool air to settle and encourages air drainage. Instead cool air moves off downslope to lower areas of topography and reduces the chance of frost on the hill slope. Water drainage on slopes occurs at a faster rate compared to flat land and is dependent on soil, rock types and slope morphology (McDonnell 2003). Soils are generally free draining on hill slopes which allows vineyard irrigation to be controlled. The free draining soils remove the majority of excess water on a slope; therefore, the amount of water supplied to the vines through irrigation can be controlled.

2.5 Case Studies

Hill slopes have been developed for viticultural purposes with great success overseas in places such as Spain, northern Italy, US, Europe and France (Townsend 2011). Three distinct wine growing areas that have developed hill slopes for viticultural purposes include the Texas Hill Country viticultural area, Napa Valley viticultural area and mountain viticulture in

Switzerland. Key points can be identified from existing hill slope vineyards because previous issues or successes are likely to be repeated.

2.5.1 Texas Hill Country, US

The Texas Hill Country viticultural area was established in Austin Texas in 1991 and is the fifth largest wine-producing state in the USA (Texas Department of Agriculture 2008). Environmental hazards arise in this area due to the climate, geology and geomorphology in this region. The Texas Hill country is susceptible to severe rainfall which results in flash flooding and erosion of soils on steeper slopes (Abbott and Woodruff 1986). This is a result of thin, well-drained rocky soils and the presence of sloping topography.

Two key points have been identified from the Texas Hill Country case study. The first is that areas of unpredictable climatic conditions such as rainfall can be particularly troublesome for hill slope viticultural development. The second is that having a thin soil cover is poor for reducing erosion effects in a vineyard and it reduces the fertility of the site.

2.5.2 Napa Valley, US

The Napa Valley viticultural area is located in north western California which is the top wine producing state in the USA (Texas Department of Agriculture 2008). The hill slopes are adjacent to Napa River and extend to the rivers headwaters (De Blij 1983). The close proximity to the San Andreas Fault results in tectonic activity controlling the geomorphology and soil formation (Townsend 2011).

A key point identified is that planting on the hill slopes in the Napa Valley, requires a good understanding of soil erosion. The Napa valley, vines are planted both parallel and perpendicular to the contours of the slope. Planting vines parallel to the contours reduces the risk of erosion but this reduces planting space and makes the use of mechanized machinery difficult. A commonly used method to control erosion in the Napa Valley is planting of crops between the rows of vines, such as wild mustard and clover (Townsend 2011). The vegetation stabilizes soil between the rows and returns nutrient-rich organic matter to the soil (Fisher 1962).

2.5.3 Mountain Viticulture in Valais, Switzerland

Mountain viticulture refers to the cultivation of grapevines located both at high altitudes and on steep slopes (Ziliani 2006). Much of Switzerland's viticulture is concentrated in the Valais Canton, at relatively lower altitude and on south-facing steep-sided slopes of the north bank of the Rhone River (Clarke 2002). Much of this area has been terraced by the construction of contoured retaining walls on which the vines are planted. Instability of surface soil layers on steep slopes inhibits plant establishment, therefore mountain vineyards need a stable location protected from mass-wasting movement of sediment that may bury or damage vines (Townsend 2011; Perez 2009). At such steep slopes, the use of mechanised equipment for planting, harvesting and maintenance is difficult. This results in human labour being used to complete the work that mechanised machinery would usually do on flat ground. Landslides, including rockslides and debris flows, are serious natural hazards that commonly occur in the Swiss Alpine mountain environment and are often triggered by heavy precipitation, snowmelt, and runoff (Arbellay *et al.* 2010). Vineyards planted on these slopes are potentially exposed to these natural hazards.

Three key points were identified and can be applied to this thesis. The first is the importance of using machinery on slopes. Hand labour on slopes is expensive and time consuming, which is why a site should be selected that is capable of machinery use. For industrial viticulture purposes on the hill slopes, machinery would have to be used to make it economically viable. The second key point is that landslides, debris flows and erosion are the major stability issues that occur in steep hill slope vineyards. The third key point is that terracing can be used when slopes get too steep, but this will reduce the quantity of rows and vines in the vineyard.

2.6 Summary

Many factors constitute a successful viticulture site, with additional benefits when a vineyard is positioned on a hill slope. The key points identified from international case studies can be applied to the South Island of New Zealand when determining viable sites for viticultural development. The key characteristic that has arisen in the background research is the slope angle. The slope angle determines what stability issues will arise, whether machinery can be used and allows the benefits of hill slopes to be utilized. A slope angle of 15° allows mechanised machinery to be used, slope stability to be controlled and does not inhibit the benefits a hill slope provides (Figure 2.3).

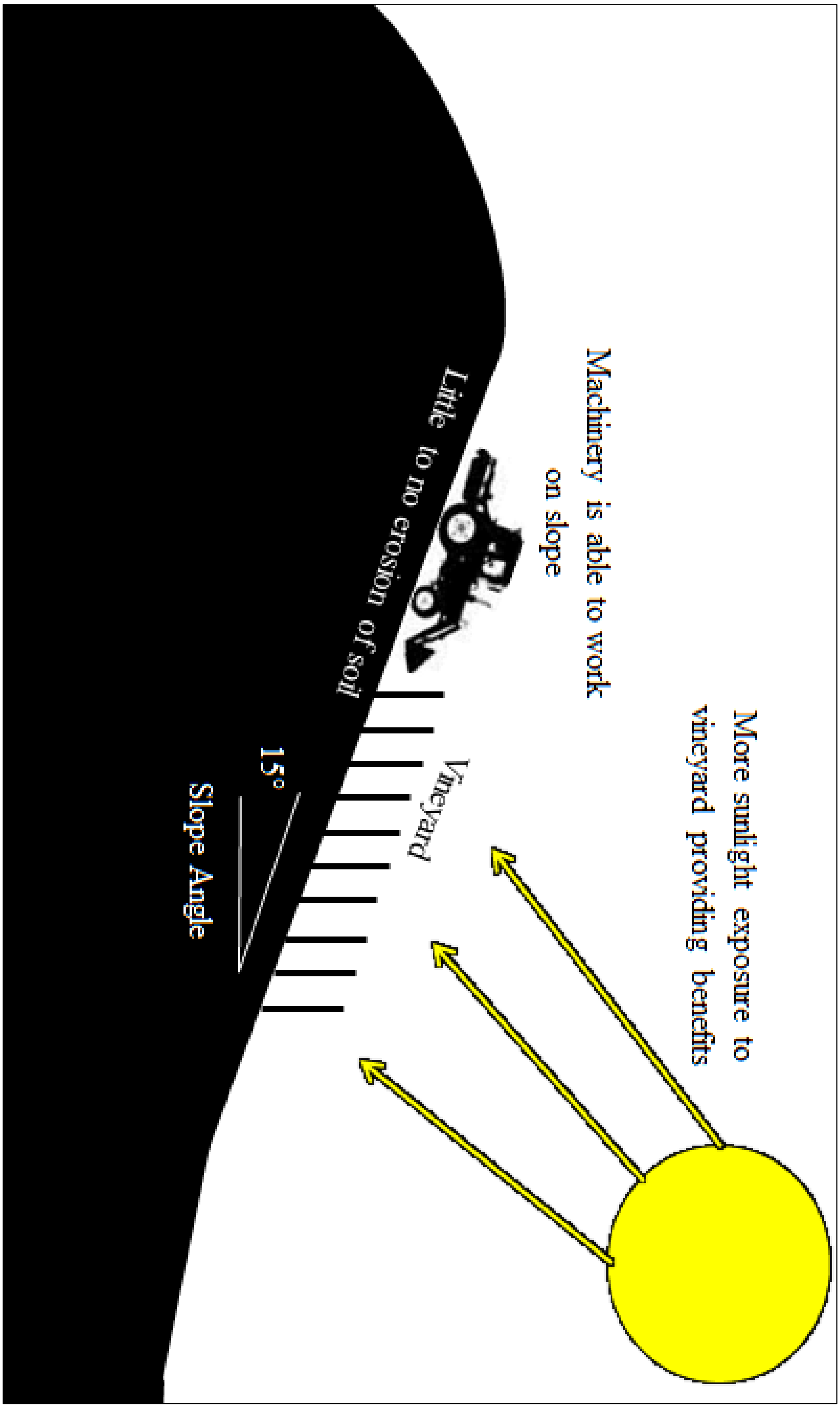

Figure 2.3 The important aspects of a vineyard positioned on a 15° hill slope.

Chapter 3

3 Research Methodology

3.1 Existing Methods used for Vineyard Site Selection

Several methods have been developed which allow physical characteristics to be analysed or combined to determine whether a site is viable for viticultural development. These methods include Geographic Information Systems (GIS) (Irimia & Patriche 2011; Watkins 1997; Jones *et al*. 2007), electromagnetic induction and soil resistance (Fulton *et al.* 2010); and climate models (Weldon 2003). From this information a methodology has been selected to identify viable hill slope sites for industrial viticultural development.

3.2 Methodology

Three main methodological steps were used to test the objective outlined in Chapter 1, these include site investigation, GIS and data loggers. The following sections define the methods used during site investigation, GIS and temperature/sunlight data logging.

3.2.1 Site Investigation

A South Island tour of three major grape growing regions was undertaken to identify the practices currently employed in existing hill slope vineyards, any issues associated with developing vineyards on hill slopes and to determine the fundamental characteristics a site requires for viticultural development. The three regions visited were Central Otago, Canterbury and Marlborough. Existing vineyards on hill slopes in these regions were approached and the vineyard managers, viticulturists and wine makers were interviewed about the vineyard with minor measurements made within the vineyard. People on-site were interviewed about slope stability (erosion and landslides), climate (frosts, temperatures and rainfalls that occur), maintenance and harvesting (mechanised or hand) and any other factors that were an issue with a vineyard on a hill slope. After interviews, permission to take a walk around the vineyard and take measurements was asked. This stage of the site investigation involved taking notes on observations made such as orientation of rows relative to slope, signs of erosion, terracing of rows and recording measurements. Measurements taken included slope angle, aspect, hand auger to 1m below ground level for soil description, GPS location and other points of interest.

3.2.2 Geographic Information System (GIS) Suitability Mapping

When evaluating a viable site for viticultural development, the sites with the best characteristics need to be considered. A GIS approach is used to combine these characteristics to produce maps that identify areas viable for viticultural development. The GIS software used for this thesis is ArcGIS 10 developed by ESRI which is used to produce suitability maps of preliminarily viable sites for hill slope industrial viticultural development (ESRI 2011). Information collected from the site investigation stage and previous literature was used to refine the data used in the GIS to the fundamental characteristics that a hill slope site requires to be preliminarily viable for industrial viticultural development. It does not consider any other factors aside from the ones that will preliminarily indicate a viable site for hill slope viticultural development.

GIS Structure and Initial Requirements

The proposed GIS approach used site investigation and previous literature outlined in the Background section to constrain topographic and climatic characteristics that are fundamental for vineyard site selection. The topographic and climatic data was combined using overlay analysis to build suitability maps of hill slope areas that are viable for viticultural development in the South Island (Figure 3.1).

