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The Projected Influence of Climate Change on the South African Wine Industry

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Contents

Abstract

The wine industry is an integral part of the Western Cape's economy, contributing just over 8% to Gross Provincial Product (GPP). The intensive labour required by the industry also provides employment for semi-skilled labour. Changes in climate induced by global warming are likely to affect many aspects of this industry. Current regional projections of rising temperatures and decreased precipitation ((Midgley *et al*, 2005; New, 2002) will put pressure on both the phenological development of the vines and on the necessary water resources for irrigation and production. This study examines these effects using three statistically downscaled GCM projections for the mid 21st century. The purpose is to ascertain the likely impacts on this industry under future climate stressors. The emphasis is placed on water related variables, mostly precipitation and derivatives thereof. A short summary of possible mitigation and adaptation strategies concludes the report.

Keywords: Climate Change, Viticulture

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About the Author

Suzanne Carter graduated with a B.Sc Hons in Environmental and Geographical Science in 2002 from the University of Cape Town. She is currently a second year Ph.D student at the same institution, after upgrading her MSc project in 2003. The title of her thesis is “Approaches to quantifying and reducing uncertainty in GCM’s over southern Africa”. The research characterises daily circulation dynamics, using pattern recognition software. Model biases will be corrected using an algorithmic regression, specific to the southern African domain.

Her main fields of scientific interest include translating climate modelling to useful formats for adaptations work and profiling extreme weather events in terms of disaster management. She was a YSSP participant at IIASA in 2005 working on the impacts of climate change on the South African wine industry - focusing particularly on the future supply of water.

The Projected Influence of Climate Change on the South African Wine Industry

Suzanne Carter

1. Context

Climate change is becoming a growing concern for global policy makers[1]. The need for adaptation and mitigation strategies, advocated by leading scientists (IPCC, 2001), still lacks the impetus in developing nations environmental policies. In the Western Cape of South Africa, climate change is projected to manifest in a warmer and (mostly) drier mean climate, with possible increases in climate variability leading to a higher incidence of extreme events (Midgley *et al*, 2005; New, 2002; Midgley *et al*, 2001). This raises concerns for many sectors of the local economy – especially those that are water dependant. The Western Cape has a strong agro-economic base that could be threatened by these changes. The wine industry is a particularly important regional player as it makes a sizable contribution to provincial GPP – around 8% (SAWIS, 2005). The goal of this report is to address the questions:

1. What will the likely impacts of future climate change be on the wine industry in the Western Cape (by the mid 21st century)?

2. What additional stressors need to be taken into account in the regional context?

A large part of the report considers background material that will influence the climatic factors. The climate analysis makes use of regional projections of future precipitation changes (2046-2065) generated using a new methodology for downscaling Global Circulation Models (GCM) projections (Hewitson, in press) and assessing the response

[1] As demonstrated at the World summit on Sustainable Development (2001) and G8 summit (2004) etc.

of the crop and the industry under these changed conditions. Three GCMs were used to assess a range of possible changes.

Climate changes will affect the industry by three primary changes:

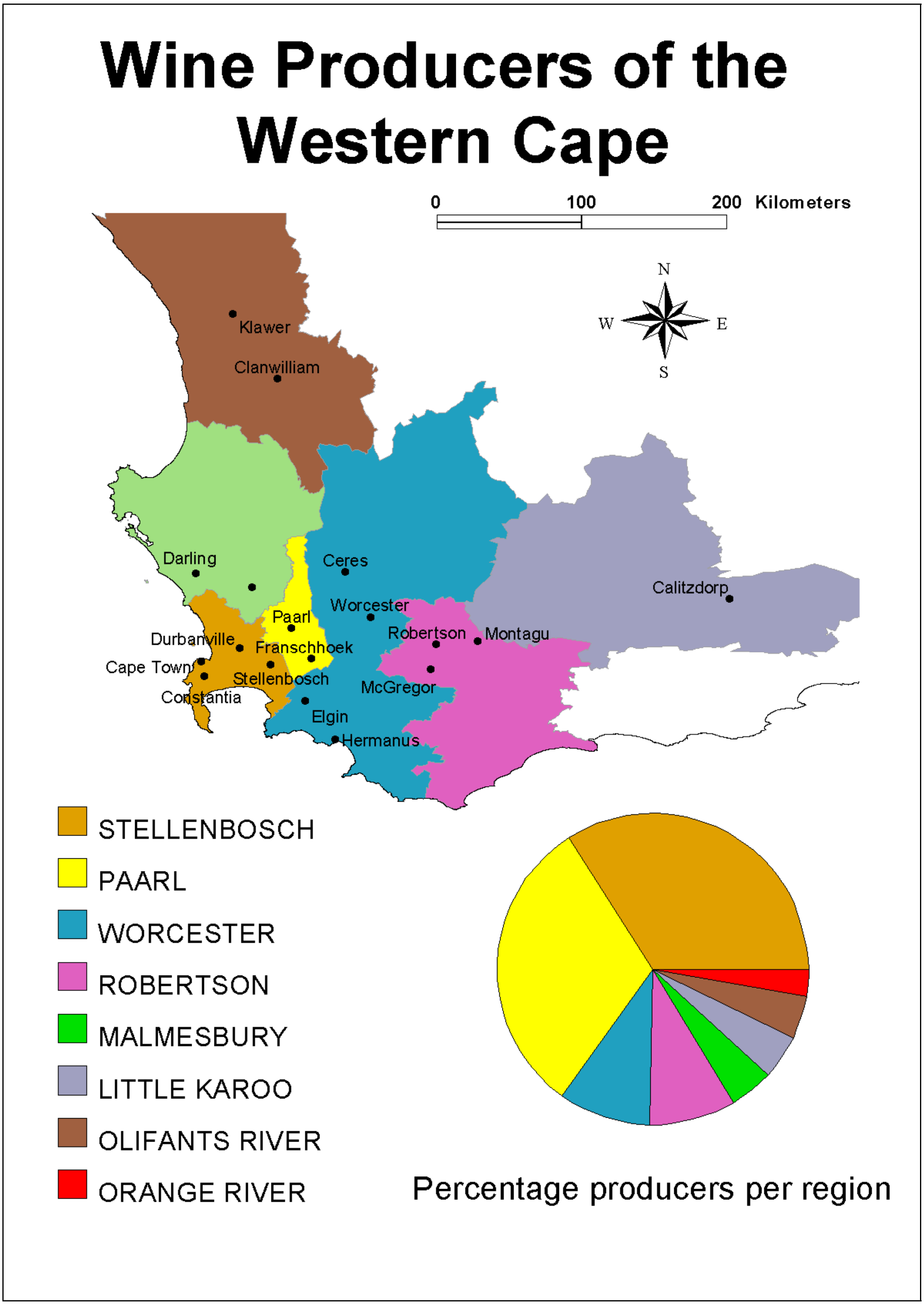
- Increased levels of Carbon dioxide
- Rising minimum and maximum temperatures
- Decreased rainfall

This report will focus primarily on the last aspect and will provide a mainly descriptive overview of possible impacts arising from these other issues, drawing from the relevant literature.

2. Geographical extent

Wine production has a rather narrow climatic suitability, which is generally referred to as a Mediterranean style climate. This band of suitability is also defined as areas within the average annual temperature range of 10 – 20°C (de Blij, 1983). The style of wines produced is determined by the baseline climate. Climate variability will determine the annual fluctuations in vintage quality (Jones, 2004; Gladstone, 1992).

The Cape Winelands consist of three primary production centres, Stellensbosch, Paarl and Franschoek. These will be the focus of the analytical work and are marked as study area in figure 1. In addition to these Constantia, Durbanville, Elgin, Hermanus, Malmesbury, Montagu and Robertson are some of the other major producers in the Province. Calitzdorp wine producers are separated from most of the rest of the producers and, as it is much hotter in this region, they mainly produce port (fortified wine).



