

# Hunter, Central and Lower North Coast

## Regional Climate Change Project

2009

CASE STUDY 1

Analysis of Past Trends and Future Projections of Climate Change and  
their Impacts on the Hunter Valley Wine Industry



An Initiative of the Hunter & Central Coast Regional Environmental Management Strategy



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(Hunter & Central Coast Regional Environmental Management Strategy – a program of the Environment Division of Hunter Councils)

**Authors:** Karen L. Blackmore (Earth Sciences, School of Environmental and Life Sciences, University of Newcastle), Ian D. Goodwin, (Climate Risk CORE, Macquarie University) and Steve Wilson (Hunter Councils)

#### **Publisher**

HCCREMS (Hunter Councils Inc. as legal agent)  
PO Box 137  
THORNTON NSW 2322  
Phone: 02 4978 4020  
Fax: 4966 0588  
Email: [envirodirector@huntercouncils.com.au](mailto:envirodirector@huntercouncils.com.au)

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## Glossary

BOM	BUREAU OF METEOROLOGY
CSIRO	COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION
EHD	EXTREME HEAT DAYS
GCM	GLOBAL CLIMATE MODEL
HCLNC	HUNTER, CENTRAL AND LOWER NORTH COAST
HVWI	HUNTER VALLEY WINE INDUSTRY
HVWIA	HUNTER VALLEY WINE INDUSTRY ASSOCIATION
HDD	HEAT DEGREE DAYS
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
MJT	MEAN JANUARY TEMPERATURE
SD	STATISTICAL DOWNSCALING
SLP	SEA LEVEL PRESSURE
ST	SYNOPTIC TYPES



## INTRODUCTION

This case study presents an analysis of the potential impacts of climate change on the Hunter Valley Wine Industry. It has been completed as part of a regional research program to identify the regional and sub regional scale impacts of climate change in the Hunter, Central and Lower North Coast region of New South Wales. In addition to an overall analysis of historical and projected climate change for the region (Blackmore & Goodwin, 2008; Blackmore & Goodwin, 2009) generated by this research, 4 case studies (of which this is one) have been developed to more specifically analyse and understand the potential impacts of climate change in the region. The focus of these case studies includes the Hunter Valley Wine Industry (HVWI), Human Health (Extreme Heat), Bushfires and Extreme Events in the Coastal Zone.

The HVWI forms an important case study for the assessment of impacts of climate change due to the importance of the industry to the region.

The wine industry is of significant importance to the Hunter region, both in terms of its economic contribution as an industry and its role in the regions' tourism profile. The HVWI comprises approximately 120 wineries and cellar doors, with the majority of these operating as boutique wineries producing 500 tonnes or less per annum. In 2003-04, the Hunter produced an estimated \$203 million in wine sales; \$147 million in the domestic market and \$37.8 million generated through exports (Macdonald 2005). Estimates of the economic contribution of winery related tourism are difficult given the lack of available data, however the region attracted an estimated 2.5 million visitors during 2007. The economic benefit from these visitors includes not only their winery related expenditure but also flow-on expenditure and job creation.

## STUDY AREA

A study area boundary has been defined in order to analyse and present projected impacts of climate change on the HVWI. This boundary encompasses all of the regions' major wine growing areas (Pokolbin, Broke-Fordwich and Upper Hunter) and extends from Muswellbrook in the north to Wollombi in the south and westward from Sandy Hollow to Gresford in the east. This boundary includes large portions of the Wollemi and Yengo National Parks, which have been excluded from the analysis. A map of the study area is provided in Figure 1.