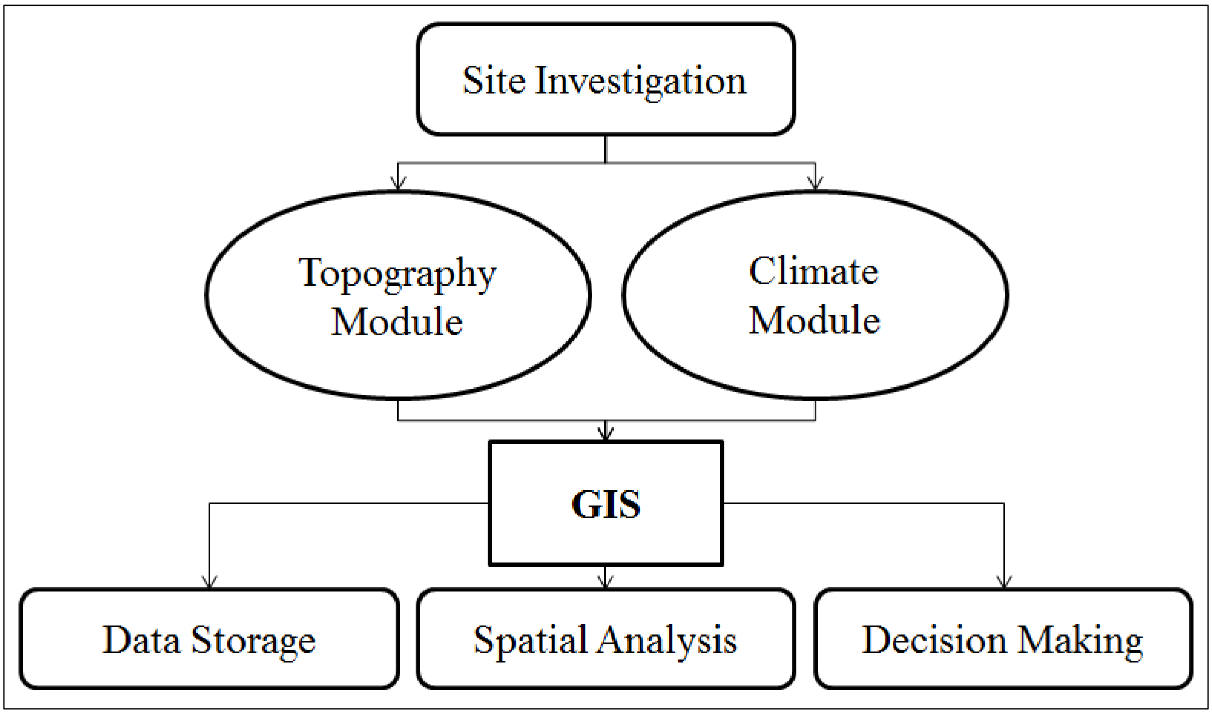

Figure 3.1 Conceptual model showing the position and role of a GIS when selecting a suitable hill slope for viticultural development (from Weldon 2003).

When using a GIS-based approach there are initial requirements that need to be considered before its application. The three initial requirements are: extent and coverage, data acquisition and accuracy of data. The extent and coverage is the geographic scale of a study area. An area with a wide extent and a large coverage will provide a low level of detail at a coarse scale. A coarse scale is at the size of New Zealand but this scale can be reduced to show more detail at regional level such as Marlborough or Central Otago (Figure 3.2). Data acquisition is the gathering of GIS layers that can be used for the study. The fundamental layers need to be gathered initially before the study begins for first order analysis. For the purpose of this thesis the layers are gathered from Landcare Research (LRIS portal), National Institute of Water and Atmospheric Research (NIWA) and the Koordinates website. The accuracy of the data is important as the quality of the final GIS map is determined by the input data. Therefore, the resolution and accuracy of the data used to select viable sites need to be appropriate if the development of a meaningful map is required.

Producing Suitability Maps

The GIS suitability maps were produced by a series of processes associated with geographic data. These involve tasks such as collection, storage and management, retrieval, conversion, analysis, modelling and display. The data used for this study had already been collected and processed by trained experts from the places mentioned above, which means it only needed to be analysed and modelled (Tait & Zheng 2007). Many layers are available to use when determining viable hill slope sites for viticultural development that could be integrated in a GIS to provide an accurate suitability map (Figure 3.3). For the purpose of this study, all the layers were not needed because data collected during the site investigation stage of this study and previous literature outlined specific characteristics of importance when selecting preliminarily viable hill slope sites in the South Island of New Zealand for viticultural development.

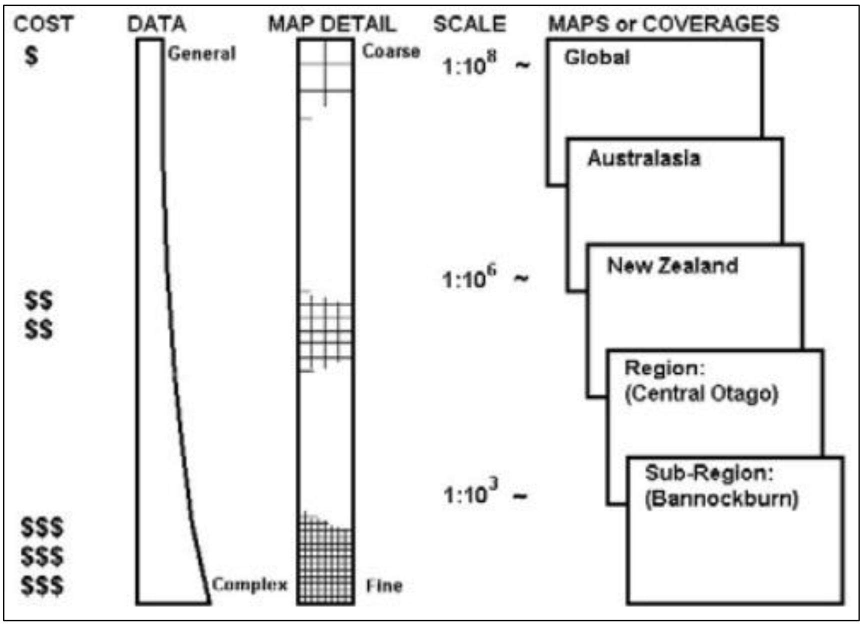

Figure 3.2 Geographic extents of coverage (from Smith 2002).

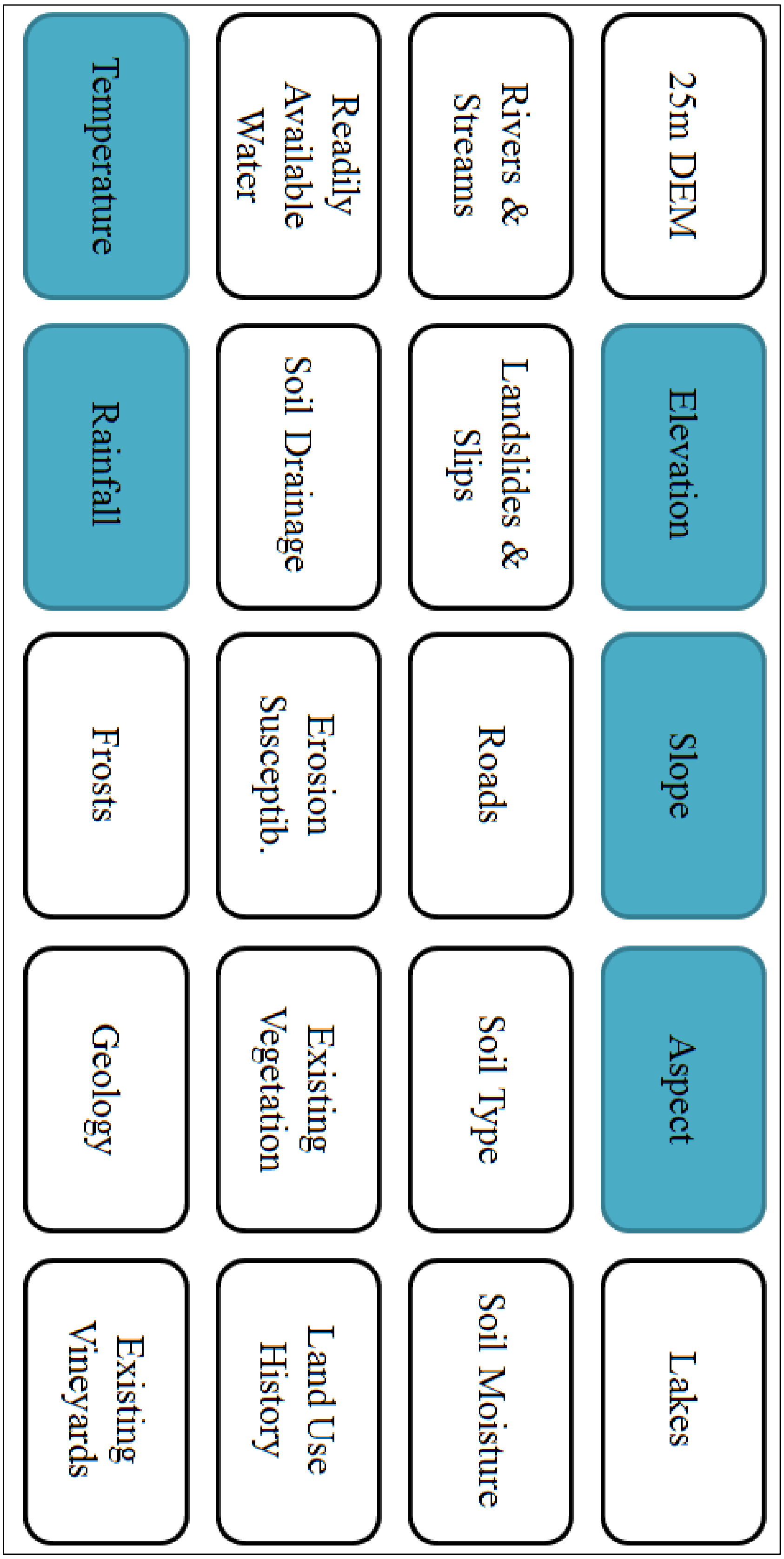

Figure 3.3 All layers available for detailed site selection on hill slopes, with fundamental characteristics highlighted.

Once layers of specific characteristics were collected, ArcGIS was used to convert the information layers into a format suitable for analysis. The site investigation stage and review of literature highlighted five characteristics that were fundamental in the preliminary selection of viable vineyard sites on a hill slope. The five characteristics were elevation, slope angle, aspect, temperature and rainfall (Figure 3.3).

A 25m digital elevation model of the South Island of New Zealand collected from the LRIS portal was used to produce the elevation, slope and aspect information layers of the South Island using spatial analysis tools in ArcGIS. The topographic information layers were combined with the temperature and rainfall layers collected from NIWA, using overlay analysis to analyse the initial suitability of the hill slopes in the South Island of New Zealand for viticultural development (Figure 3.4). Each layer added to ArcGIS was given a cell size of 25m to ensure all layers were the same resolution.

A suitability analysis of the hill slopes for viticultural development used reclassification of each individual characteristic into ranked classes based on their importance when selecting preliminary suitable sites for viticultural development on hill slopes (Table 3.1).

The factors within each characteristic were ranked between 0 (not suitable), 1 (suitable) or 2 (very suitable) based on that values importance in preliminary vineyard site selection. Some factors in each characteristic were given the same rank value because they were seen to have the same importance in site selection. The characteristics were then given the same weighting and overlain each other using the raster calculator to produce the suitability maps. Each characteristic was given the same weighting. The suitability maps will highlight preliminary areas of the South Island where hill slope industrial viticultural development is viable.

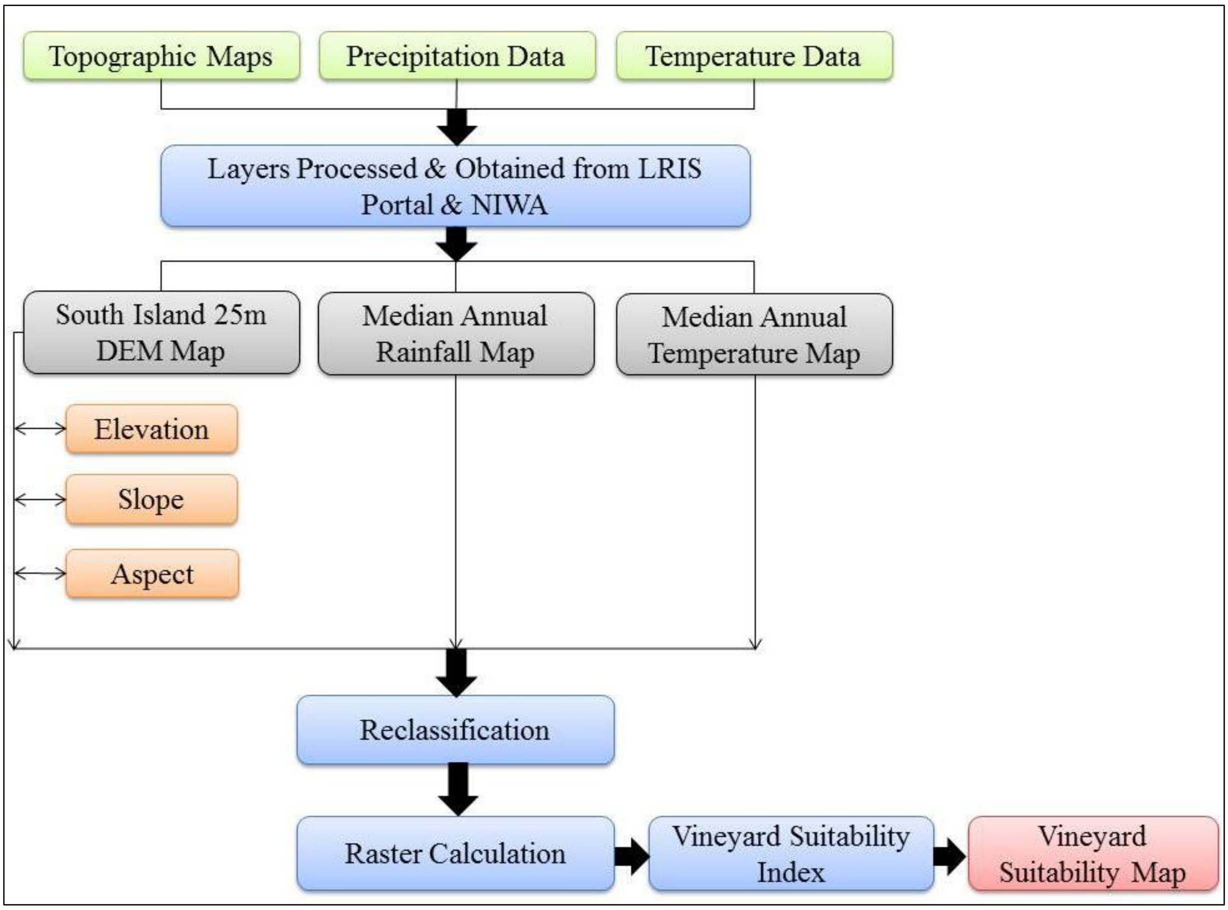

Figure 3.4 Flowchart of GIS-based overlay analysis used for hill slope vineyard suitability mapping (based on Kritikos & Davies 2011).