<u>Figure 1</u>: Wine producers per region – from the wine of origin database (SAWIS, 2005)

The total area cultivated by grape vines in the Western Cape was 124 749 hectares in 2004 and the metric tonnage of production was 1 312 184 (SAWIS, 2005). This produced 1 015 million gross litres of wine related products (wine makes up just under 70% of this). The Western Cape makes up 85% of the national wine grape production (SAWIS, 2005).

	Total Crop	**Grape Production tons**	**Hectares (excluding young vines 1 - 3 years old)**	**Tonnage per hectare**	**Litres per hectare**
Industry	1 015 696 992	1 312 184	96 451.50	13.60	10 530.65
Orange River	162 066 061	206 193	14 576.49	14.15	11 118.32
Olifants River	131 865 484	178 590	8 739.89	20.43	15 087.77
Malmesbury	65 621 875	103 947	13 153.40	7.90	4 988.97
Little Karoo	33 834 164	44 522	2 651.76	16.79	12 759.14
Paarl	120 932 062	138 802	15 432.33	8.99	7 836.28
Robertson	139 955 194	184 095	10 985.31	16.76	12 740.21
Stellenbosch	88 428 673	115 276	14 865.35	7.75	5 948.64
Worcester	272 993 479	340 759	16 046.97	21.24	17 012.15

***Table 1*: Productivity indices for the wine producing regions of South Africa (Adapted from SAWIS, 2005)**

The largest production areas in the Western Cape are Worcester, Robertson and Olifants River (Table 1), followed by Paarl, Stellenbosch and Malmesbury. Even though the first three are much larger regions they still out produce the traditional centre of the wine industry in terms of tonnage per hectare and litres per hectare. In terms of wine quality, low yields per hectare are preferable, which is why the smaller production regions are the more famous. Much of the wines from the large producers tend to be cheaper, easy drinking wines whereas the Paarl and Stellenbosch producers are more selective and can therefore charge premium prices.

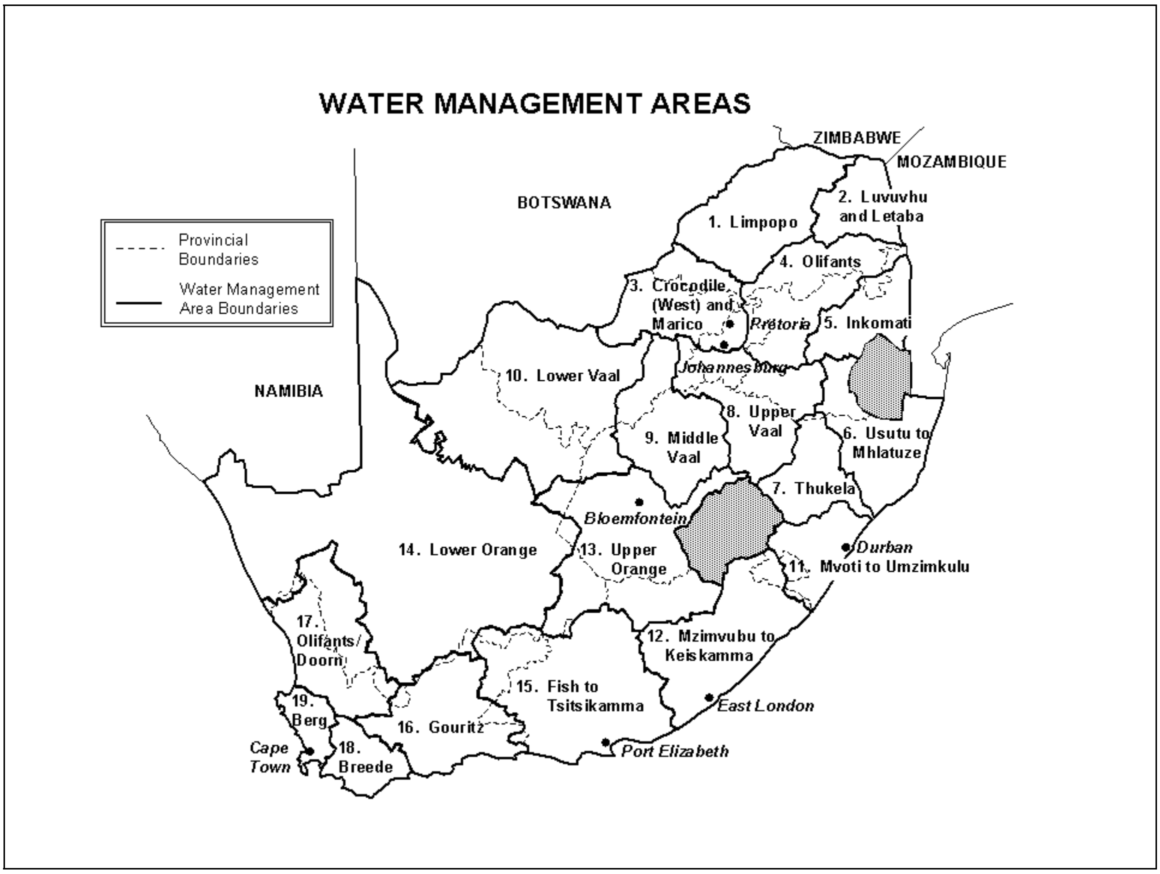
3. Water dependencies of the Cape winelands

The Department of Water Affairs and Forestry (DWAF) determines the allocation of all water resources in South Africa. To redress past imbalances in access to water during Apartheid, DWAF is responsible for improving equity for users while maintaining the access for economically successful sectors of the economy. A basic level of free water for all domestic users (6000 kilo litres per household per month) is allocated to promote equitable access. Previous riparian rights were revoked in the late 1990's to facilitate this redistribution. The only access to 'free' water is covered in the following clause:

"…allows a person to take water for small gardening (not for commercial purposes) and the watering of animals (excluding feedlots) on land owned or occupied by that person, from any water resource which is situated on or forms a boundary of that land, if the use is not excessive in relation to the capacity of the water resource and the needs of other users. This means that most users using groundwater in towns and cities and those users with windmills on their own properties need not register." (DWAF, 2005)

This may change as increased water scarcity may force monitoring and payment for use of groundwater sources. In the City of Cape Town borehole users have been allocated registration numbers but as yet are not required to make payment.

Water pricing in South Africa is also controlled by DWAF and is differentiated within each catchment based upon the needs and supply of that catchment. There are 19 national water management zones, which are each named after the catchment they enclose. The Western Cape draws mostly from four water management zones: Berg, Breede, Gouritz and Olifants (see figure 2).



<u>Figure 2</u>: Water Management Areas of South Africa (source: DWAF)

The winelands fall mostly into the Berg river catchment, however as the water here is insufficient to meet demands, it is supplemented by water transfers from two dams (Theewaterskloof and Palmiet) in the neighboring Breede river catchment. Theewaterskloof is the major supplier of the agricultural sector's water. The price paid by each farmer is based upon the individual farm's demand and the resource availability within each of the 121 water boards of the Western Cape. An annual maximum quota (litres per m^3) is assigned for each user. During times of water restrictions, the farmers allowance to draw decreases. For example in 2004 a 40% restriction was imposed on the draw from the Theewaterskloof allocation (pers. comm. Jacques Rossouw, June 2005).