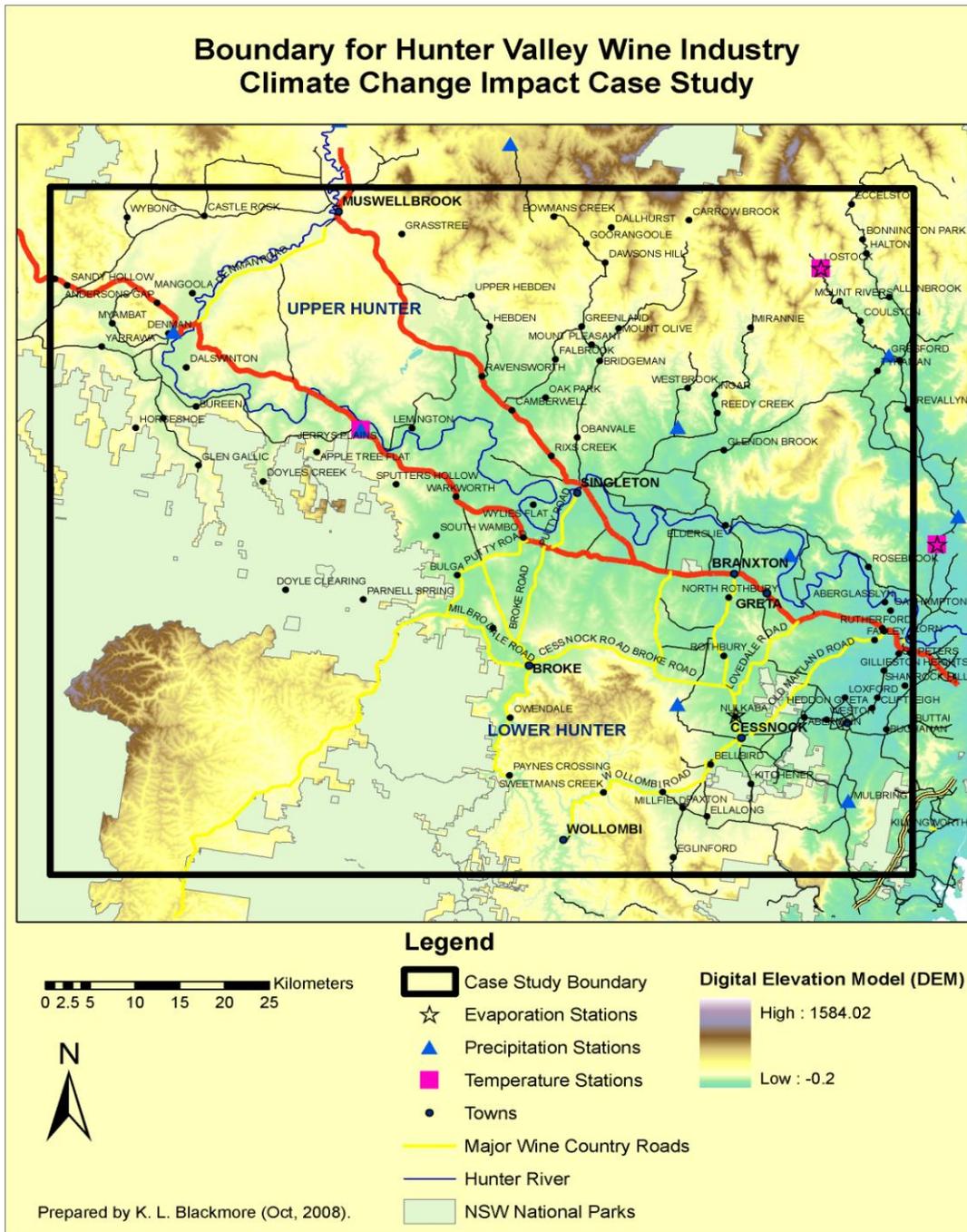


Figure 1 - Map of the study region

## IDENTIFICATION OF KEY CLIMATE ISSUES

### INDUSTRY CONSULTATION

The climate issues that are analysed within this case study for the purpose of identifying potential impacts arising from climate change have been identified through consultation with the Hunter Valley Wine Industry Association (HVWIA) and Industry and Investment NSW. These issues relate primarily to changes in extreme heat events, average temperatures, frost events and rainfall. The impact of climate change on pests and diseases such as Queensland Fruit Fly was also identified as a primary concern. A description of the nature and significance of each of these issues to the industry is provided below.

#### EXTREME HEAT EVENTS

Extreme heat events result in leaf burn on vines and were identified by stakeholders as a key concern. Extreme temperature threshold values vary according to wine variety, thus no single threshold value relevant for all varieties exists. A recent report by the Grape and Wine Research and Development Corporation (Australian Government 2008) provides results of research conducted on Semillon which can be used as a guide for assessing heat impacts on grapes. Stakeholders have identified the potential for Semillon to be considered as a 'canary in the mine' variety due to its relatively low heat tolerance compared to other varieties. Semillon is also regarded as an icon wine variety for the Hunter Region and is thus of regional significance. The report identifies a threshold value of 38°C for leaf burn in the Hunter.



Figure 2 - Photo of Leaf burn on vines

#### AVERAGE TEMPERATURE



Figure 3 - Photo of frost damage during budburst

A relationship exists between average temperatures and grape yield, particularly through its influence on soil temperature which is the trigger for vine bud burst. Warmer average winter temperatures contributing to higher soil temperatures and earlier budburst is of key concern as this scenario renders vines more susceptible to frost damage.