Table 3.1 The five selected fundamental factors with their ranked classes indicating what set of values are most important for vineyard site selection.

Factors	**Classes**	**Rank Values**
Elevation	< 450m	2
	450 - 500m	1
	> 500m	0
Slope	0° - 5°	0
	5° - 10°	1
	10° - 15°	2
	15° - 20°	1
	> 20°	0
Aspect	N – NW – NE	2
	E - W	1
	SW - S - SE	0
Temperature	> 10 °C	2
	9 - 10 °C	1
	< 8.9 °C	0
Rainfall	600 - 900mm	2
	500 - 600mm	1
	900 - 1000mm	1
	< 500mm	0
	> 1000mm	0

Justification of the Five Selected Characteristics

Elevation

Elevation is important when selecting suitable hill slopes for viticultural development. At higher elevations (>450m MSL), the air is cooler and temperatures are generally too cool to sustain a vineyard. The presence of cool temperatures above 450m in elevation is a limiting factor on vineyard location and is a major consideration when determining the preliminary viability of hill slope sites for industrial viticultural development.

Slope Angle

As mentioned in the background section, a slope angle up to 15° allows machinery to be used and slope stability to be controlled, but does not reduce the benefits that hill slopes provide. This is why slope angle is considered a major factor when determining preliminarily viable areas for hill slope industrial viticultural development.

Aspect

Aspect is a characteristic that is important when selecting a preliminary viable hill slope for viticultural development. Aspect controls the exposure of a slope to rainfall, wind and sunlight. Sunlight exposure is largely controlled by aspect which affects the temperature and microclimate of a hill slope site. For this reason, the South Island of New Zealand's north-east, north and north-west facing slopes would receive the largest amounts of sunshine. The ability of aspect to affect temperature and microclimate is the reason why it is fundamental when preliminarily determining viable hill slope sites for industrial viticultural development.

Temperature

Temperature is important when determining viable hill slope sites as a site needs to have a certain median temperature year round and especially around fruit ripening to sustain successful grape development. Hill slope areas in the South Island of New Zealand with an average temperature of above 10 °C are seen as viable for industrial viticultural development.

Rainfall

Rainfall at certain times of the year can be damaging to the development and establishment of a vineyard. The amount of rainfall that a site receives year round must be limited to minimise damage to the vineyard during cultivation, planting and ripening (Wolf & Boyer 2003). In the South Island of New Zealand, rainfall between 600 – 900 mm per year is considered to be acceptable for viticultural development to occur, providing appropriate management of the vineyard is undertaken (MPI 2012). If rainfall is outside this range it is generally considered too wet for viticultural success. This allows rainfall to be used in the GIS to preliminarily eliminate unviable areas for industrial hill slope viticultural development in the South Island.

3.2.3 GIS Validation

When using GIS it is important that the results are validated because of the errors that can occur in processing and use of the data. This allows a meaningful result to be taken from the map produced by the GIS. A second trip around the South Island was undertaken to visit sites identified as preliminarily viable during GIS suitability mapping. At these sites the elevation, slope angle and aspect were recorded, with annual median rainfall and temperature determined using the NIWA water resources explorer website to ensure a meaningful GIS result is produced by comparing the GIS result to actual measurements at the site.

3.2.4 HOBO Data Loggers

HOBO data loggers are produced by Onset and record temperature and sunlight. Two data loggers have been installed together at three separate locations. The first data logger was to record temperature/sunlight and the second was buried in the soil to record soil temperature. They were positioned on a north facing hill slope, south facing hill slope and on the flat to determine GDD and microclimate benefits by comparing how much light was received and the differences in temperature at each location. They were located on site for approximately one month, starting on the 24^{th} September 2012 at 12:00am.

The temperature/sunlight data loggers were placed on a platform above the ground, parallel to the ground surface where they received the sun throughout the duration of each day. They were positioned away from shadows and unimpeded so the results show accurately what is happening at each of the respected locations. Temperature data loggers were buried 50mm below the ground surface, adjacent to the temperature/sunlight data loggers at each of the locations to record how the soil responds to the heat absorbed during the day and compare this between the three sites. These are installed by digging down to the required depth, placing the data loggers in the soil and covering back over the data logger. Once the data was collected from all the data loggers, it was analysed using Onset software to determine GDD and microclimate benefits of hill slopes.

GDD Calculation

The data loggers were set up to record data that could be used to calculate the number of GDD at each location. The GDD calculation is:

$$GDD = \left[\frac{T_{MAX} + T_{MIN}}{2}\right] - T_{BASE}$$

where T_{MAX} is the daily maximum air temperature, T_{MIN} is the daily minimum air temperature, and T_{BASE} is the temperature below which the process of interest does not progress. T_{BASE} varies depending on what species is grown and at what stage of growth it is at (Wang 1960; McMaster & Wilhelm 1997). For viticulture, T_{BASE} is approximately 10 °C (Wang 1960).

Chapter 4

4 Results

4.1 Site Investigation

Site investigations were undertaken to build up a data base of existing vineyards on hill slopes in these three regions and guide the GIS suitability mapping. Photos taken of each vineyard visited are presented in Appendix 1.

4.1.1 Central Otago

Eight vineyards on hill slopes were visited in Central Otago in the regions of Cromwell, Bannockburn and the Gibbston Valley (Figure 4.1). The findings from site visits in Central Otago are summarised below and in Table 4.1.

- Hill slopes in Central Otago had been developed on slopes as steep as 30°.
- The highest elevation vineyard visited was 400m above mean sea level. At higher elevation above this site problems arose when snow fell and produced cold temperatures.
- Erosion in the hill slope vineyards was limited, even in the vineyards developed on slopes approaching 30°. This was because all the vineyards had sufficient grass cover on rows and a good layer of topsoil.
- Erosion issues arose when strong winds blew soils around during cultivation on baron land. Some preventative measures had been used to prevent erosion in the form of catch fences.
- In Central Otago, rainfall was normal to arid in most places due to rain shadow effects, creating a microclimate. The only places that had higher rainfall than others but still acceptable was the Gibbston Valley.

- People in Central Otago highlighted the importance of warm temperatures and minimal rainfall as the key characteristics that defined a good season.
- Frosts on the slopes were generally not an issue because of the air drainage and providing they were above the frost line (in the inversion layer). Problems arose when katabatic frosts or the poor formation of an inversion layer occurred. If snow was present above a vineyard it can cause frost damage because it can produce cool temperatures. If the slope had little basins or slumps, the cold air pooled causing frost. Sometimes frosted young plants inside protective covers.
- The single biggest issue for developing on the hill slopes was the wind. The hillside is more exposed to wind and battered around the plants causing loss of shoots and stunted growth in exposed places. At some sites the use of shade cloth as a wind break has been implemented or the establishment of wind break (mounded dirt or trees).
- All of the vineyards hand harvested their grapes because of the pinot noir variety but the people approached said that their vineyard has the potential to harvest and use machinery. In some areas they said that machinery could only be used downslope and if sufficient headland was available.
- The soils encountered in the hand auger boreholes were similar across all of the sites as they were all finer grained clay or silt based soils, underlain by schist bedrock.

Figure 4.1 Google Earth image displaying locations of vineyards visited in Central Otago.

Table 4.1 Summary table of findings after hill slope vineyard visits in Central Otago.

Vineyard Name	Erosion (Y/N)	Mechanised/ Hand (M/H) Harvest & Maintenance	Row Orientation	Frosts (Y/N)	Slope Angle (°)	Aspect	Notes
Golden Terraces	N	M maintenance, H harvest	Perpendicular to slope	N	17	N	Use 0.5m terrace rows across slope
Zebra	Y	M maintenance, H harvest	Parallel to Slope	N	15	N	Frosts when snow on the peaks above. Erosion when first established by wind
Peregrine	N	M maintenance, H harvest	Parallel to Slope	N	16	N	Narrow rows. Water not retained well because it is on a gravel bank.
Mt Edward	N	M maintenance, H harvest	Parallel to Slope	N	25	E	Planted on steep angled sluice material. Ground is quite compact and not fertile.
Misha's Vineyard	N	M maintenance, H harvest	Parallel to Slope	N	22-26	NW	Wind a big issue. Use shade cloth to mitigate.
Akarua	N	M maintenance, H harvest	Parallel to Slope	N	17	SW	Partly terraced. Water supply is an issue in summer.
Brennan	N	M maintenance, H harvest	Parallel to Slope	N	15	NW	Slightly more rainfall. Katabatic frosts have affected the area.
Chard Farm	N	M maintenance, H harvest	Parallel to Slope	N	10	N	No issues due to the slope angle.

4.1.2 Canterbury

Five vineyards on hill slopes were visited in Canterbury in the regions of the Port Hills and the greater Waipara area (Figure 4.2). The findings from site visits in Canterbury are summarised below and in Table 4.2.

- Hill slopes in Canterbury were developed on hill slope angles up to 20°.
- Erosion was not an issue except where cultivation was undertaken prior to a rainfall event or where water flowed through rabbit holes, creating tunnel gullies.
- Frosts were not an issue except where there was a poor formation of an inversion layer.
- Wind was not as greater issue here as it was in Central Otago because the vineyards were protected by topography or wind breaks.
- The people with vineyards positioned on the steeper slopes throughout Canterbury identified that slopes greater than 10° provided good drainage and that they could not envisage safe grape development on slopes greater than 30°.
- The soils encountered around Canterbury were fine-grained loess soils that ranged from clayey silts to sands that were underlain by volcanic rock or limestone.