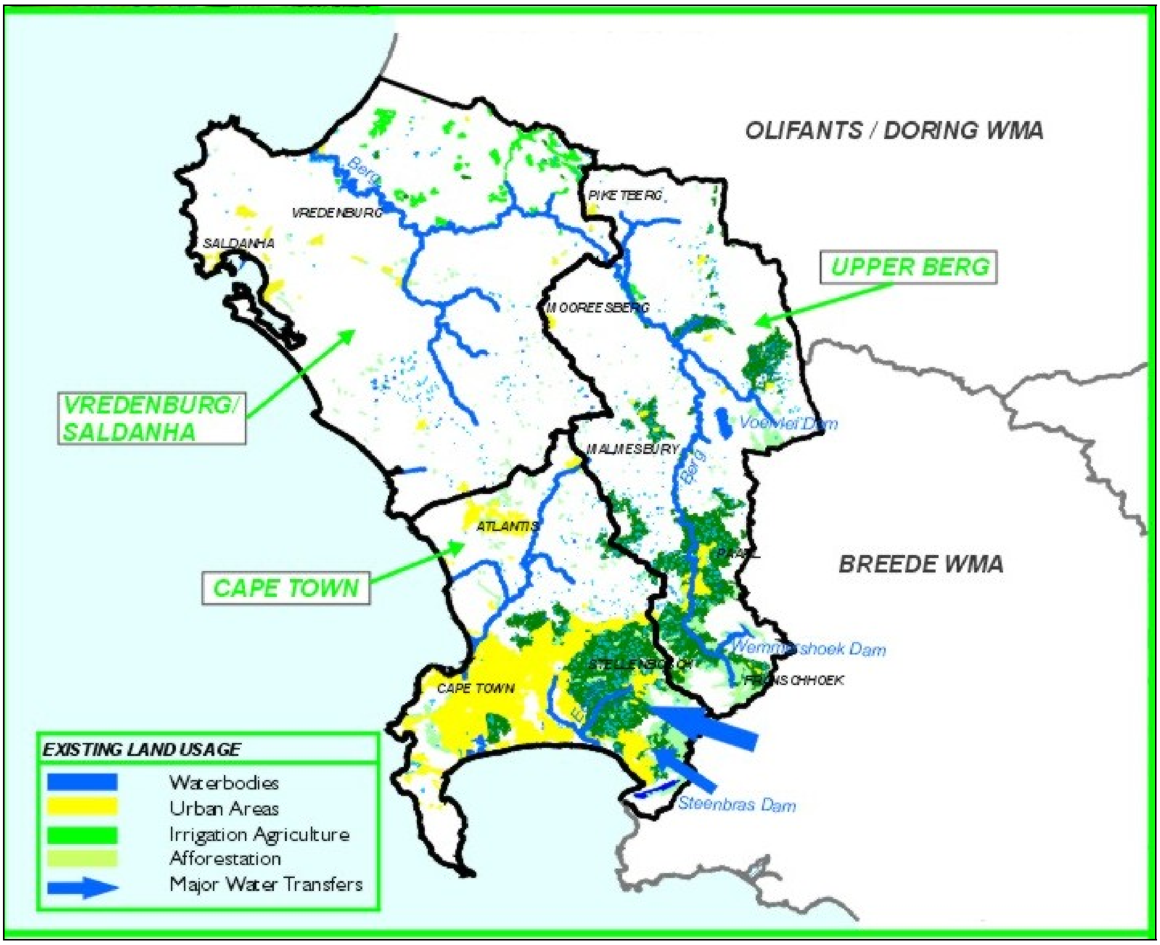
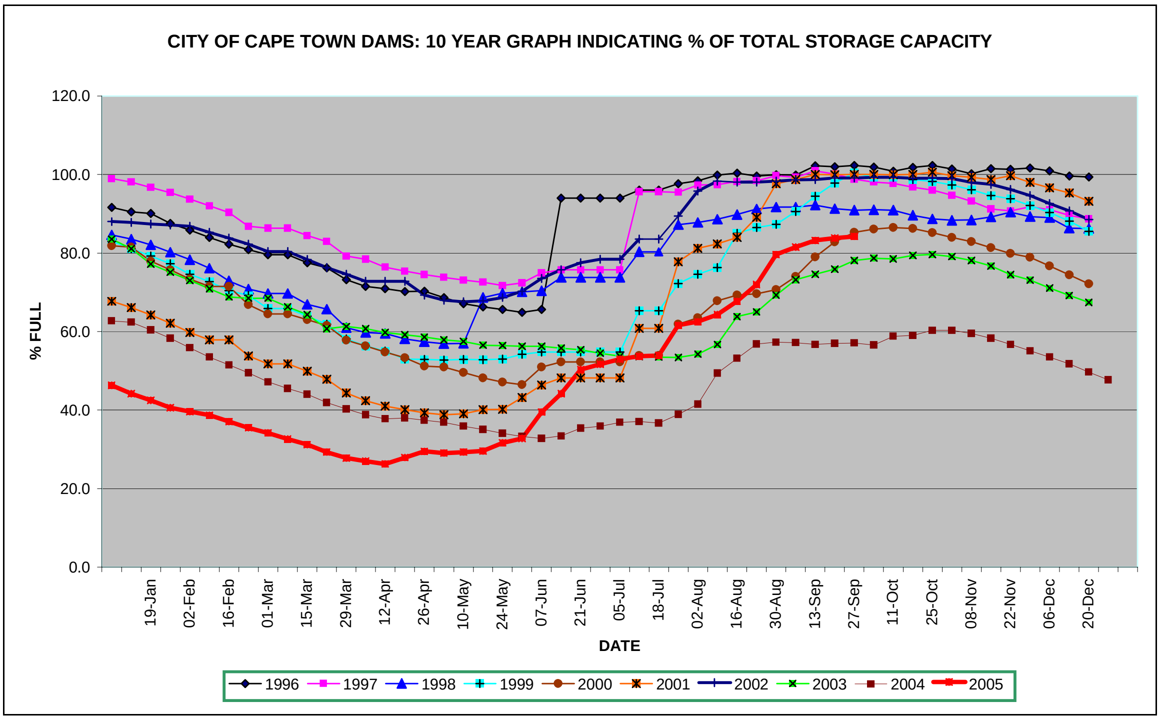


***Figure 3*: Berg river Water Management Area's water resources (source: DWAF)**

The wine industry is charged two rates for water consumed; one for agricultural usage and the other for vinification (wine making) uses. Industrial and domestic usage is charged at a much higher price. In the Berg river catchment users pay the highest domestic/industrial charges in the whole country (R3.25 per m^3), or roughly double the national average charge (DWAF, 2005) due to the high scarcity of water in this locale.

Unlike any of the other Water Management Areas in the Western Cape, urban water use is significant in the Berg WMA due to the high degree of urbanisation, hence the reliance on neighbouring catchments supplies for agriculture. The City of Cape Town draws water from Wemmershoek, Voëlvlei, Steenbras (all part of the Berg river catchment) and Theewaterskloof.



***<u>Figure 4</u>*: Dam levels as of the 26 September 2005 (source: Cape Town city council, 2005)**

Over the last 10 years (figure 4) there have been summer water restrictions in 2000/2001, 2003/2004 and 2004/2005. In 2003 and 2004 the winter rains were lighter than in previous years. This led the Cape Town City Council to implement level 2 (20 % reduction in usage) water restrictions. Level 2 restrictions include such things as restricting watering of gardens to one day a week and no hosepipes to be used to wash cars. The largest users of water, agriculture and industry, were also given strict targets to meet. Table 2 shows the recent recovery of the dam levels to acceptable levels. Note that Theewaterskloof makes up 62 % of the total storage capacity, hence the heavy reliance on this resource.

Dam	**Gross 4-April-05**			**Gross 26-Sep-05**			**Increase**
	Capacity	Storage	%	Capacity	Storage	%	Mcm
Steenbras Upper	31.7	13.6	43%	31.7	31.8	100%	18.2
Steenbras Lower	33.5	13.2	39%	33.5	29.9	89%	16.7
Wemmershoek	58.6	20.5	35%	58.6	53.8	92%	33.3
Voëlvlei	165.4	35.7	22%	165.4	131.0	79%	95.3
Theewaterskloof	480.2	124.1	26%	480.2	401.4	84%	277.3
Total	769.4	207.1	26.9%	769.4	647.9	84.2%	440.8

***Table 2:* Storage capacity of Cape Town supply dams as of 26 September 2005 (DWAF, 2005)**

In the wake of current water restrictions – the strain on current water supplies has many concerned. The Cape Town City Council is looking into many options to meet the expected increased population and subsequent increased demand (City of Cape Town, 2001). These options include the Berg river dam project, increased domestic use of "grey water" options, desalination of seawater (which is estimated to double domestic water charges), treating sewage water and tapping into the Table Mountain Group Aquifer. All new water harvesting projects in the Berg river catchment will be directly used and paid for by the City of Cape Town.