Average temperatures are also important to growing degree days. According to industry stakeholders, grape vines in the Hunter Valley require around 130 – 140 days of around 25 °C between budburst and harvest (September to March). In light of the number of variables (e.g. soil temperature and moisture)

in addition to ambient temperature that influence bud burst, stakeholders considered that average temperatures alone would not provide sufficient information to ascertain the potential impacts of climate change on this aspect of plant growth. Despite this, there was agreement that analysis of average temperature, cloudiness, sunshine hours and changes to seasonality of rainfall patterns (i.e. likelihood of increased rain and cloud in spring and summer) would inform potential impacts on growing degree days. Unfortunately, analysis of cloudiness and sunshine hours is not possible due to limited availability of relevant data. As such, the climate indicators identified by Webb et al (2005) that are likely to be associated with grapevine growth and/or grape quality have been assessed.

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## FROST

Temperatures of  $-6^{\circ}\text{C}$  to  $-7^{\circ}\text{C}$  degrees can cause direct physical damage to the vascular systems of the vines, which in turn inhibits fruit development and energy storage during the subsequent growing season. Severe frost conditions of this nature are most likely to occur in frost hollows. The timing of frost events is also significant. Bud burst (for Chardonnay) generally occurs around 1<sup>st</sup> / 2<sup>nd</sup> week in September. Frost after this can cause significant damage. Stakeholders identified that frost is a lower priority for inclusion in the case study relative to the other climate parameters that have been identified, however it was nevertheless acknowledged that frost information would still be of benefit to growers. The identification of frost hollows was not considered a priority for the case study given that this issue is generally accounted for in vineyard design and planting (i.e. frost hollows are avoided).



**Figure 4 - Photo of vine split as a result of frost**

It was agreed that  $-6^{\circ}\text{C}$  provides an appropriate threshold for examining the impacts of extreme frosts that can cause vascular damage as well as trunk cracking (which in turn has impacts on long term viability due to pathogen invasion). In regard to frost timing, it was agreed that frosts occurring in October / November are of particular concern due to their impact on new growth.

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## RAINFALL



**Figure 5 - Photo of harvesting issue caused by rainfall**

Stakeholders identified that the maximum rainfall for successful viticulture is 700mm - 750mm per annum. Summer rain is a key issue however, particularly where it occurs around harvest time when it encourages fungal disease, often stalls ripening and also makes harvesting physically difficult (e.g. difficult to get machinery on paddocks). Change to the seasonality of rainfall (particularly the potential for an increase in summer rainfall) was identified as a priority for the case study analysis. Rainfall was also identified as the key issue in regard to pest infestations and disease infection events

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## QUEENSLAND FRUIT FLY

The potential for changing climatic conditions to exacerbate the problems posed to the viticulture industry by pests and diseases is of concern to stakeholders. QLD Fruit Fly is one such pest whose infestations are affected by a combination of climatic factors. Their rate of development is temperature dependent and reproduction decreases/mortality increases with decreased rainfall (Yonow, et al., 2004). Stephens et al.'s (2007) model of the geographic distribution of QLD Fruit Fly under climate change scenarios projects extension of their current tropical and sub-tropical ranges further towards the poles. They also note the potential for range contraction in areas where precipitation is projected to decrease substantially. Climate change scenarios where warming of 0.5, 1.0 and 2.0 degrees Celsius are projected suggest an expansion of the current endemic range of the QLD Fruit Fly (IPCC 2007b).

## SCIENTIFIC LITERATURE REVIEW

In addition to the concerns and climate parameters identified by industry stakeholders, a review of available research has confirmed the close relationship between climate and viticulture, and the consequent susceptibility of the wine industry to climate change. A relationship between temperature and wine-grape quality has been established (Jackson and Lombard 1993) and assessment of the impacts of projected temperature change has been made (Webb et al. 2005). Webb et al. (2005) also identify a number of climate indicators that are likely associated with grapevine growth and/or grape quality. These indicators include:

- Heat degree days (HDD) (Amerine and Winkler 1944);
- Annual rainfall (Webb et al 2005);
- Mean January temperature (MJT) (Dry and Smart 1988);
- Latitude temperature index (LTI) (Jackson and Cherry 1988);
- Winter minimum temperature (June to August);
- Harvest maximum temperature (Average of December to March) (Happ 1999);
- Rainfall (summer) (Nicholas et al. 1994);
- Diurnal range (January maximum temperature minus January minimum temperature); and,
- Continentality (January mean minus July mean) (Gladstones 1992).

General climate change projections indicate an increase in temperature and possibly precipitation. As such, a change in these noted indicators is likely to provide data relevant for the assessment of impacts on the wine industry. It is noted a priori that these projected changes are likely to impact on the grapevine growth and/or grape quality, potentially leading to varietal substitution and/or shifting suitability of viticulture areas (Webb et al 2005). This case study will focus on the HVWI using regionally specific historical and projected data to ascertain likely impacts.