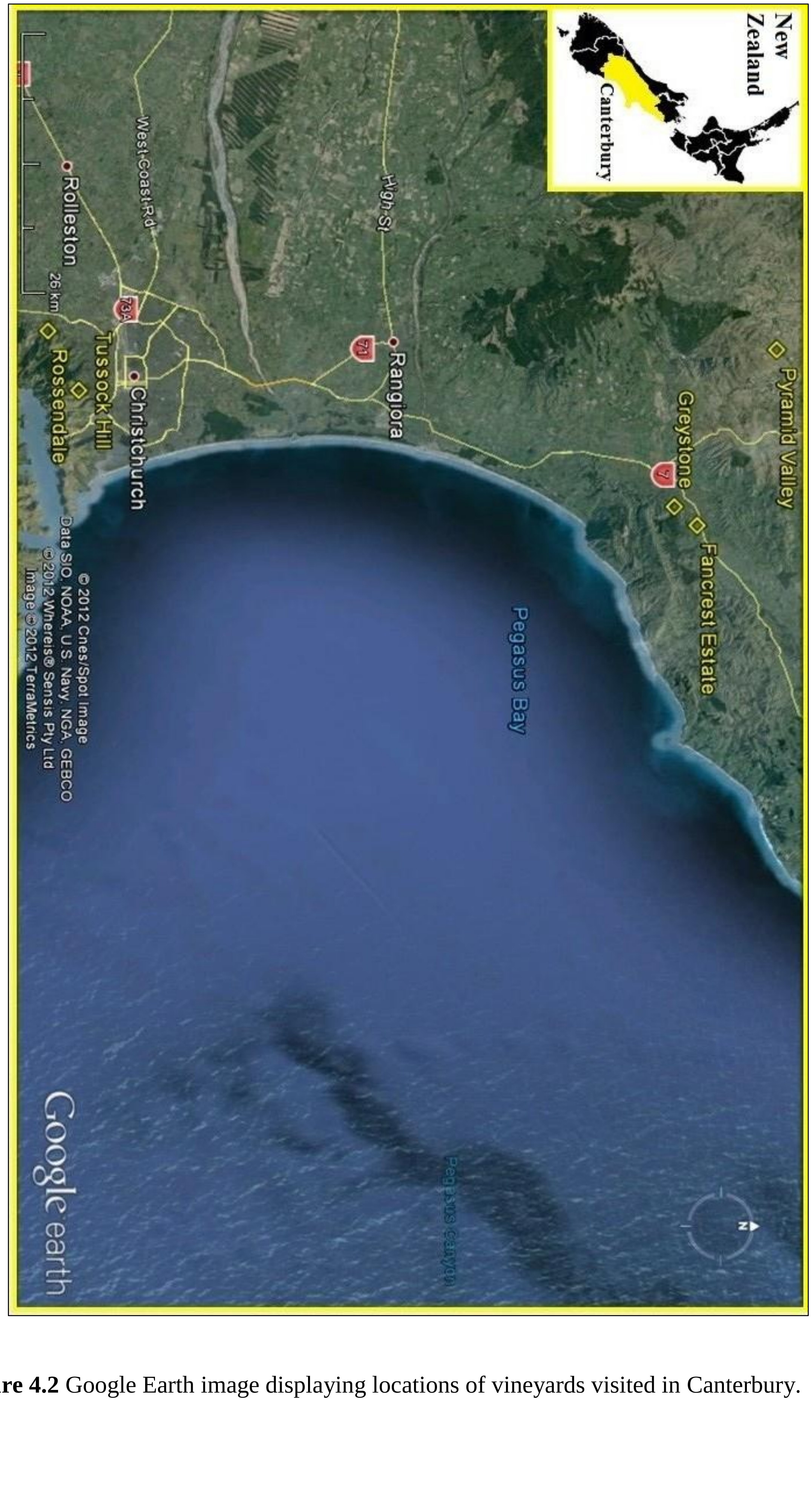

Figure 4.2 Google Earth image displaying locations of vineyards visited in Canterbury.

Table 4.2 Summary table of findings after hill slope vineyard visits in Canterbury.

Vineyard Name	Erosion (Y/N)	Mechanised/ Hand (M/H) Harvest & Maintenance	Row Orientation	Frosts (Y/N)	Slope Angle (°)	Aspect	Notes
Rossendale	N	M	Parallel to slope	N	16	N	Labour on the hill slopes is expensive.
Tussock Hill	N	H	Parallel to slope, with some diagonal	N	20	W	Wind is split by the peninsular.
Greystone	Y	M maintenance, H harvest	Parallel to slope	N	18	N	Erosion problems to start with due to bad cultivation and rainfall. Bad inversion layer.
Fancrest Estate	N	H	Parallel to slope	N	13-15	N-NW	Soils are limestone based. Above the frost line.
Pyramid Valley	N	M maintenance, H harvest	Parallel to slope	Y	16	N	Frosts happen but protected by water and have monitoring programme.

4.1.3 Marlborough

Five vineyards on hill slopes were visited in Marlborough in the regions of the Wairau and Awatere Valleys (Figure 4.3). The findings from site visits in Marlborough are summarised below and in Table 4.3.

- All vineyards have had significant re-contouring undertaken on them. The vineyards that performed well were the ones that had a good topsoil cover and had soil replaced in the same order it was removed in. Ones that did not perform well and had erosion were the vineyards that had limited topsoil with poor drainage pathways and poor vegetation cover.
- Hill slopes in Marlborough were developed on slope angles up to 20°.
- The southerly wind in Marlborough had caused damage to vines on hill slopes. The northerly facing vineyards were generally protected from this wind, with people stating the importance of aspect for grape development.
- Some of the people interviewed said that the rain often affects the crop and in the case of Ingrid Estate, led to erosion problems.
- The soils encountered in the Marlborough regions were fine-grained loess soils comprising silts and clays underlain by saline sands and interbedded sandstone and mudstone.

Figure 4.3 Google Earth image displaying locations of vineyards visited in Marlborough.

Table 4.3 Summary table of findings after hill slope vineyard visits in Marlborough.

Vineyard Name	Erosion (Y/N)	Mechanised/ Hand (M/H) Harvest & Maintenance	Row Orientation	Frosts (Y/N)	Slope Angle (°)	Aspect	Notes
Yealands	N	M	North-South aspect planting	N	15-20	All	Terraced where rows cut across slope. Close to sea.
Ingrid Estate	Y	M	Parallel to slope	N	23	N	Poor re-contouring and water management leading to erosion problems.
Redwood Hills	N	M	Parallel to slope	N	15-20	SW	Wind a problem but they use extra wires on the rows. Re-contoured.
Calrossie	Y	M maintenance, H harvest	Parallel to slope	N	15	NW & NE	Tunnel gullies where little topsoil is present. Re-contoured.
Brancott	N	M maintenance, H harvest	Parallel to slope	N	14	E-NE	Terraced. Wind not an issue because sheltered by hills.

Key Findings

No vineyard reported having unfavourable conditions for growing grapes in any of the regions visited. They all had appropriate rainfall and temperatures with limited issues. They highlighted the need for appropriate temperatures and rainfall for successful grape production. It was stated on more than one occasion that slopes over 30° would provide issues for viticultural development as a result of danger to machinery operators and erosion problems. The higher elevation hill slope vineyards in Central Otago indicated that cool temperatures associated with snow and wind were issues that needed to be considered. The aspect of vineyards was mentioned by people that had planted on the slopes that did not face north. They stated that people surrounding them with vineyards positioned on north facing slopes had more productive grape vines and 'wished' their vineyards were positioned on a north facing slope.

The general majority used mechanised equipment on their slopes for spraying and trimming but harvested their grapes by hand. Many people that were interviewed highlighted the cost of doing everything by hand was high and that machinery reduced these costs. Several vineyards could only use mechanised equipment downslope and needed the rows to be slightly wider with a suitable headland for turning at the top & bottom of the row. In all areas where erosion occurred, it appeared to be the result of vineyard management, vegetation cover and topsoil depth. Localised frosts were not an issue on hill slopes except for when heavy frosts that affected a whole region occurred, poor formation of an inversion layer occurred or where there were uneven hollows on a slope. The wind was one of the biggest factors affecting vineyards on hill slopes as it damages buds and shoots at important times of the year. Vineyards in the three regions visited have both localised and regional factors associated with development of vineyards on hill slopes that need to be analysed and understood. Once understood, these existing vineyards can be used to determine suitable hill slope areas for viticultural development in the South Island of New Zealand.

As a result of these findings it was concluded that the most preliminary viable hill slope sites for industrial viticultural development would be selected based on elevation, slope, aspect, temperature and rainfall as noted in the Methodology section. These are the five factors that will be used in the GIS suitability mapping of preliminarily viable hill slope areas for industrial viticultural development in the South Island of New Zealand.

4.2 GIS Suitability Mapping

ArcGIS was used to produce suitability maps of preliminarily viable areas for hill slope industrial viticultural development using the five factors (elevation, slope angle, aspect, temperature and rainfall) identified during the site investigation stage of this thesis. The suitability mapping identified 0.7% of the South Island as preliminarily viable for hill slope industrial viticultural development based on the five factors (Figure 4.4). There are many regions that have been identified with a greater number of hill slopes that are preliminarily viable for hill slope viticultural development. These regions are Nelson, Marlborough, Waipara, the Port Hills and areas throughout Central Otago (Figure 4.5 – 4.8). This suggests that the hill slopes adjacent to flatter areas in the major wine producing areas appear preliminarily viable for hill slope industrial viticultural development. It is important to assess the meaningfulness of the GIS results after a suitability map has been produced. This is undertaken by looking at the data limitations and assumptions made when ranking each characteristic and how the final map was classified.

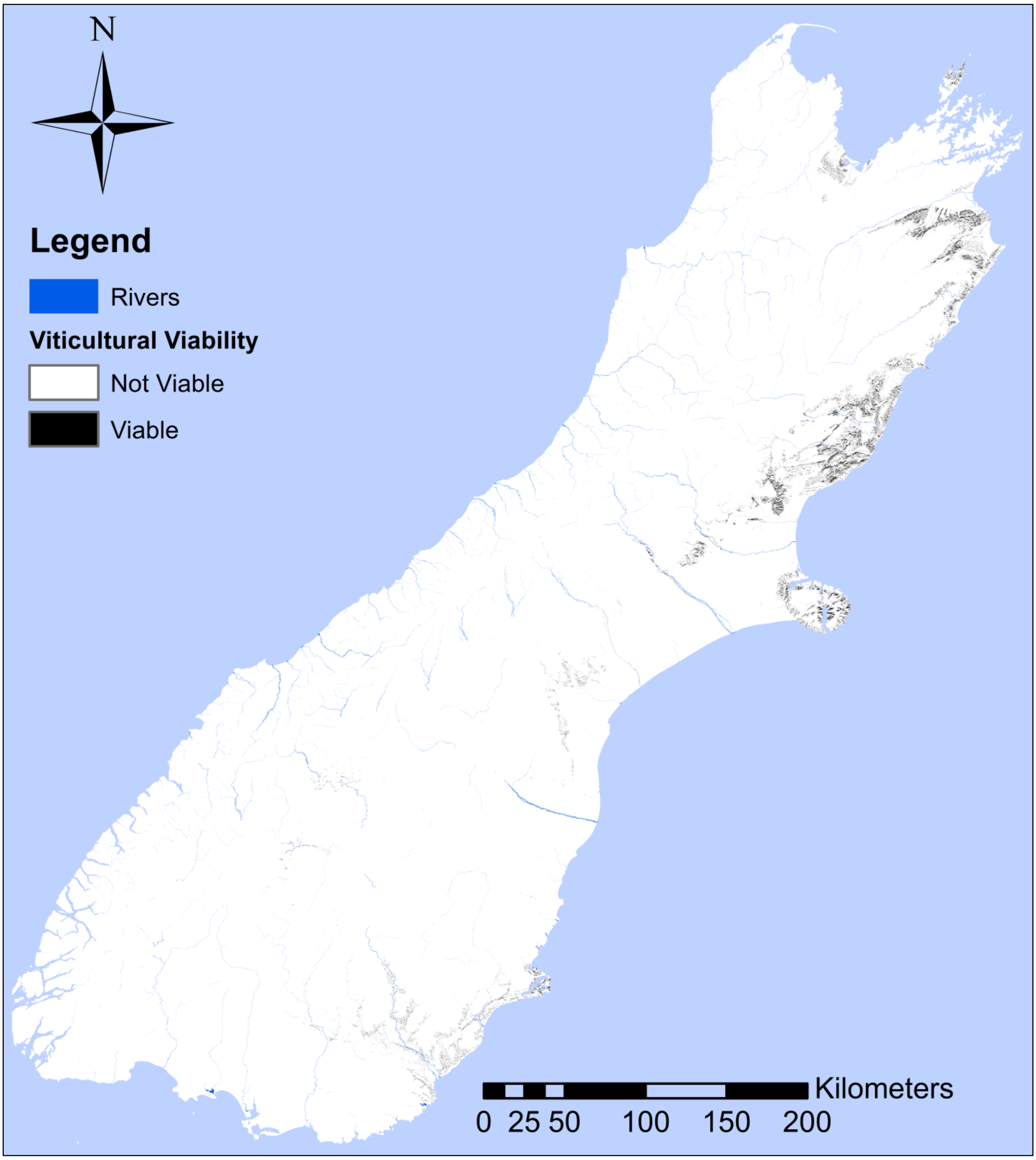

Figure 4.4 Preliminarily viable areas for industrial hill slope viticultural development in the South Island of New Zealand.