4. Production requirements of water for Vinification (wine making)

During the wine making process, a lot of water is used in cleaning and manufacturing practices (on top of any irrigation methods that may be used). It is estimated that between 1 and 4 litres of water are required in the production (i.e. excluding irrigation) of every litre of wine (pers comm. Jacques Rossouw). This water usage is charged at industrial/domestic prices, which as outlined above are the highest in the country. We can make an assumption that the average water used for this purpose by most farms will be ~2.5 litres for every litre of wine produced. In 2005 a total of 696 788 280 gross litres of natural wine (not fortified) were produced in South Africa (SAWIS, 2005). The

Western Cape made up 85%, resulting in an estimate of 592 million gross litres. This equates to roughly 1 480 million gross litres of water used by the wine industry. The farmers' allocation will be affected by the increased costs of water in the Berg river catchment (as water becomes more scarce and domestic demand increases) and will add to input costs in years to come.

A questionnaire-based study by Sheridan (2005) elicited wine makers' and their workers' perceptions of water usage, effluent produced and environmental management. From this study it was seen that 65% of respondents did not know the actual amount of water being used. Borehole water was the largest water source used (50%), which probably accounts for the lack of monitoring. Accordingly, even fewer respondents had any idea how much waste water (effluent) was generated (5 % of respondents). Most wastewater is used for irrigation of pastureland. This lack of awareness may be a barrier to implementing better water management strategies.

5. Current economic trends in the South African wine industry

South Africa is the 8th largest wine producing nation in the world, with significant revenue generated from domestic and export sales. The South African Wine Industry Information and Systems (SAWIS) estimated sales of R8.5 billion (equivalent to $US 1.27 billion) for 2003. In the same year the wine industry's contribution to annual GDP (incl. Tourism) was R22 549 million. As reported by Conningrath (2004), 70% of the wine industry's activity has direct impacts on the Western Cape economy, with an estimated contribution to the provincial GGP of 8.2% (Conningarth, 2004). In some smaller communities the wine industry is even regarded as the backbone of local commerce.

Export sales made up 38.5 % of total wine production in 2005. South Africa's first democratic elections in 1994 had significant impacts on the wine industry. The lifting of international trade sanctions created an international demand for newly available South African wines. The weak Rand also made the price of wines very competitive with overseas markets. Subsequent Rand appreciation against the Dollar and Euro has caused some demand fluctuations in the trade but the consistent strength of the British Pound has secured continued UK exports. In 2004 the United Kingdom imported 40% of the total wine exports from South Africa (SAWIS, 2005)

6. Climatic requirements for growth and development of vine

Vines are quite sensitive to climatic factors – certain cultivars are better suited to different temperature regimes, which is why many areas specialise in the production of a few specific cultivars. Microclimatic factors such as soil and slope aspect also influence the choice of cultivar for each farm. However, the macro climatic factors can have a much larger influence than these local forcings.

Jones et al (2005) compared wine growing regions of the world and classified South Africa as just falling into the 'warm' grapevine climate/maturity group on a spectrum of cool, intermediate warm and hot. According to these authors, the following varietals thrive in these conditions: Cabernet Franc, Tempranillo, Dolcetto, Merlot, Malbec, Viognier, Shiraz (or Syrah), Table grapes, Cabernet Sauvignon, Sangiovese and Grenache. Of these South Africa grows large quantities of (in order of importance) Cabernet Sauvignon (10%[2]), Shiraz (6.5%) and Merlot (5.5%). Interestingly none of the popularly grown white wine varietals fall into the 'warm' list. Chenin Blanc (20%), Colombar (10%), Chardonnay (6%) and Sauvignon Blanc (6 %) favour slightly cooler climates (classified as intermediate by Jones *et al*). As the South African average growing season temperature of 17.1ºC only just falls into warm classification (17-19ºC) it is therefore not surprising that some cooler varietals are grown in SA. These 'cooler' varietals may become harder to cultivate if the average temperature increases beyond thresholds of viability.

The South African hybrid of Pinotage (which made up 6% of all vines planted in 2001) is not listed in the Jones et al analysis, as it is uniquely South African. This cultivar is a

[2] Percentages of total white and red grapes planted are derived from Statistics of Wine Grape Vines as of 30 November 2001 (SAWIS). Subsequent reports do not break down cultivar percentages.

cross between Cinsaut and Pinot Noir that was developed in 1925 by Abraham Izak Perold. Pinot Noir is a subtle flavoured grape, which can be very difficult to cultivate whereas Cinsaut is easy to grow. Thus the cross resulted in a flavoursome and easy growing new cultivar. Pinotage thrives in the Western Cape, as it is a robust cultivar, which also ripens early, making it suitable to warmer climate regimes (Pinotage Association, 2005).

The most widely planted grape in South Africa is Chenin Blanc, but since the opening to international markets, the demand for Sauvignon Blanc and Cabernet Sauvignon, amongst other noble varietals, has lead to increased plantings of these grapes. White wine grapes are still the larger cultivated crop; however, of the new vines planted, there is an increasing predominance of red wine grapes (SAWIS, 2005). This indicates a change in consumer tastes but also will be beneficial under future climate warming (as red grapes are more suited to a hotter climate).

Table 3 lists ideal suitability thresholds for different styles of wine in the month of ripening. Low mean temperature leads to grapes with a high acid content at ripening. During winemaking, these grapes tend to make semisweet styles, where the residual sugars balance the high acid levels (e.g. Riesling). Ripening temperatures between 15-21˚C generally produce naturally balanced dry wine styles or if allowed to over ripen, sweet late harvest wines. Fortified wines are made from grapes where the mean ripening month temperature exceeds 24˚C (Gladstones, 1992).

	Table Wine				Fortified wines and drying grapes		
	Delicate, white sweet	Light, dry or sweet	Medium, dry or sweet	Full, dry soft	Light, aromatic styles	Medium, port styles	Liqueur styles, drying
Mean temp, °C	12-15	15-18	18-21	21-24	20-22	22-24	24-26
Rainfall mm	<50	<75	<75	<75	<50	<25	<10
Highest max temp, °C	<27	<30	<33	<36	<36	<38	<40

***Table 3:* Ideal averages for ripening month for different wine styles**

(Selected from: Gladstones, 1992)

If the annual average temperature is greater than 19ºC, there are very few varietals that are sustainable and perhaps more importantly, none of these varietals are currently planted.

7. Phenological implications under climate change

There are three main climatic changes significant to the wine industry. These are changes in temperature, precipitation and carbon dioxide. Figure 5 provides a conceptual framework, showing the links between changes in these parameters and their impact on the wine industry.