## DISCUSSION OF KEY CLIMATE PARAMETERS

The key climate parameters that have been used in the analysis for this case study, to determine potential impacts on the climate issues and indicators that have been identified above, include daily precipitation, daily maximum and minimum temperature, daily pan evaporation, humidity and water balance. Historical records for these parameters have been obtained from the Australian Bureau of Meteorology (BOM) for the period from the beginning of record keeping for individual stations until December 2007. These parameters are briefly discussed below.

It is important to ensure that the data sets used in this study are of a sufficient length, cover a common time span, and are reasonably complete. Thus a data interrogation process was used to determine the completeness of each of the records. Each climate parameter time series was checked for missing data between the years of interest (1948 and 2007)<sup>1</sup> and this was converted to percentage completeness. It was determined that a good spatial coverage could still be maintained by restricting the final data set to stations with daily records that are at least 90% complete.

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### DAILY PRECIPITATION

Of the 80 BOM precipitation stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, seven (7) stations lie within the viticulture case study area. Applying a 10km buffer around the study area includes an additional three (3) stations for analysis. Precipitation records are available from as early as 1863 at Branxton, with the last of the stations commencing operations from October 1932. Thus for all but one station, a minimum of 100 years of historical precipitation records are available. The 10 stations are listed in Table 1.

BOM ID	NAME	SITE_OPEN	LATITUDE	LONGITUDE	ELEVATION*
61016	DENMAN (PALACE STREET)	01/1883	-32.3885	150.6890	105
61000	ABERDEEN (MAIN RD)	01/1894	-32.1655	150.8910	183
61086	JERRYS PLAINS POST OFFICE	01/1884	-32.4972	150.9090	90
61095	ROUCHEL BROOK (ALBANO)	10/1932	-32.1939	151.0930	305
61056	POKOLBIN (BEN EAN)	08/1905	-32.7965	151.2800	140
61050	SEDFIELD (BUNDAJON)	01/1903	-32.4997	151.2860	73
61014	BRANXTON (DALWOOD VINEYARD)	01/1863	-32.6385	151.4170	40
61048	MULBRING (STONE STREET)	01/1932	-32.9029	151.4820	31
61024	GRESFORD POST OFFICE	01/1895	-32.4266	151.5380	85
61096	PATERSON POST OFFICE	01/1901	-32.5997	151.6180	21

\* Metres above sea level

**Table 1 – Available precipitation stations**

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<sup>1</sup> The year 1948 was chosen as the lower bound as this corresponds to the first year for which the atmospheric data is available in the NCEP/NCAR dataset (and therefore was also be the first year for which the synoptic typing was carried out).

## DAILY MAXIMUM AND MINIMUM TEMPERATURE

Of the 17 BOM maximum and minimum temperature stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, only two (2) stations (Jerrys Plains and Lostock Dam) lie within the viticulture case study area. Applying a 10km buffer zone around the study area results in an additional one site selected (Paterson).

BOM ID	NAME	SITE_OPEN	LATITUDE	LONGITUDE	ELEVATION*
61086	JERRYS PLAINS POST OFFICE	01/1884	-32.4972	150.9090	90
61288	LOSTOCK DAM	01/1969	-32.3322	151.4590	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.6296	151.5920	30
* Metres above sea level					

Table 2 - Available maximum and minimum temperature stations

The length of record for maximum and minimum temperature is much shorter than that available for precipitation. Only one of the stations in the study area (Jerrys Plains) has historical records available for over 100 years.

## DAILY PAN EVAPORATION

From the seven (7) BOM pan evaporation stations meeting 90% complete criteria in the Hunter, Central and Lower North Coast region, only two (2) stations (Cessnock and Lostock Dam) lie within the viticulture case study area. Applying a 10km buffer zone around the study area results in an additional one site selected (Paterson).

BOM ID	NAME	SITE_OPEN	LATITUDE	LONGITUDE	ELEVATION*
61288	LOSTOCK DAM	01/1969	-32.3322	151.4590	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.6296	151.5920	30
61242	CESSNOCK (NULKABA)	01/1966	-32.8093	151.3490	62
* Metres above sea level					

Table 3 - Available pan evaporation stations

## HUMIDITY

Of the twelve (12) 3 hourly humidity stations meeting 90% complete criteria, only one station (Lostock Dam) lies within the study area. The addition of a 10km buffer zone around the study area results in an additional one site selected (Paterson).