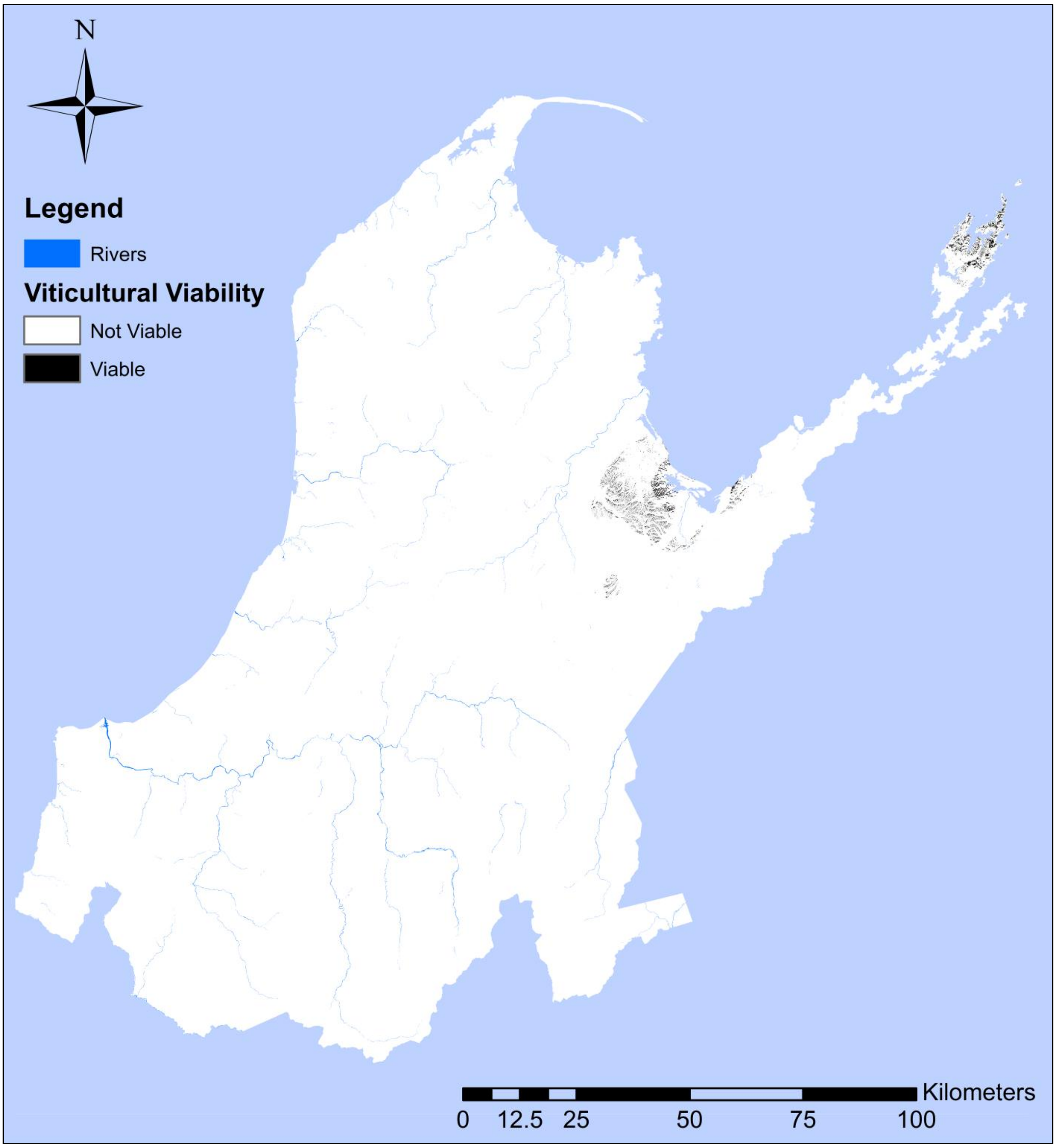

Figure 4.5 Preliminarily viable areas for industrial hill slope viticultural development in Nelson.

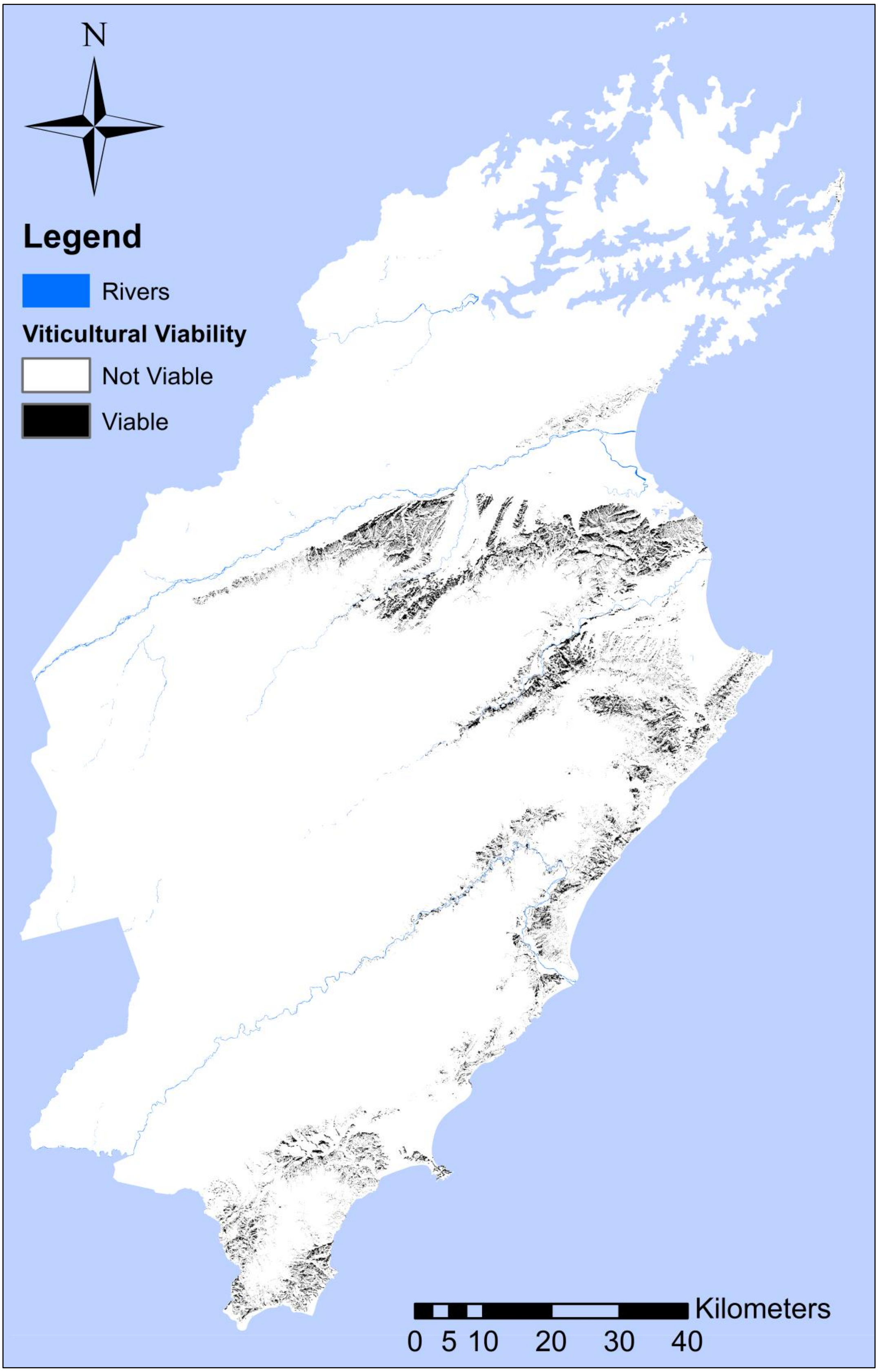

Figure 4.6 Preliminarily viable areas for industrial hill slope viticultural development in Marlborough.

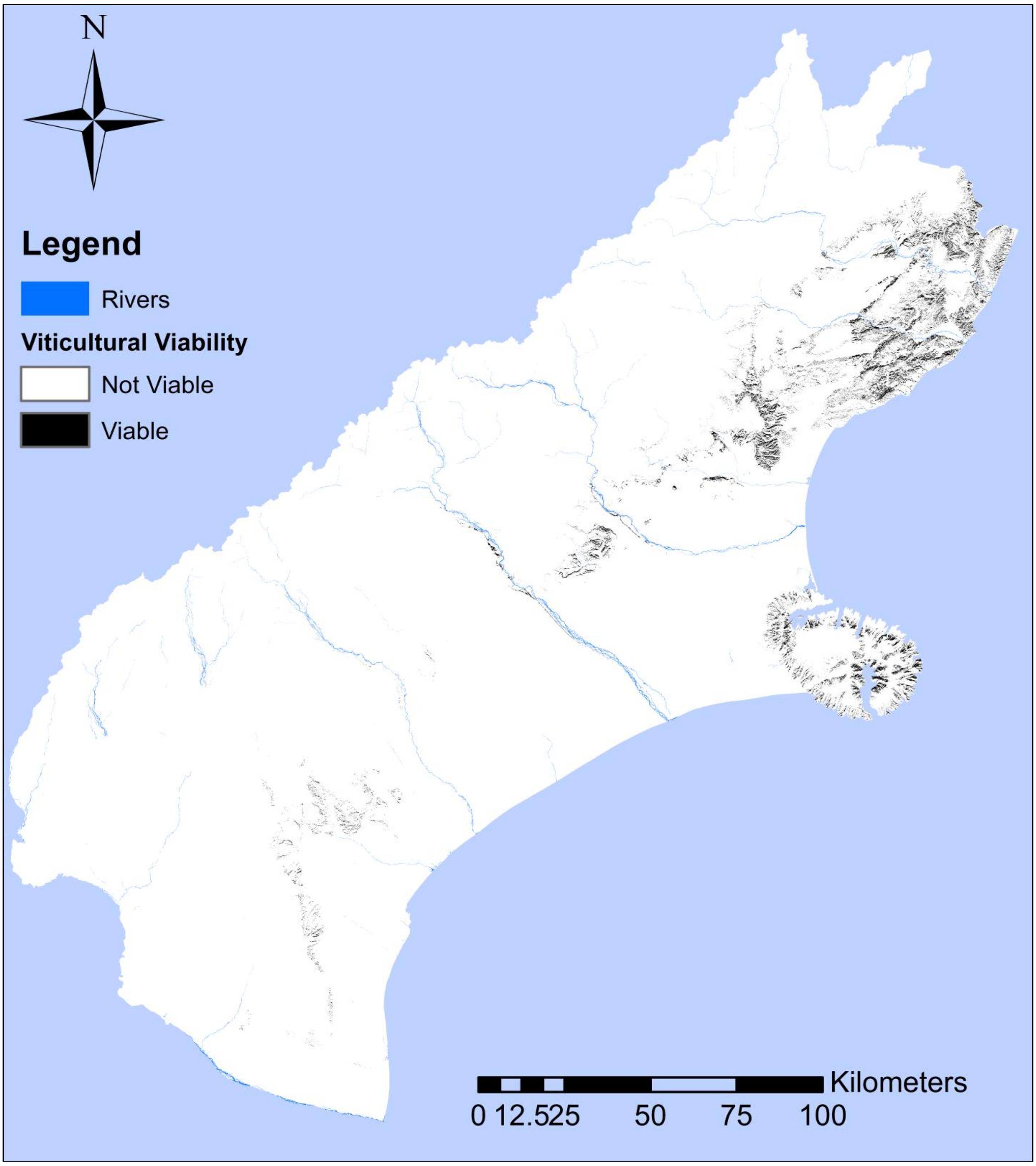

Figure 4.7 Preliminarily viable areas for industrial hill slope viticultural development in Canterbury.

Figure 4.8 Preliminarily viable areas for industrial hill slope viticultural development in Central Otago.

4.3 GIS Validation

Eighteen sites identified as preliminarily viable by the GIS study in the regions of Nelson, Marlborough, Canterbury and Central Otago were visited to validate the GIS results. This ground truthing of these sites ensures a meaningful GIS result is produced by comparing the GIS result to actual characteristics at the site (Table 4.4).

Table 4.4 GIS measurements compared to actual site visit measurements for GIS validation.