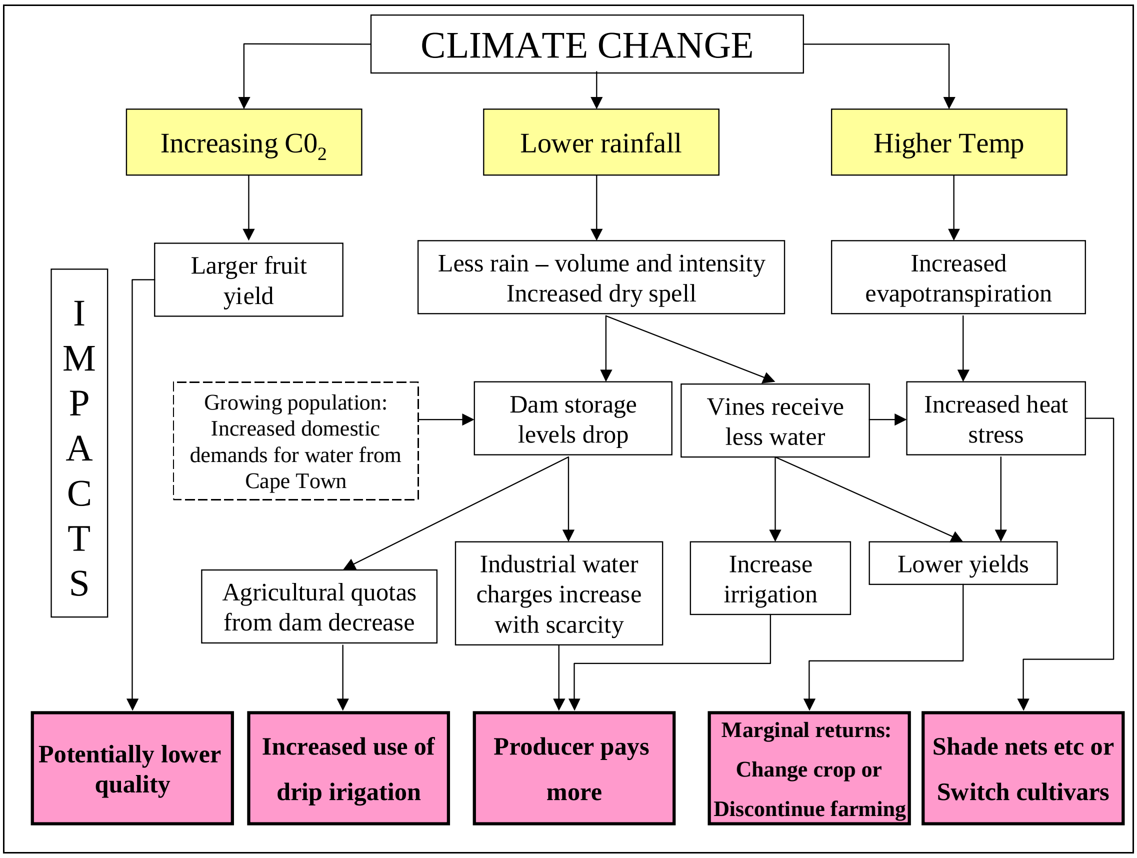


Figure 5: Overview of some of the possible impacts on wine industry with future climate change

7.1 Direct Carbon Dioxide effects

Increased levels of CO_2 encourage greater biomass accumulation (larger fruit/yields) in plants and increased water efficiency, through increased photosynthesis and decreased photorespiration. Experiments by Bindi *et al* (1995) proved that the grape vine would react similarly. This may appear beneficial, however as Tate (2001) described, the extra photosynthetic material usually comes in the form of sugars, not starches, which would change the flavours (and therefore potentially the quality) of the grapes. In experiments examining the effect of higher levels of CO_2 on wheat, it was seen that although the crop yield increased and became more water efficient the grains produced inferior quality flour (Rogers *et al*, 1998). This could have serious implications for vines, as wine is so heavily reliant on the grape quality in determining its price and profitability.

There are unfortunately no experiments on this implication for vines, leading to only speculative comment at this stage.

7.2 Water requirements for plant growth

Irrigation is common practice for most South African wine growers. This is not surprising as the variable nature of rainfall in this region can cause total crop failure. Irrigation is implemented by overhead sprinkler or by drip irrigation systems – the latter is more water efficient and cost effective in the long run, although initial expense is high. In some countries, such as France, vines are solely a rain fed crop. In some areas in the Western Cape, vines can also survive without irrigation; however, as the climate regime is generally very hot and dry over the ripening period, there is a chance of dehydration. Irrigation is implemented to minimise this risk, especially in the Olifants River. Currently most farmers do not use their full quota of irrigation water, therefore could possibly draw more water as temperatures rise. This would come at a cost and as demand for water increases; wine growers and producers will pay more per unit of water.

Vines produce better quality fruit when they are made to struggle, the yield is smaller but of better quality. There is a threshold of viability between better quality and lower yield. If the yields become too small, the capital invested in the vines is not recouped in sales of the wine. This could lead to discontinuance of that cultivar or of vines in general.

Some speculation has been made as to the resilience of the crop to adapt to climatic stress. Compared to many other deciduous fruits, such as apples, vines are much hardier. Greater resilience may make the vine more water efficient; however, it is unclear whether this may also affect the quality of the wine.

7.3 Temperature

So far the trend of warming has increased the quality of wines (Nemani *et al*, 2001), with higher ratings for recent vintages. However, in some areas where the warming has been more pronounced there seems to be a threshold over which quality can be sacrificed if ripening occurs too early. Identifying this threshold level of warming should help to determine the future viability of the wine industry in a region. Each cultivar and style of wine will also have different susceptibilities and coping ranges.

The production of wine is not believed to be at risk in South Africa, as is the case in some other wine producing regions such as southern California. Jones *et al* (2005) compared the changes in temperature from the HadCM3 model for the period 2000-2049 and found South Africa to have the lowest increase in temperature (0.88°C for the period) compared to all other global wine producing regions. A few regions in the Northern Cape and Olifants River will potentially become too hot for viable production. In the Western Cape (where the majority of the wine production occurs) there is a much lower risk as the ameliorating effects of the ocean dampens the net increase in minimum and maximum temperatures. Models suggest that the region should expect an increase of ~1.5°C at the coast and 2-3°C inland (Midgely *et al*, 2005). Other international grape growing regions are expecting up to double this warming (Jones, 2005).

Increased temperatures will have two main outcomes; increasing evapotranspiration from plants and water bodies and secondly inducing heat stress in the plant. The use of shade netting is one adaptive strategy that could be implemented to minimise moisture losses due to heat. The farmer could also chose to switch to a cultivar or crop that is better suited to the new higher temperature regime. Therefore, the dominance of the already flourishing reds will be likely to continue at the expense of the traditional white wine styles. It is also important to remember that these are long term averages, masking seasonal variations that might be large enough to have impacts. Climate change is likely to manifest in increased extreme events (IPCC, 2001), such as droughts and floods. The increased variability of the climate will decrease many farmers' coping capacity.

8. Climate Projections

The three Global Climate Models (GCMs) chosen for this analysis have data for a 30 year control climate (1960s-1990s) and a future projection of 20 years mid century (2046-2065). This long time horizon may at first seem too far into the future to be of use for agricultural adaptations. However – vines are long lived crops, with productive harvests between the ages of 3 and 25 years dependant on the cultivar. Any changes in cultivar requires a lot of forward planning, so it is important that farmers make informed choices when replanting.

All three models come from IPCC endorsed modelling groups. They are:

- The Geophysical Fluid Dynamics Laboratory (GFDL) CM 2.1 developed at Princeton University (Delworth *et al* 2004, Gnanadesikan *et al* 2004)
- The Model for Interdisciplinary Research on Climate (MIROC) developed by the Centre for Climate System Research (CCSR), NIES and FRCGC medium resolution run (K-1 model developers, 2004)
- Meteorological Research Institute Coupled GCM 2.3.2 (MRI CGCM) developed by the Japan Meteorological Agency (Noda *et al*, 2001)

Precipitation projections were downscaled to 0.25º x 0.25º lat/long in a methodology described by Hewitson (in press). In short, dominant synoptic circulation patterns are identified using Self Organising Maps (also called Kohen maps). Each state has an associated probability distribution function of rainfall for observed station data (i.e. the station response to a synoptic state). When looking at the future projections it is then possible to derive new rainfall frequencies at a spatial resolution which is at least ten times finer than the models native resolution. As precipitation is a highly spatially dependent variable, this is a desirable output for any impact study.

A caveat to the methodology:

- Downscaling of results is based upon establishing an empirical relationship between large scale dynamics and local responses. This assumes that the future large scale forcing will produce the same response. As the time horizon is relatively short this assumption should be robust. However, the technique is conservative and will at worst underestimate the change.

- It has been noted that the downscaling tends to underestimate rainfall in mountainous areas (which is higher then on the plains due to orographic forcing). Therefore, farms located in highland areas should consider these projections as the lower limits of future precipitation.

Predictions for the Western Cape of precipitation have greater model agreement than the summer rainfall areas of the rest of the country. There is some consensus that rainfall will decrease but the actual magnitude is still rather uncertain. Conservative estimates indicate only a slight decrease in annual precipitation. However, runoff changes can be 30% greater, leading to an amplified hydrological impact (Schulze, 2001).