BOM ID	NAME	SITE_OPEN	LATITUDE	LONGITUDE	ELEVATION*
61288	LOSTOCK DAM	01/1969	-32.3322	151.4590	200
61250	PATERSON (TOCAL AWS)	11/1967	-32.6296	151.5920	30
* Metres above sea level					

Table 4 – Available humidity stations

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## WATER BALANCE

The analysis of key climate variables will also include consideration of water balance. Simple water balance is calculated by subtracting the average daily pan evaporation (mm/24hr) from the average daily precipitation for each season. Evapotranspiration is not taken into account. In the study area (and 10km buffer), only the Paterson station records both precipitation and evaporation (that meets the selection criteria). Cessnock (Nulkaba) precipitation is available from January 1966 and for Lostock Dam from January 1969. Thus data from these two precipitation stations will be included in order to assess water balance.

## CASE STUDY METHODOLOGY

A two step methodological process has been adopted for the analysis of climate parameters completed for this case study. Firstly, key climate indices relevant to the viticulture industry have been identified and changes in these indices are assessed using historical records obtained from the Bureau of Meteorology (BOM). Secondly, climate projections for the region obtained from Global Climate Model (GCM) output for the A2 (high) emissions scenario and a process called Statistical Downscaling (SD) have been utilised to assess likely impacts on the relevant key climate indices for the period from 2020-2080 A.D.

GCMs generate future climate scenarios and provide output for a range of key climate variables. The CSIRO Mk3.5 GCM has been determined as the most appropriate GCM to identify projected changes in climate for the Hunter, Central and Lower North Coast region. Because of the coarse scale outputs generated by GCM's however, the additional process of SD has also been used to generate climate projections more relevant and applicable for regional scale analysis and management purposes. SD is a term given to techniques used to derive values for climate variables at a regional or sub-regional level from the coarse scale output of GCMs. Specifically, a weather typing approach to SD has been adopted for the research presented in this case study. In summary, this process has included:

1. Identifying the key synoptic types (STs) that drive climate variability in the region.
2. Identifying the relationships between these STs and BOM historical records for key climate variables.
3. Using the GCM to identify projected changes in the frequency of occurrence of these key STs based on sea level pressure (SLP) output data generated by the GCM
4. Combining our understanding of how the regions weather is impacted by these key STs with projected changes in their frequency to project likely changes in key climate variables across the region.

A more detailed overview of the methodology is included in the report *Climatic Change Impact for the Hunter, Lower North Coast and Central Coast Region of NSW* (Blackmore & Goodwin, 2009). The key benefit of this approach is that it provides a richer understanding of the “drivers” of weather patterns within the region and how these drivers are likely to change in the future.

The projections are reported in terms of three climate zones derived for the (HCLNC) region (Blackmore & Goodwin, 2008). The study region for this case study incorporates two of these identified climate zones (western and central zones – see Figure 6).

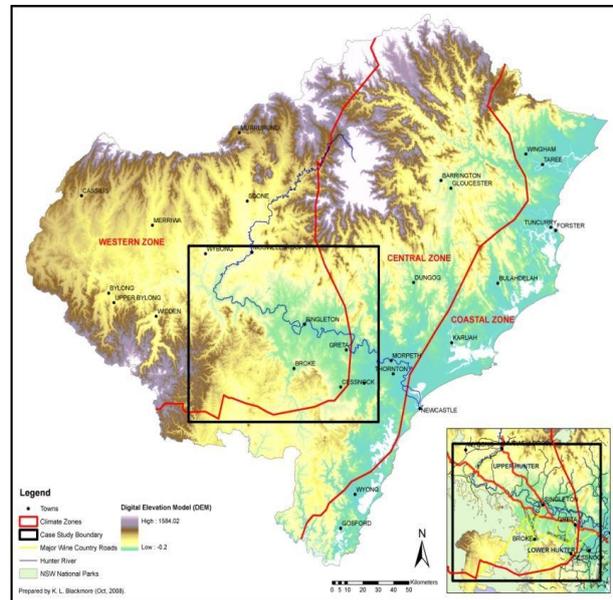


Figure 6 - Climate zones incorporated in the study region

## HISTORICAL CLIMATE VARIABILITY AND TRENDS

### PRECIPITATION

Average annual precipitation in the HVWI study region varied between 416mm and 1451mm for the period from 1933 to 2007, a range of 1035mm (Figure 7). Although record keeping at some precipitation stations in the study region extends back to the mid to late 1800's, the 1933 – 2007 time period has been selected because records prior to this date are incomplete and do not provide sufficient spatial coverage. No observable trends are evident over this time period (shown as a red linear trend line in Figure 7). Thirty four of the seventy five years analyzed (34%) recorded average precipitation for the study region below the upper bound of 750mm (the noted maximum annual precipitation identified by stakeholders).