	GIS Measurement					**Site Visit Measurement**				
	Elevation (m above MSL)	Slope (°)	Aspect	Median Annual Temperature (°C)	Median Rainfall (mm per year)	Elevation (m above MSL)	Slope (°)	Aspect	Median Annual Temperature (°C)	Median Rainfall (mm per year)
Site 1	60	22	NW	12.6	963	55	23	NW	12	896
Site 2	105	16	NW	12.6	908	106	14	NW	12	898
Site 3	160	13	N	11.9	1047	161	11	N	12	942
Site 4	163	21	NW	12.5	956	160	19	NW	12	822
Site 5	57	12	N	12.7	626	60	14	N	12	633
Site 6	275	23	NW	11.8	966	273	21	NW	11	729
Site 7	370	18	NE	12.4	796	367	20	NE	11	857
Site 8	132	11	NE	11.7	1127	130	12	NE	12	753
Site 9	171	15	N	11.8	1090	168	17	N	11	815
Site 10	256	13	NW	11.5	700	251	13	NW	11	614
Site 11	312	17	N	10.9	943	310	15	N	11	792
Site 12	415	20	N	10.6	722	410	18	N	10	625
Site 13	255	15	N	10.4	698	254	13	N	10	607
Site 14	55	18	N	10.2	840	56	19	N	10.5	688
Site 15	140	19	NW	10.1	770	143	18	NW	9	719
Site 16	130	21	N	10.3	825	128	19	N	10	836
Site 17	388	16	N	10.4	685	386	17	N	9.8	608
Site 18	375	16	N	9.4	784	376	15	N	10	671

4.4 Data Loggers

Temperature and sunlight data collected by the three sets of data loggers on the north facing, south facing and flat sites were collected after approximately one month of logging. They were installed to compare how much light is received and the differences in temperature between each of the data loggers positioned at each of the locations, compare the number of GDD at each location and to determine how the soil responds to the heat absorbed during the day. Figure 4.9 below shows the sunlight/temperature graphs and soil temperatures from each respected location. The graph highlights that a north facing slope receives more sunlight, is slightly warmer and has more growing degree days than the south facing slope and the flat site (Table 4.5).

Table 4.5 Average temperatures, sunlight received and GDD on the north facing, south facing and flat sites.

North Facing Slope	Air Temperature (°C)	14.37
	Soil Temperature (°C)	12.72
	Sunlight (Lux)	46684
	GDD	15
South Facing Slope	Air Temperature (°C)	13.39
	Soil Temperature (°C)	10.33
	Sunlight (Lux)	40829
	GDD	14
Flat	Air Temperature (°C)	13.99
	Soil Temperature (°C)	12.7
	Sunlight (Lux)	43624
	GDD	9

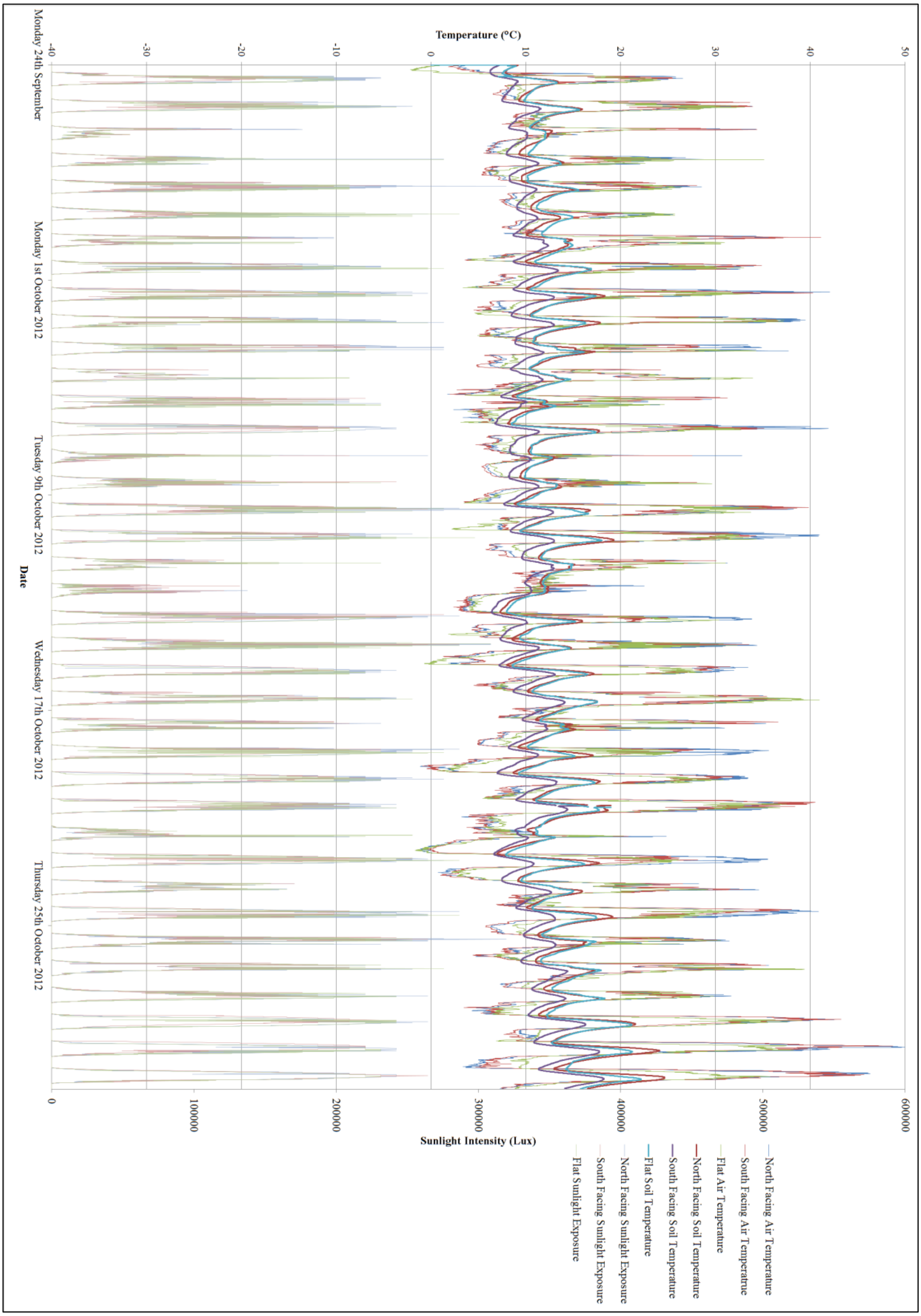

Figure 4.9 Air temperature, soil temperature and sunlight received by the flat, north and south facing slopes over the period of September/October.

Chapter 5

5 Discussion

Through the application of site investigation, GIS suitability mapping and data loggers, the hill slopes on the South Island of New Zealand are viable for industrial viticultural development. The regions of Nelson, Marlborough, Canterbury and Central Otago were highlighted as having the greatest number of hill slopes viable for development. These regions were identified by the selection of the five most important characteristics (elevation, slope, aspect, temperature and rainfall) for developing vineyards on hill slopes. Slope stability associated with hill slope viticultural development is not considered to be an issue, due to vineyard management mitigation or preventing stability issues. Slope stability is, however, considered to be an important factor when first establishing or expanding a vineyard on a hill slope. For this reason, erosion a factor associated with hill slope viticultural development is discussed below. Another finding highlights that hill slopes increase the number of GDD and provide a number of benefits for growing grapes. Discussing these points allows the viability of hill slopes for industrial viticultural development to be assessed.

5.1 Current Viticultural Development on Hill Slopes of New Zealand

Hill slope viticultural development in New Zealand is limited, with the majority of the development occurring in Central Otago. Existing vineyards on hill slopes appear to have an understanding of how to produce grapes and the issues associated with developing on hill slopes. With this considered, certain trends began to arise during the site investigation stage between the three regions of factors that might influence the viability of industrial viticultural development on hill slopes. The factors and issues encountered were wind, slope angle, terracing and re-contouring work, vineyard management, climate and soil type.

Wind

Wind is one of the factors that affect vineyards on hill slopes of the South Island. In most hill slope locations, the vineyards are protected from certain wind directions because they are on the lee ward side of a slope. Even though this is the case, there are always winds blowing from different directions that have the possibility of damaging the grape vines in a vineyard. Wind has been mitigated through the use of extra wires to hold vines in position, shelter belts of vegetation or fill to protect from certain wind directions and shade cloths on rows to try and break the flow of wind through the vineyard. Wind is a problem that needs to be addressed after the preliminary viability of hill slopes for viticultural development is assessed.

Slope Angle

Interviews with people on existing hill slope vineyards provided confirmation that selecting an appropriate slope angle was an important decision in the life of a hill slope vineyard. Many people stated that hill slopes could be developed on slopes up to 30° but developing these slopes had many issues such as slope stability and the cost of labour on the steeper slopes. This confirms that a slope angle needs to be selected which allows slope stability can be controlled and machinery to be used. Previous studies combined with this finding allowed a slope angle of 15° to be selected.

Terracing and Re-Contouring Works

In all three of the regions visited during the site investigation was evidence of terracing, with re-contouring evident only in Marlborough. Terracing was a common method adopted in these regions for development on hill slopes up to 30° or where rows cut across a slope.

Terraces had also been cut to improve the slope stability on the steeper hill slopes. Re-contouring work was prominent throughout the Marlborough region. Vineyards had most of their slopes altered in some way through the use of earthworks to provide a favourable aspect or slope angle for the vines to grow on.

Vineyard Management

Vineyard management largely determines an established vineyards success. The scope of this research does not cover vineyard management but several trends were highlighted during the site investigation stage. These trends included grape variety, headland size, row spacing and row orientation which had an influence on the site selection process to allow enough space for proper viticultural development.

For industrial viticultural development on hill slopes to be viable; all grape varieties are required to grow on slopes and be harvestable by machinery. The headland in a vineyard has to be an appropriate size to cater for all machinery and the rows have to allow for machinery to work on them while not reducing the production capacity of the vineyard. These are factors that a vineyard manager will need to consider when designing and determining the viability of an industrial vineyard on the slopes of the South Island.

Climate

The climate encountered throughout the three regions of the South Island varied, with localised areas within regions showing more favourable climatic conditions for growing grapes. In general, the three regions visited had favourable conditions for growing grapes with appropriate temperatures and rainfall to sustain a vineyard on a hill slope. Within these regions, hill slope vineyards in localised areas had a rain shadow effect with formation of an inversion layer which established a microclimate optimum for producing grapes. In all of the regions, there were climatic events that would occur at random during the growing season that would have adverse effects on the vineyards. The most unfavourable climatic systems are low winter temperatures, late spring frosts, excessive summer heat, and unpredictable precipitation.

The climatic conditions of Central Otago, Canterbury and Marlborough appear to be appropriate for industrial hill slope viticultural development. There are limited climatic events that could have adverse effects on vineyards which indicate that climatic conditions in the South Island are appropriate for industrial hill slope viticultural development.

Soil Type

Throughout the three regions of the South Island the soil types are very similar. They are comprised of fine-grained materials ranging from clay to fine sands, underlain by differing bedrock, depending on the location. The vineyards that appeared more favourable were the ones that were underlain by limestone or schist. The soil types were generally favourable for viticultural development but further site investigation would be required to fully determine appropriate hill slope sites for viticultural development.

The above factors highlighted during vineyard visits throughout grape producing regions of the South Island build a database of current hill slope viticultural practices in New Zealand and highlight the issues associated with them. With the knowledge of what methods, practices and conditions occur in each region; current viticultural development on hill slopes can be better understood.

5.2 GIS Considerations

The GIS suitability mapping used elevation, slope angle, aspect, temperature and rainfall to identify viable hill slope sites for industrial viticultural development. The suitability map identified 0.7% of the South Island as preliminarily viable for hill slope industrial viticultural development. The sites identified are in the regions of Nelson, Marlborough, Waipara, the Port Hills and areas throughout Central Otago. The majority of the sites identified are thin bands along the base or top of hill slope with the area between being too steep to allow for machinery to work. In these areas re-contouring could be undertaken to lower the slope angle and provide a greater area for viticultural development, but care is needed to mitigate slope stability problems. When using a GIS it is important to determine the meaningfulness of the results. This is undertaken by looking at the data limitations, assumptions made when ranking the categories in each characteristic and how the final map was classified.

Data Limitations

When producing suitability maps using GIS, data limitations concerning resolution, scale and accuracy have to be considered as these may affect the quality of the map produced. The resolution of the maps used to produce the suitability map varied from 25m to 500m, with a final map produced at a resolution of 25m. The temperature and rainfall layers were originally at a 500m resolution which meant they had to have their resolution changed to 25m. This meant all data layers have the same resolution so when they were combined in the GIS, the resolution stayed at 25m. Changing the resolution did not change the accuracy of the map. The scale of layers acquired and processed should be the same as the anticipated scale of the final map. Both the climatic and topographic layers were produced at 1:50,000 scale. The rainfall and temperature maps were produced using spatial interpolation by way of inverse distance weighting. If the scales differ, then the accuracy of the map can be affected and produce an unrealistic result. The accuracy and quality of the input data both carry through to the final outcome. Therefore, the data acquisition and processing are important steps and must always be performed carefully. The layers used were collected from the LRIS portal and NIWA who had collated data that had been collected over the years and used them to produce the GIS layers. The data was collected by professionals that have been trained in

GIS map production so the values within each map are assumed to be close to the true values experienced at the actual site. The use of site investigation determines that these values are accurate. Data accuracy issues arise at the collection level, before the processing has been done. Issues such as accuracy of collecting rainfall, temperature or the 25m scale of the DEM can be of concern. Through reading how the layers were processed, accuracy assessments undertaken, and the scale and resolution used on the layers used in this thesis, the results are meaningful (Barringer *et al.* 2002).