What is of greater concern is the distribution of rainfall events. In the last 50 years there has been an increase in the number of dry days between rainfall events (also termed dry spells). If dry spell duration increases, the period of increased evaporation also increases. In the last 50 years there has already been an increase in dry spell duration of roughly 2 days on average in the Western Cape region (Hewitson, 2004).

Climate change is also expected to increase the occurrence of extreme events. Heavier rains less frequently are not always desirable as a lot of water is lost to runoff. Floods are also capable of ruining agricultural crops, although vines are usually cultivated on well drained soils. Increased drought (which is more likely given the longer dry spells already observed) is of great concern to the agricultural sector of the Western Cape.

Study area

The heart of the winelands is made up of three towns: Stellenbosch, Paarl and Franschoek (in the SAWIS industry directory Franschoek is within the Paarl statistics). They are the largest producing districts making up approximately 64% of the industry (according to the number of farms registered in these regions by SAWIS). Therefore, a grid box encompassing this area was chosen with co-ordinates 33.5 - 34 °S, 18.75 – 19.25 °E (4 grid cells). Figure 5 illustrates the boundaries of the study zone.

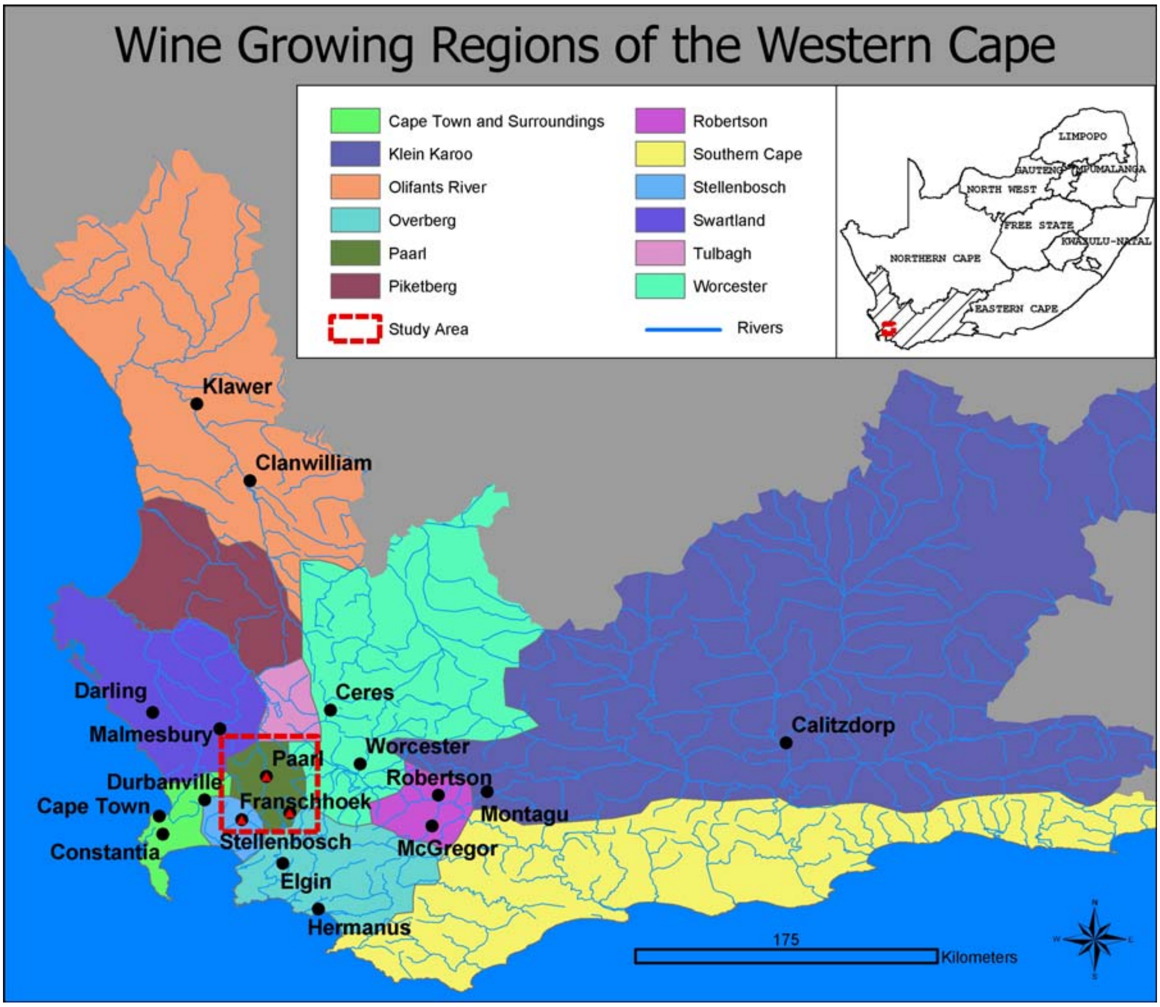


***Figure 5**: Geographic context of the Western Cape wine growing regions derived from the SAWIS industry directory, highlighting the study area*

The average for the two most common climate indicators is given below. Temperature results have not been downscaled and are therefore at the GCMs native coarse resolution. The values are for the grid cell centred on 34°S and 19°E.

	PRESENT (1960-1990)		**FUTURE (2046-2065)**	
	Growing season[3]	Ripening month	Growing season	Ripening month
Downscaled Mean monthly Rainfall	8.2 – 14.9 mm	5.9 – 12.9 mm	6.5 – 9.1 mm	6.1 –10.1 mm
Mean monthly Temperature	14.8 – 16 °C	14.8 – 16 °C	15.4 – 17.4 °C	15.8 – 17.4 °C

Table 4: ***Average changes of precipitation and temperature taken from mean monthly values***

For the scope of this study – it is sufficient to look at the monthly distribution of rainfall for the control and future climate simulations. Further research of a more detailed nature is certainly possible.

Table 4 gives results as a range from the three downscaled models for the growing season (December, January and February) and the ripening month (January – most vines start to be harvested at the end of this month depending on annual conditions). From the above results it is apparent that summer rainfall is currently negligible, perhaps indicating that further decreases will have little effect on plant physiology. Upper estimates of summer rainfall are lower by a few mm (roughly 20%) in the future projections. As these values were very low to start with, this percentage change appears large. However, total annual rainfall (not shown) is also changing by 17-29% depending on model selection. Within the ripening month moisture is particularly constrained.

According to Gladstones (1992) ideal averages in table 3, there should be less than 50mm rainfall/month. However, an estimate of minimum requirements is not presented.

[3] Growing season is summer which in the Southern Hemisphere is December- February

Usually this is not a problem as irrigation can be used to offset any deficit. However, if there are water restrictions or an increased demand for water, it will become increasingly difficult to provide supplemental irrigation. It should also be restated that areas under vine next to steep topography might benefit from increased orographic rains that may offset the predominant drying trend.

Temperatures increase across all models for all months of the year. Models vary greatly with regards to the amplitude of warming. GFDL is rather conservative whereas the other two show large changes between present and future scenarios (by as much as 2°C in some months). For the summer growing season the average increase is 0.6°C and for the ripening month just over 1°C. However when looking at individual models the changes can be larger. Year round temperature increases will lead to increased evaporation from water bodies. This will change the supply of water available for consumption.