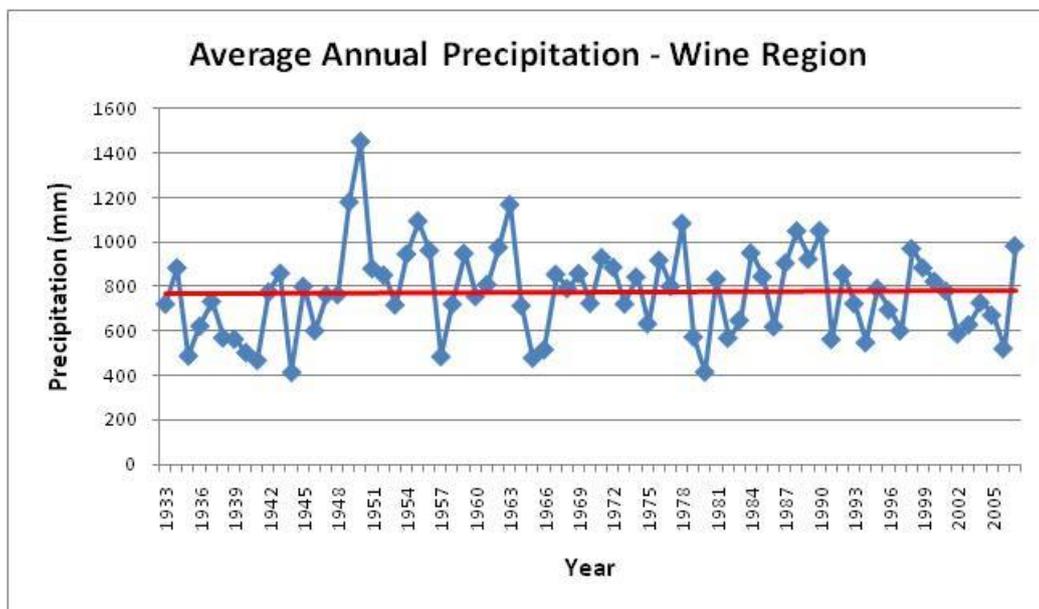


Figure 7 - Average annual precipitation for the Hunter Valley wine region

Precipitation for the region is plotted for each season from 1933 to 2007 (Figure 8). Average summer precipitation for the 1933 to 2007 time period varied between 74mm and 609mm (a range of 535mm) with an average of 271mm for the season. Autumn precipitation is less variable, ranging between 53mm and 492mm and averaging 203mm. Despite receiving the lowest average seasonal precipitation of 155mm, winter variability is highest with a range of 27mm to 643mm. Spring precipitation varied between 35mm and 400mm during the time period, a range of 176mm. The average precipitation for this season was 176mm.

In addition to differential ranges, observable trends are evident for the seasonal data. Negligible change is evident in summer however observable increases are present in autumn and spring. An observable decrease is evident in winter. Combined however, these slight changes in seasonal patterns produce no change at the annual level. Analysis of the trends using regression analysis also finds these trends statistically insignificant.

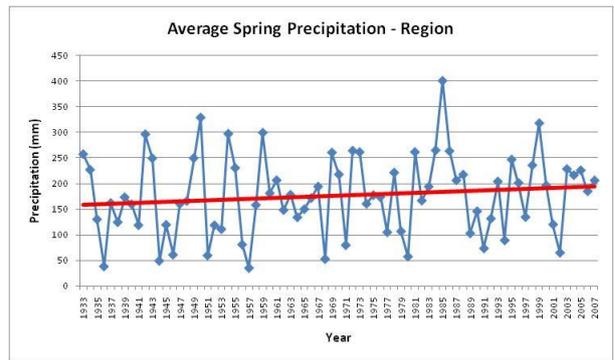
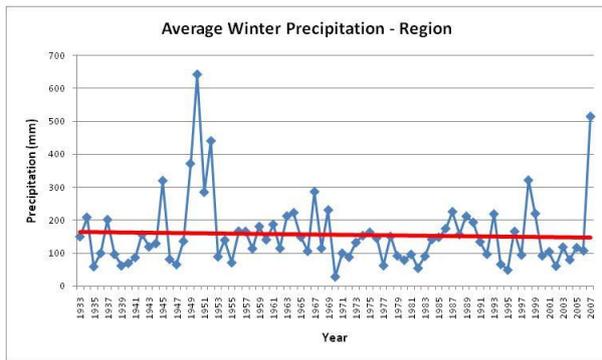
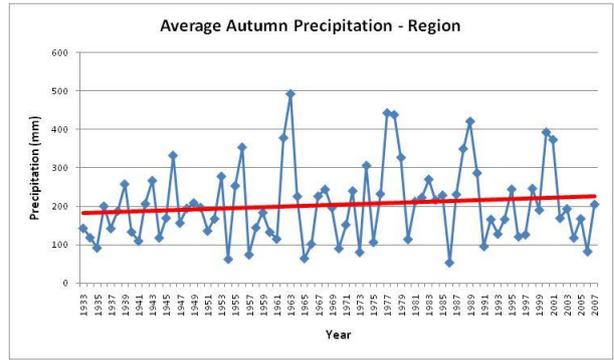
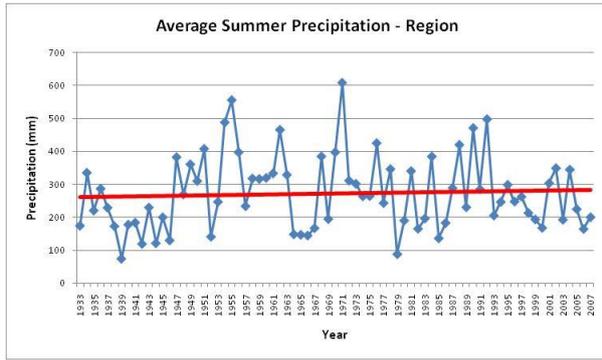