Assumptions when Ranking Categories in Each Characteristic

The five characteristics (elevation, slope, aspect, temperature and rainfall) used to produce the suitability maps were ranked into categories based on how important they were to preliminary hill slope industrial viticultural development. Each characteristic was divided into three categories; very suitable, suitable and not suitable. They were divided into these categories based on knowledge from existing literature and findings from the site investigation. Previous literature has identified issues with the selection process involved when categorising characteristics. Voogd (1983) indicates that there will always be some doubt as to whether all the relevant criteria in the characteristics have been correctly defined. Other studies such as Heywood *et al.* (1995) and Eastman (1997) have also expressed their concern with whether all relevant criteria have been taken into account and if these criteria reflect the objectives set out by the categorisation. The assumptions underlying the classification of each parameter are that existing literature and interviews with people who have developed vineyards provides a reliable understanding of each of the selected characteristics. That categories selected as very suitable will not change dramatically over the life of the proposed vineyard and that the categories selected include all appropriate values for preliminary site selection.

Classification of Final Suitability Map

Suitability maps produced of regions in the South Island that are preliminarily viable for viticultural development are classified from 0 to 10 based on the five characteristics (elevation, slope, aspect, temperature and rainfall). Each characteristic had the values within it reclassified into a number of 0 (not suitable), 1 (suitable) or 2 (very suitable) based on that values importance in preliminary vineyard site selection. Combining all these reclassified layers in the raster calculator using overlay analysis, the suitability maps were produced of areas classified from 0 to 10. Areas that received a combined number of 9 or 10 after the overlay process were identified as areas with the highest viability for hill slope industrial viticultural development in the South Island. Combined number classes of 9 and 10 were selected over other combinations such as 8, 9 or 10 because if an area has a combined number value of 9 or 10 it means that it has all of the suitable values from each characteristic. If sites were selected as suitable from 8 to 10 then the sites with values of 8 may have received numbers for suitable values in some characteristics or might have the best values for four of the characteristics and missing the last characteristic. This would lead to including sites that do not have suitable values for all the characteristics which would defeat the purpose of the suitability mapping.

GIS Validation

The GIS validation of undeveloped sites identified that the parameters in the GIS topographic module are consistent with data collected from the actual sites. However, the GIS rainfall and temperature data and measurements from the NIWA water resources explorer website are less consistent. The data collected from the water resources explorer is based on virtual climate stations that are set up in a grid formation four kilometres apart from one another over the whole of New Zealand. These virtual stations are created based on the actual measurements collected from nearby weather stations. As a result of how these virtual stations are set up and because virtual stations are typically distant to the sites visited creates an increased margin for error. This is why the climatic GIS module differs from the NIWA water resources explorer results. In GIS obtaining a meaningful result which is one which is useful because it is supported by real life measurements is important. The GIS validation has proven that the GIS result is meaningful because it aligns with what was recorded at each site.

5.3 Hill Slope Viticultural Development Compared to the Flat

Hill slopes provide various benefits, mentioned in the background, over the flat surrounding land. The results from the data loggers provide evidence of these benefits. Through the results of the data loggers, the sunlight and temperature on north facing hill slopes are higher compared to flat land. As a result, sunlight exposure and increased temperatures on hill slopes will provide better ripening and growing conditions for grapes. When we compare the north facing sites maximum temperature to the flat facing site, it is ~10 °C higher. It also shows a slightly higher average temperature, which implies it has a more established microclimate. A higher average temperature results in the north facing site having a higher number of GDD compared to its surrounding areas. Based on the GDD calculation, the north facing hill slope has 1 more GDD day a month compared to the flat site. This is not much but it is an increase in the number of days which shows hill slopes increase the number of GDD compared to other sites. This increase in GDD on north facing hill slopes will provide vineyards positioned on these hill slopes with an increased chance to produce grapes suitable for wine production.

The soil temperature on hill slopes appears to act differently when compared to flat sites. Based on the findings from the data loggers, soil temperatures are slightly higher on the north facing slope compared to the other two sites. This indicates that soils on the north facing hill slopes retain more heat than the other locations. This heat is released after the sun sets and is radiated at night which keeps hill slopes warmer than surrounding flat areas. This provides a better microclimate for grapes to grow and acts as an additional heat source. The amount of heat stored and radiated by the soil is controlled by certain soil characteristics and the nature of the hill slope. These controls are surface cover, shading, aspect, soil colour, soil depth, geology and biological processes in the soil.

5.4 Other Considerations

5.4.1 Erosion

Erosion within hill slope vineyards of the South Island is limited because of the techniques and methods employed by the vineyard managers. When selecting a suitable hill slope site for viticultural development, it is important to know what stability issues will arise. Below slope stability problems associated with a hill slope vineyard are presented based on the findings from interviews with people and site investigation.

Slope Stability Issues Associated with a Vineyard on a Hill Slope

As mentioned in the Background section, the major slope stability issues on hill slopes are erosion and landslides. These issues are largely dependent on the vineyards location, topsoil cover and how the vineyard is managed. Areas such as Central Otago are more arid than areas in Marlborough which can result in differences in erosion. In more arid regions, wind tends to contribute to erosion, whereas, water will be the main driver for erosion in less arid areas. For these reasons, the main drivers of erosion on hill slopes in New Zealand are wind and water. These become an issue when they come in contact with a soil profile that has been disturbed or has a lack of vegetation cover. Below are the slope stability issues associated with hill slope viticultural development based on what was discovered during site investigations. These can be grouped into time periods during development where slope stability problems can occur and include vineyard establishment, layout and maintenance, everyday use within a vineyard and hazards.

Establishment

During vineyard establishment the cultivation of the land and installation of rows, roads, posts and headlands disturb the soil. If rain or strong winds occur when a hill slope site is being developed, the ripped rows act as gutters with intense scour occurring, damage to slope surface and vast quantities of soil are lost from the site. The use of machinery throughout the hill slope vineyard establishment stages can disturb the soil profile and increase the soils susceptibility to erosion. The use of re-contouring and terracing when first establishing a vineyard can lead to erosion problems if not undertaken correctly. Stability issues associated with establishing re-contouring and terracing is that stripping large quantities of soil off a slope removes vegetation cover and topsoil. Exposing the underlying soils to wind and water, especially in regions throughout the South Island will lead to erosion. This is because of the erodible nature of the underlying soils. The amount the soil is reworked during establishment stages of a vineyard leaves it exposed to wind and water which is why care is needed when first establishing a vineyard on a hill slope.

Layout and Maintenance

Layout of the hill slope vineyard and the way it is maintained can create stability problems. These problems are row orientation, mowing and weed spraying, and installation of new posts. Depending on row orientation, either parallel or perpendicular to the slope, can impact erosion in a hill slope vineyard. Rows oriented parallel to slope have no mechanism to break the flow of water and can act as preferential pathways for water to flow down, hence, increase the erosion potential. This is dependent on vegetation cover and topsoil depth. Most hill slope vineyards of the South Island are oriented parallel to slope and have limited stability issues as a result correct management of the rows. Rows oriented perpendicular to slope can break the flow of water down slope and give water time to be absorbed. This is a less used orientation as rows have to be spaced further apart to allow machinery to work which reduces the number of vines in the vineyard, therefore reducing productivity. Maintenance in a vineyard often means that mowing and weeds spraying need to be undertaken. The removal of this vegetation and the use of the machinery can reduce stability of soil. This is caused by exposing the topsoil to wind and water which can increase erosion down the vineyard rows. Posts often break in vineyards and need to be replaced. When replacing posts, care needs to be taken to avoid having post holes open for extended periods of time as it may rain and create erosion problems such as tunnel gullies under the ground.

Everyday Vineyard Life

In the everyday life of a vineyard there are activities which can affect the stability of the soil in a hill slope vineyard. These are the use of machinery in the vineyard, irrigation and the presence of pests such as rabbits. Machinery is used daily in a vineyard for transportation and to undertake maintenance. The abrasion of machinery tyres on the vegetation cover and topsoil of the rows and headlands can contribute to erosion. This is the result of tyres removing cover vegetation and disturbing the topsoil. The process is gradual but can be exacerbated if machinery is driven at excessive speed around the vineyard and if machinery is used during or immediately following rainfall. Irrigation is used most days during the growing season in a vineyard. In a hill slope vineyard if the irrigation is set up incorrectly water can pool at the base of the slope causing stability problems. Continual saturation of the ground increases the mobility of the soil as the water may begin to flow further down slope. If pests such as rabbits are present in a hill slope vineyard, their burrows under the ground can expose the soil to water and wind. Areas of their burrows can pool water and increase the chance of tunnel gullies or erosion problems.

Hazards

Several slope stability hazards are associated with hill slope viticultural development. Hazards that face hill slope vineyards are dependent on where they are located and how they are established. If the vineyard is located on the slopes adjacent to a river, hazards such as debris flows may be an issue. In the case of the South Island, the areas identified by the suitability mapping are not in close proximity to rivers to be affected by this hazard. For this reason, the main hazards posed to hill slope viticultural sites in New Zealand are landslides and slips.

These are likely to occur in a vineyard that has been positioned on an already existing landslide feature or after a significant amount of rainfall and can be shallow or deep seated. If the hill slope vineyard is established using re-contouring, subsidence or slumping hazards may eventuate from all of the earthworks. Subsidence and slumping usually occurs where a hollow has been filled with soil to flatten it out. If the soil fill is not compacted correctly it may settle causing subsidence and if water is present, the soil may slump down slope.

When soil is removed by erosion from a vineyard it can have hazardous impacts both on-site as well as off-site. On-site problems include nutrient loss and long term productivity loss of the degraded soils, which impact directly on the success of the vineyard. Soil erosion has a wide range of environmental problems derived from sediment delivery to off-site locations such as drainage networks and reservoirs (Martinez-Casasnovas & Ramos 2006; Hansen *et al.* 2002; Verstraeten *et al.* 2003).

5.3.2 Drainage

It was stated in the background how an inversion layer or thermal belt is formed from cool air drainage and that hill slopes are less susceptible to frosts. A vineyard positioned on the slope above a valley floor where an inversion layer or thermal belt is located can increase the temperature of the vineyard compared to the surrounding land (Figure 5.1). The results from data loggers identify that the north facing hill slope is slightly warmer than surrounding areas which indicates that there has been formation of inversion layer or thermal belt. Figure 5.1 below displays that a vineyard positioned on a hill slope with an inversion layer will provide better temperatures for growing grapes, providing the slope is free of obstacles.

The data loggers reveal that north facing hill slopes are less susceptible to frosts compared to surrounding areas. The data loggers recorded certain days where the south facing and flat sites experience negative temperatures, but the north facing slope remains above freezing or consistently at a slightly higher temperature than the other sites. The data loggers on the north facing site record increased sunlight exposure and warmer soil temperatures. This increased sunlight and higher soil temperature in combination with the cool air drainage that forms the inversion layer or thermal belt result in north facing hill slopes being less susceptible to frosts than surrounding areas.

Disease

When a vineyard is established there are hazards that face the vines. One of these hazards is disease which can be caused by periods of bad weather (Winkler *et al.* 1974). There are several diseases which affect the root systems of vines and are present in the soil at a contaminated site (Wassilieff 2009). On hill slope sites, soil disease needs consideration because the sloping nature of the land results in soil disease spreading easily through the vineyard. If a vine at the top of a slope gets infected, the disease easily moves through the soil structure under the forces of gravity and is transported by water or wind.