9. Further Analysis of Precipitation Changes

Analysis of future changes can be misleading when only looking at mean values. Below are some statistics that give insight into the type and magnitude of rainfall expected:

- Mean total rainfall
- Rain days with greater than 2 mm rainfall
- Rain days with greater than 20 mm rainfall
- Mean dry spell duration

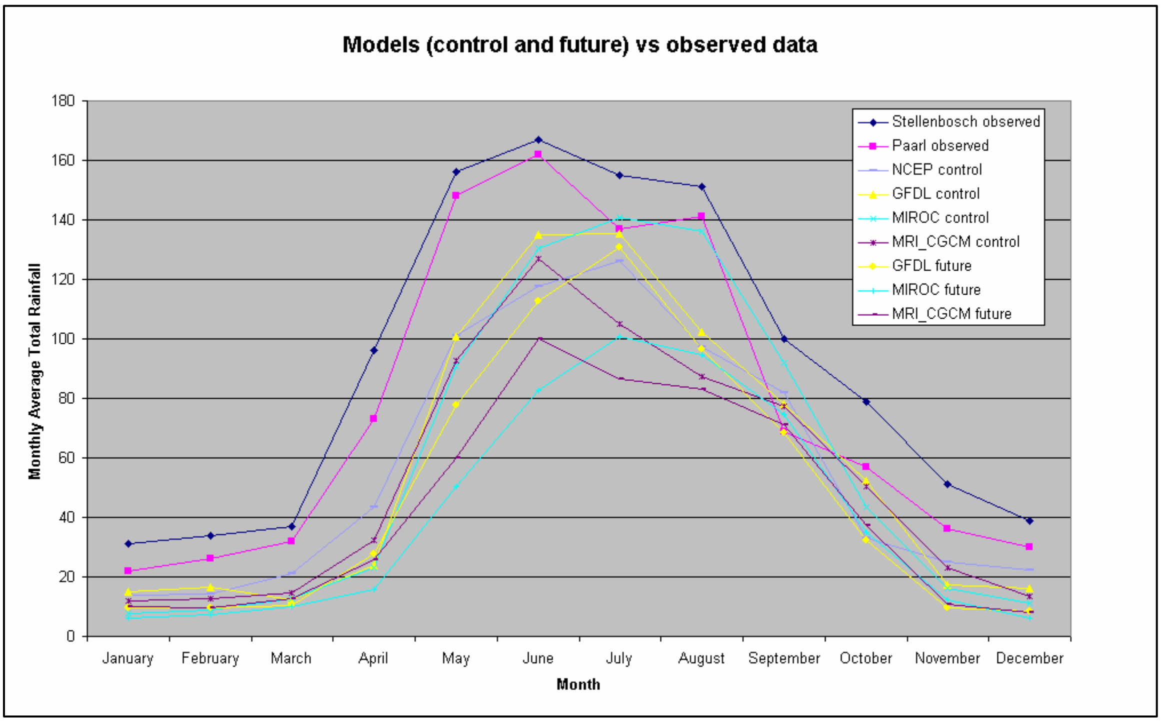
In this study the monthly averages of these variables were analysed for both the control and future time periods. As these are averages, it is important to note that seasonal variations will produce greater extremes than are reflected in these results.

Changes of interest to the wine industry concern the timing and magnitude of summer rainfall and the total changes in annual winter rainfall (which supplies the irrigation water over the dry summer months).

9.1 Mean monthly rainfall

The mean monthly values for the control monthly rainfall data depict a base line climate pattern. Most results are expressed as the anomaly between the future and control run of each of the three models. A general description for the whole province is followed by a short description of the implications for the study area.

All models showed an average decrease in rainfall. However, in the eastern half of the province the summer months showed increases in summer rains by as much as 15mm per month. This addition of rainfall would double the summer averages (which are small), but would not exceed the limitations of viability described in Table 2 (Gladstones, 1992). In the winter months, all models projected consistently drier conditions throughout the province, from 15 to 50mm less, depending on model. This represents up to 1/3 of monthly rainfall being lost in winter months.



***<u>Figure 6</u>*: Comparison between all 3 downscaled models (control and future projections) for the case study region vs. two station (observed) records and downscaled NCEP data**

To check the consistency of the data, the downscaled values for mean average rainfall were compared to observational sources (figure 6). NCEP data, derived from global remotely sensed data and station observations, is often used to validate GCMs, as it is also a gridded data set of a similar resolution. These results were downscaled using the same technique and can therefore represent a base line climate for the case study region. Two rainfall monitoring stations from Stellenbosch and Paarl were also used.

The stations have consistently higher rainfall all year round by about 10 – 40 mm (depending on model and season) than the control downscaled model projections. The downscaled models also show a lag in winter onset dates (one month) and all fail to capture the peak rainfall in June. The models seem to capture the shape of the curve better in the second half of the year, although still at slightly lower average values. The location of the stations may be in the mountains, which would explain the higher values in winter and the earlier onset of winter. In any case, comparisons between grid and point data would be expected to differ. The downscaling technique also tends to predict less rainfall; therefore the lower values should be expected.

For this reason comparison to the NCEP data is important because it exhibits the same resolution and has been subjected to the same statistical techniques. NCEP data matches the models' control runs much more closely. Larger early winter values in April and a smaller winter peak in NCEP indicate that the models may be producing marginally wetter projections. On the whole the models perform well and the deviations from both observed data sets are within reasonable variance.

Looking at the future projections, all three downscaled models showed decreases in the winter months (May – August). GFDL results showed the least changes (up to 20mm) between present and future projections and MIROC the greatest (as much as 40mm). These reductions represent 15-30% decreases in monthly winter rains. This reduction will have impacts on the future supply of the water resource in the Western Cape, which is already battling to meet all its users' needs. It is likely that there will be greater restrictions for agricultural end users more often.

Projections for September – April were closer to present day values. Wine farmers would be concerned about changes in summer wetness and in the study area this period showed fairly small reductions in rainfall between present and future runs. This is good news as unseasonable summer rains can lower the concentration of flavours and can lower the quality of the wine produced.

9.2 Dry factor

The "dry factor" is a measure of the number of dry days between rainfall events. This statistic gives some indication of the likely trend towards drier and therefore more water scarce conditions.

Summer months show much larger increases in dry spells. The climate is already characterised as dry, receiving less than 40mm average rainfall per month in summer. Changes in November, December and January are between 0-3 days increased dry spell. This is the time of ripening for the vines and subsequently the time that they are most susceptible to changes in available moisture. The southern Cape shows the least changes in dry spell – usually remaining the same as present. Areas to the north of the province (Olifants River) have some of the largest changes in increased dry spell. For December and January, the Little Karoo shows some decreases in dry spell (1-3 days) that might be problematic for ripening, depending on the intensity of the rain.