Figure 8 - Average seasonal precipitation for the Hunter Valley wine region

## TEMPERATURE

### EXTREME HEAT EVENTS

An annual count of extreme heat events (i.e. days with maximum temperature above or equal to 38°C) is plotted for the years from 1957 to 2007 in Figure 9. The number of extreme heat events per annum varied between 1 (1976, 1978, 1984, 1986, and 1992) and 19 (1957) during this time period. On average the study region experiences six (6) extreme heat events per annum.

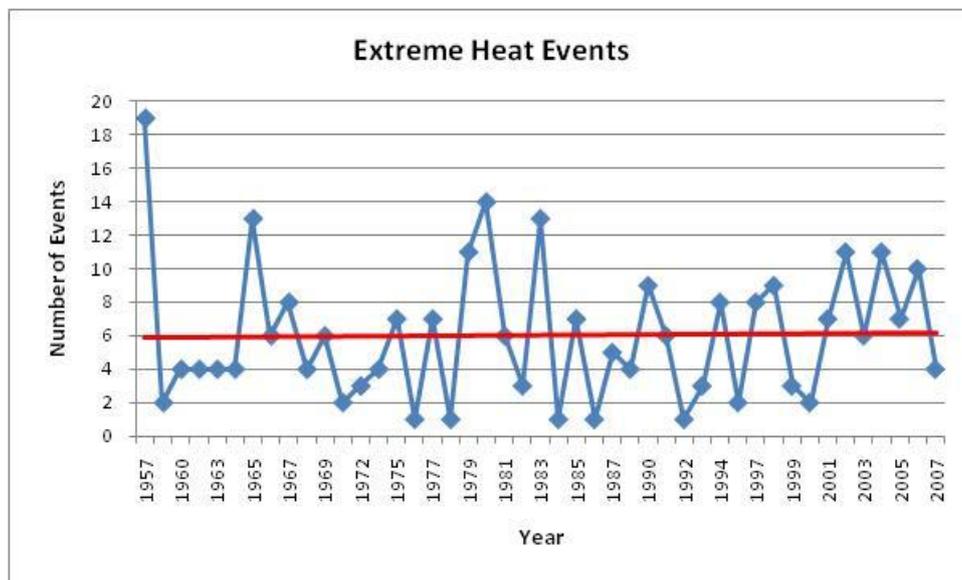


Figure 9 - Frequency of extreme heat events (1957-2007)

The number of extreme heat events occurring per annum was assessed to determine if any increasing or decreasing trend is evident. No discernable trend is evident.

### HEAT DEGREE DAYS (HDD)

HDD is a measure of the warmth of a region. It is obtained by subtracting the minimum temperature from a day's maximum temperature (to obtain the mean daily temperature) then subtracting 10°C from this mean value. The value of 10°C is used because vines do not function below this temperature. Each day's adjusted temperature is then added to achieve a growing season summation. In Australia, the growing season is considered to extend from 1 September to 31 March and thus the summation is calculated over this time period. The summation is calculated from 1957 to 2008, thus each data point includes data from a growing season spanning two years (i.e. 1958 data point includes data from September 1957 to March 1958).