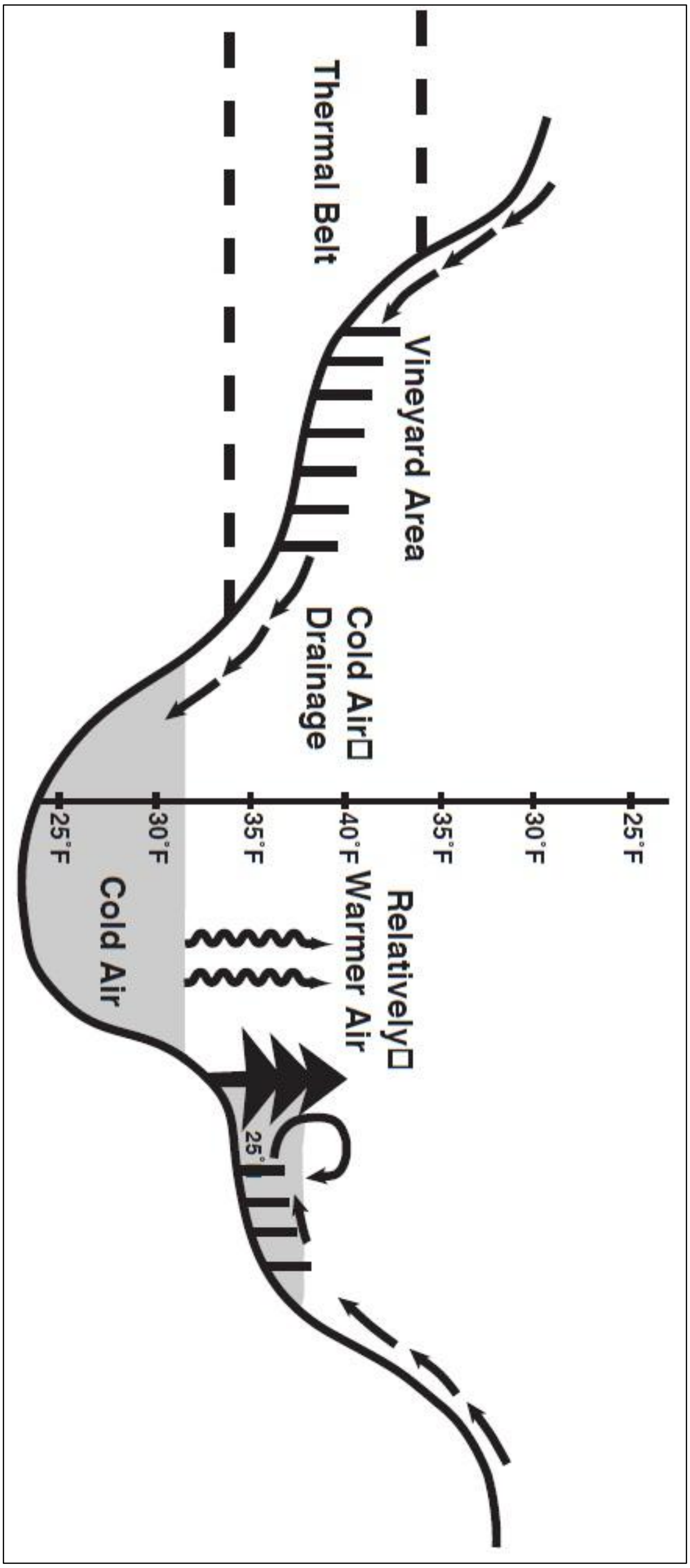

Figure 5.1 Patterns of cool air drainage and formation of inversion layer in a valley or hill slope setting (Jones & Hellman 2002).

5.4 Full Viability Assessment of Hill Slopes for Industrial Viticultural Development

The GIS suitability mapping and site investigations undertaken for this research have assessed the preliminary viability of hill slopes for industrial viticultural development. To assess these sites full viability for viticultural development, further investigations would have to be undertaken. Future investigations would involve site visits to identify slope stability issues, measurements to validate the GIS results and an assessment of all characteristics that make a suitable viticultural site. When visiting these sites, certain parameters would be measured and assessed which are required to fully determine the viability of a potential viticultural site. The parameters utilised would be elevation, slope, aspect, temperature, rainfall, current land use, stability issues, soil type, soil drainage, soil pH, soil depth, geology, depth to groundwater, proximity to irrigation sources and proximity to roading. The flow chart in Figure 5.2 below identifies how to go about fully selecting and undertaking a hill slope viticultural development.

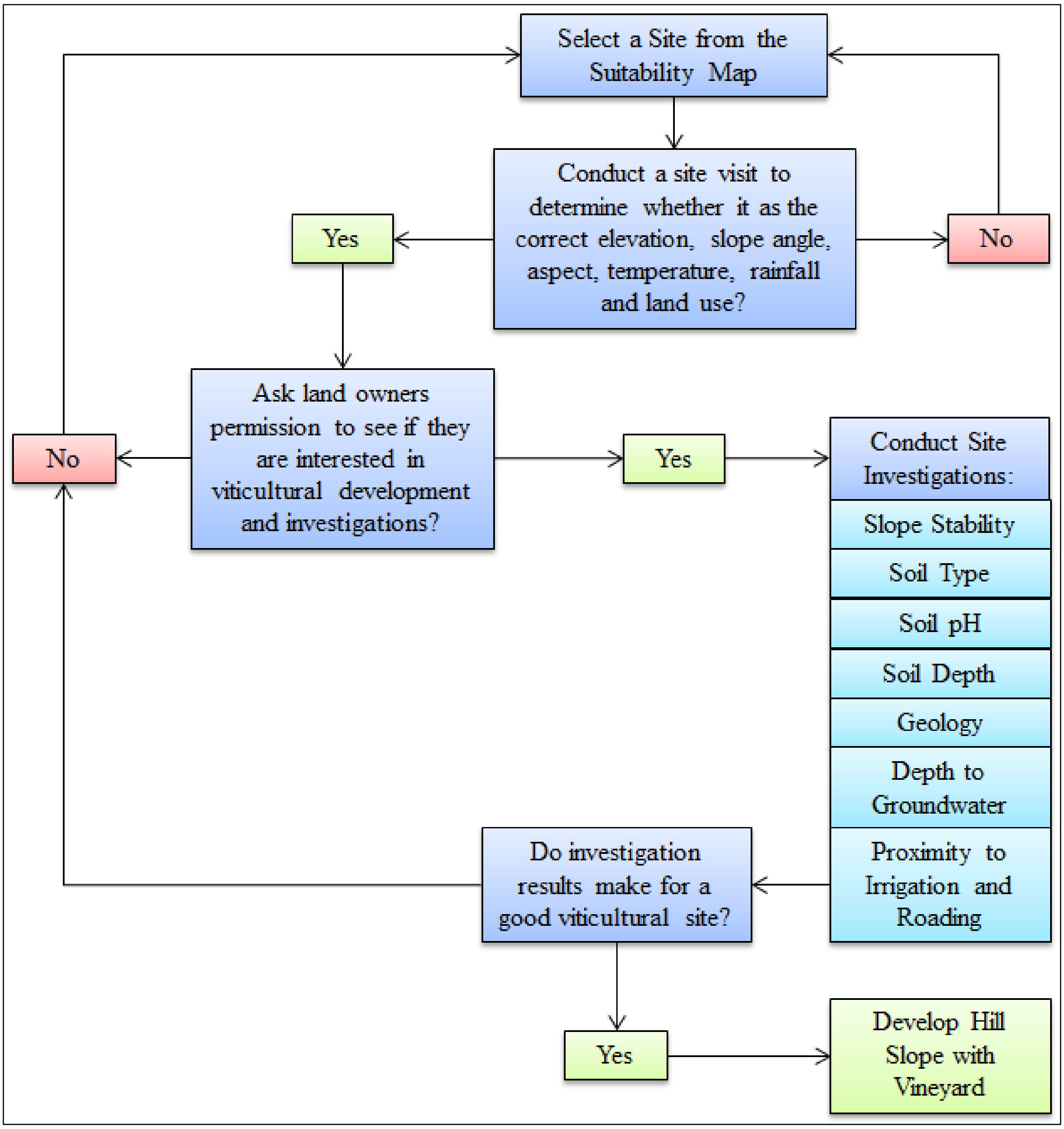

Figure 5.2 How to fully determine the viability of a hill slope site in the South Island of New Zealand for viticultural development.

Chapter 6

6 Conclusions

This study describes the application of site investigation, data logging and GIS suitability mapping to determine the viability of hill slopes in grape growing regions of the South Island of New Zealand for industrial viticultural development. Results from this research show that we can provide an assessment for utilizing slopes for viticultural development. This is important to the viticulture industry because developing hill slopes in vineyards can increase the productivity and variability of grapes grown and potentially produce wine, similar, if not better than surrounding flat areas. The results have proven that hill slopes provide various benefits over flat sites for viticultural development which show they have good potential and are worth further investigating in the future.

6.1 Future Research

Several opportunities for future research can be investigated following the results of this study. The first of these would include undertaking GIS suitability mapping of the North Island of New Zealand to determine the viability of its slopes for viticultural development. After refining these viable areas, higher resolution suitability mapping of the areas highlighted as viable would be required. The higher resolution suitability mapping would involve combining more of the characteristics that make for suitable sites. This would have to be done at a smaller scale to ensure that all the layers in the GIS could be managed. This is ultimately what would be needed to truly define hill slopes for viticultural development in New Zealand and would benefit the wine industry in New Zealand.

Secondly, using GIS in combination with site investigations to identify sites throughout New Zealand that need little to no maintenance would provide another industrial benefit to New Zealand viticulture. These ‘plant & walk away’ sites are potentially in New Zealand but these sites have to have very specific characteristics. Things such as rainfall, temperature, frosts and soil have to be appropriate at certain times of the year and a certain type to make these sites possible. This would require very detailed GIS mapping to constrain sites, followed by site investigation to test that the sites would be viable for these low maintenance viticultural developments. This would help the international wine industry as it would reduce costs on labour and maintenance and would require few people to run the vineyard.

Thirdly, the design of machinery that could work on steep slopes up to 45° or greater would be hugely beneficial to the wine industry as it would unlock areas that would have never before been developed. The new machinery would also reduce the hazards of working with machinery on steep slopes.

If future research was to be undertaken in the above areas a collaboration approach between major viticultural players and the science world would be required. This would be beneficial to the wine industry as the science behind the wine can lead to production of a better product. Industry would hopefully not only provide funding for such research topics but would also gain knowledge from the experience.

Chapter 7

7 References

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Appendix 1: Photos of Vineyards Visited

Central Otago

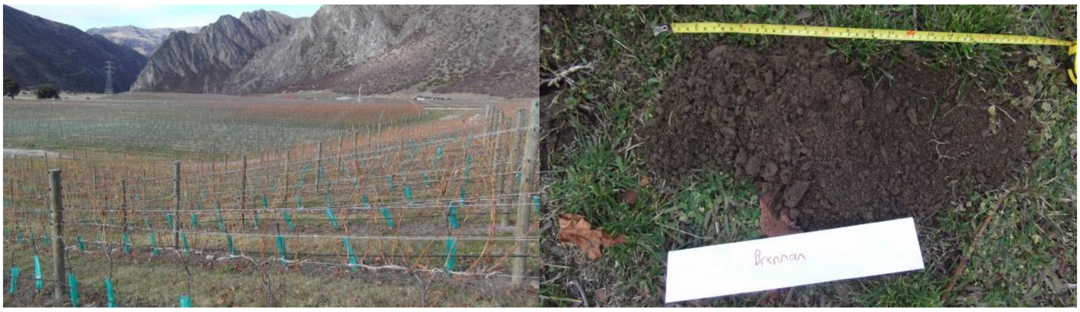
Golden Terraces: Left: Vineyard, Right: Hand Auger Borehole

Zebra: Left: Vineyard, Right: Hand Auger Borehole

Peregrine: Left: Vineyard, Right: Hand Auger Borehole

Mt Edward: Left: Vineyard, Right: Hand Auger Borehole

Misha’s Vineyard: Left: Vineyard, Right: Hand Auger Borehole



Brennan: Left: Vineyard, Right: Hand Auger Borehole

Chard Farm: Vineyard

Canterbury

Rossendale: Left: Vineyard, Right: Hand Auger Borehole

Tussock Hill: Left: Vineyard, Right: Hand Auger Borehole

Greystone: Left: Vineyard, Right: Hand Auger Borehole

Fancrest Estate: Left: Vineyard, Right: Hand Auger Borehole

Pyramid Valley: Left: Vineyard, Right: Hand Auger Borehole

<u>Marlborough</u>

Yealands: Left: Vineyard, Right: Hand Auger Borehole

Ingrid Estate: Left: Vineyard, Right: Sedimentation Problem

Redwood Hills: Vineyard

Calrossie: Left: Vineyard, Right: Hand Auger Borehole

Brancott: Vineyard