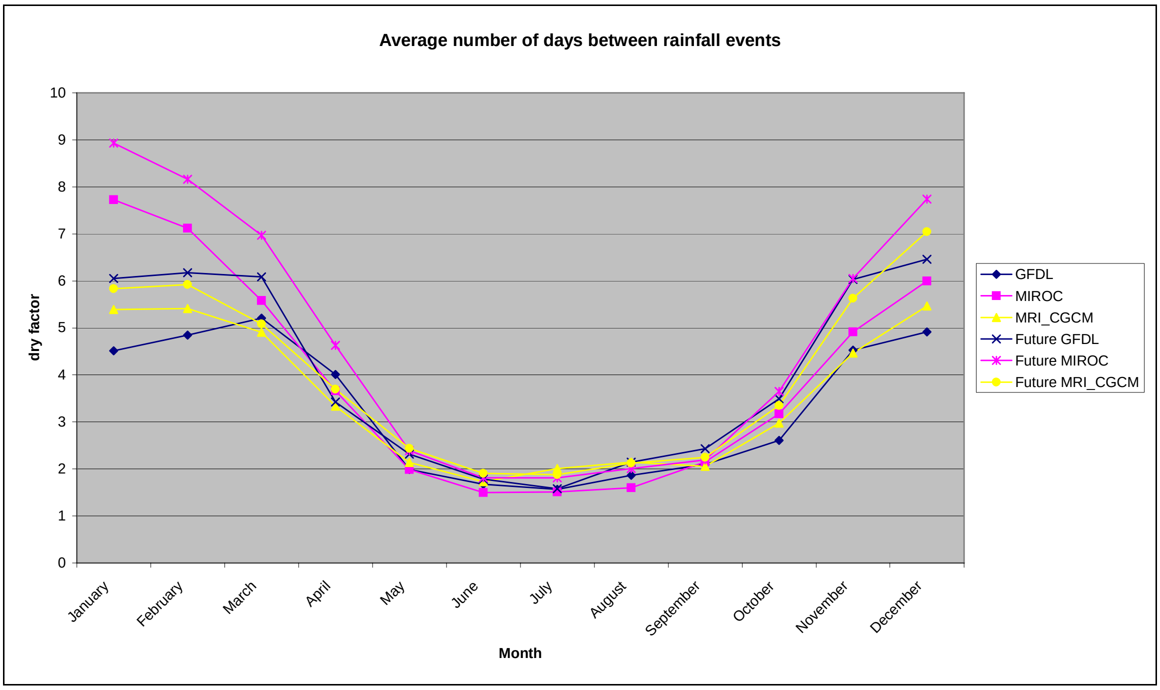


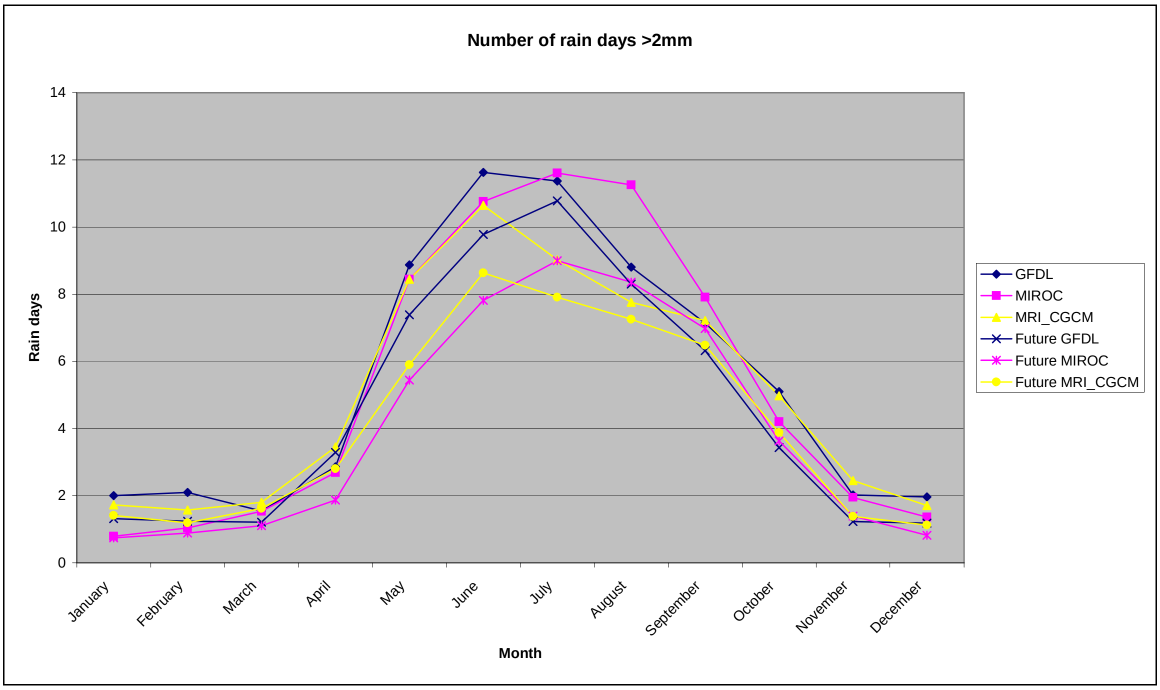
Figure 7: Changes in dry spell duration in the study area for all three models

In the study area dry spell is increasing by 1-2 days in the summer months and remains relatively constant in winter. The need for increased summer irrigation is likely.

9.3 Rain days above 2mm

By isolating days with above 2mm of rain – the analysis is restricted to those days where enough rain fell to affect the soil moisture and in summer potentially dilute the flavours in the grape berries.

In the winter months, decreases are noted of 1-2 days, especially in the onset months. All models showed decreases in June. MRI CGCM showed the largest changes in May but this was not as evident in the other two downscaled models. Both MIROC and MRI CGCM have increased January and February rain days of 0.5-1.5 days, which could potentially effect summer ripening. The Cape peninsula is the only area that showed some decreases in the summer months.



<u>Figure 8</u>: Changes in number of rain days with more than 2mm precipitation in the study area for all three models

In the case study area, the greatest changes are in the winter months of May and June, where rain days' decreases by 2 days for all models. Summer months show almost no change. The supply of water to dams in winter is confirmed to be decreasing.

9.4 Rain days above 20mm

This statistic isolates hard or sustained rainfall that would increase dam levels and groundwater. In the climate regime of the Western Cape we would expect this to be constrained to the winter rainfall period (June, July and August). During the summer months the average monthly rainfall is usually below 20 or even 10mm per month, so these months will be generally unrepresented. The anomaly in this variable is of a smaller magnitude, as there are far fewer of these events. All models showed a consistent decrease in the number of heavy rain days, indicating that there is not only a decrease in total precipitation but also in intensity, especially over the greater Cape Town area. In the major dam catchments (incl. Theewaterskloof) there are decreases of 0.5-1 days in the early winter months. These decreases equate to a loss of roughly 12% of the rainfall in these months. In the study region the same trends were seen, especially evident in June rainfall.

9.5 Summary of results

The results presented in Table 5 show an overall drier climate. There is a consistent trend to lower rainfall in all derived statistics. This indicates that not only is there on average less rain falling, but also fewer heavy rainfall events. Dry spells also have a consistent trend of increase, indicating longer dry periods between rainfall events. This coupled with expected increases in minimum and maximum temperature, which would lead to increased evaporation, should raise concern among water resource managers.

Requirement	**Spring**		**Summer**		**Autumn**		**Winter**	
Time period	Control	Future	Control	Future	Control	Future	Control	Future
Mean number rain days >2mm	4.61 - 4.88	3.66 - 4.00	1.03 - 1.91	0.81 - 1.24	4.16 - 5.04	2.80 - 3.96	8.92 - 11.15	7.93 - 9.62
Mean number rain days >20mm	0.55 - 4.71	0.38 - 3.91	0.04 - 1.59	0.03 - 1.24	0.44 - 5.04	0.21 - 3.44	1.68 - 8.92	1.12 - 7.93
Mean dry spell duration	3.06 - 3.39	3.74 - 3.98	5.04 - 6.91	6.22 - 8.28	3.33 - 3.74	3.74 - 4.66	1.52 - 1.93	1.83 - 1.98

***Table 5*: Anomalies in rainfall statistics for the study area given as a range of the three models results**

10. Discussion and Conclusion

The climate projections presented, coupled with present stressors on the water management system and existing demands for water of the wine industry, demonstrate a rather complex system. Section 7 discussed some of the overarching interactions between climate change and the wine growers'/ producers' possible reactions. The implication is that the practice of wine making is likely to become more risky and more expensive. The most likely effects will be shifts in management practices to accommodate an increasingly limited water supply. The changes that increased temperature and CO_2 might have on quality have not been addressed here. As the temperature changes do not exceed the range given by Gladstones (1992) for ideal conditions, it may be fair to assume that quality will not be greatly affected by temperature in the next 50 years. The increased expertise in wine making post apartheid should mean that wine makers are better equipped to deal with sub optimum conditions and produce quality wines through more careful timing of harvesting, blending wines to produce better flavours and improved production facilities.

The impacts of water shortages on the wine industry might include:

- Increased price of wine – production inputs increased from higher water pricing, increased use of irrigation water, implementing drip irrigation schemes to all vines or uprooting of cultivars less suited to future climate.
- Reduced number of wine growers – smaller profit margins discourage new enterprises (large capital investment needed on outset), growers already making low returns forced out of business, borderline climatic zones pass threshold of temperature suitability (wines quality reduced and therefore less profitable).
- Implementation of adaptive strategies – shade netting, drip irrigation etc and/or the planting of more suitable cultivars

The wine industry seems to be in a fairly robust position for dealing with the changes that are projected for the mid 21^{st} century. With careful management and early investment into water saving strategies as well as informed cultivar choices, there should be sufficient capacity to avoid major impacts on productivity in this industry.

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