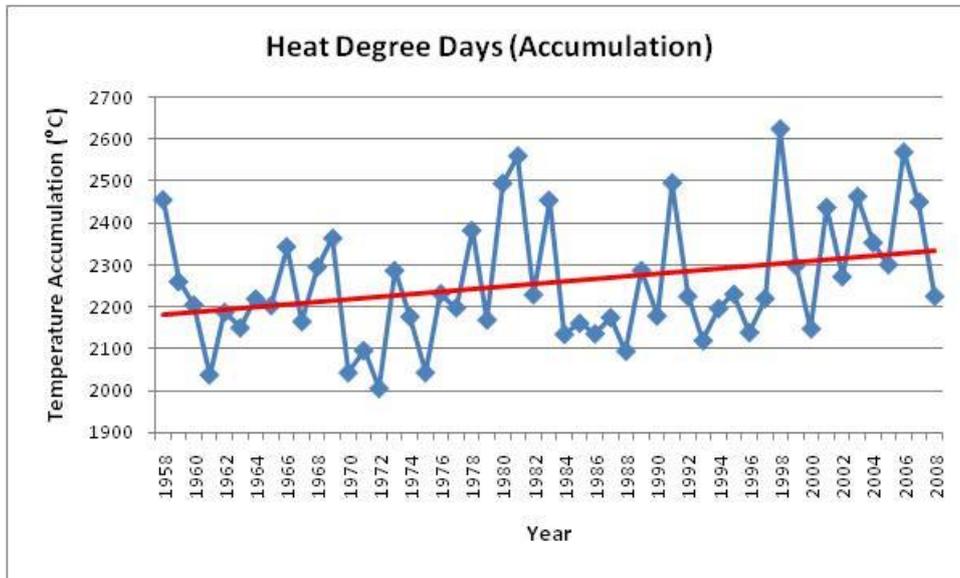


Figure 10 - Heat degree days (accumulation 1958-2008)

The HDD summation for the study region ranges between 2006 and 2623, with an average of 2258 (Figure 10). A statistically significant ( $P=0.03$ ) increasing trend in the HDD for the study region exists. A total 152.58°C (approximately 3°C per year) increase in the HDD summation was recorded for the period from 1957 to 2008.

### MEAN JANUARY TEMPERATURE

The mean temperature for January is derived from daily maximum and minimum temperature averaged for the month (i.e. daily maximum temperature + daily minimum temperature / 2). Mean January temperature for the study region ranged from 21.0°C to 26.6°C for the period from 1957 to 2008 (Figure 11). An observable increasing linear trend in mean January temperature of approximately 0.8°C is evident over this time period, however it should be noted that this trend is not statistically significant.

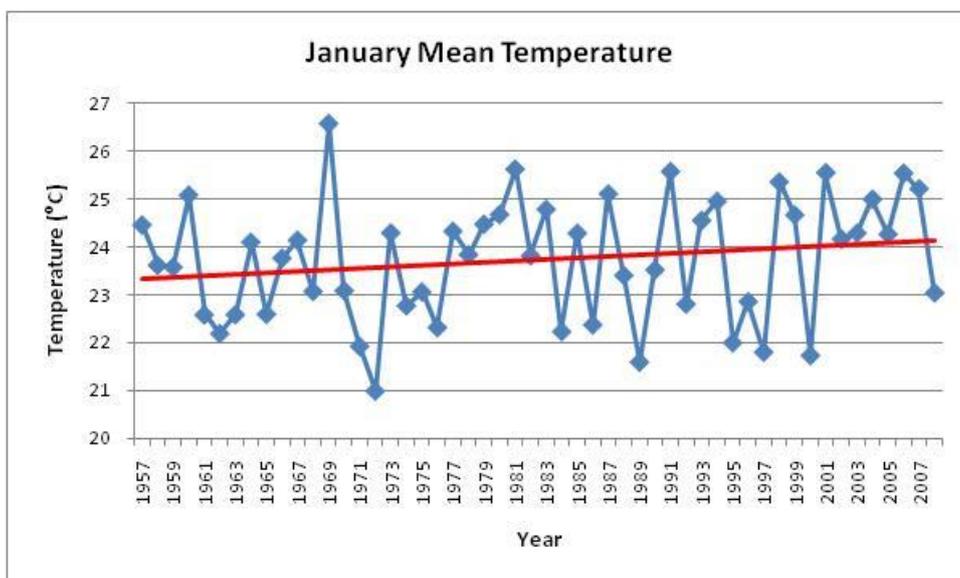


Figure 11 - January mean temperature (1957-2008)

## WINTER MINIMUM TEMPERATURE

Average winter (JJA) minimum temperature for the period from 1957 to 2007 is shown in Figure 12. Average temperatures for winter range between 3.6°C and 7.8°C over this time period, with an average of 5.85°C. A statistically significant ( $P=0.0$ ) increasing linear trend in winter minimum temperatures is evident. This increase is approximately 1.7°C over the time period. This increase is evident despite an increase in frost days (see page 17).

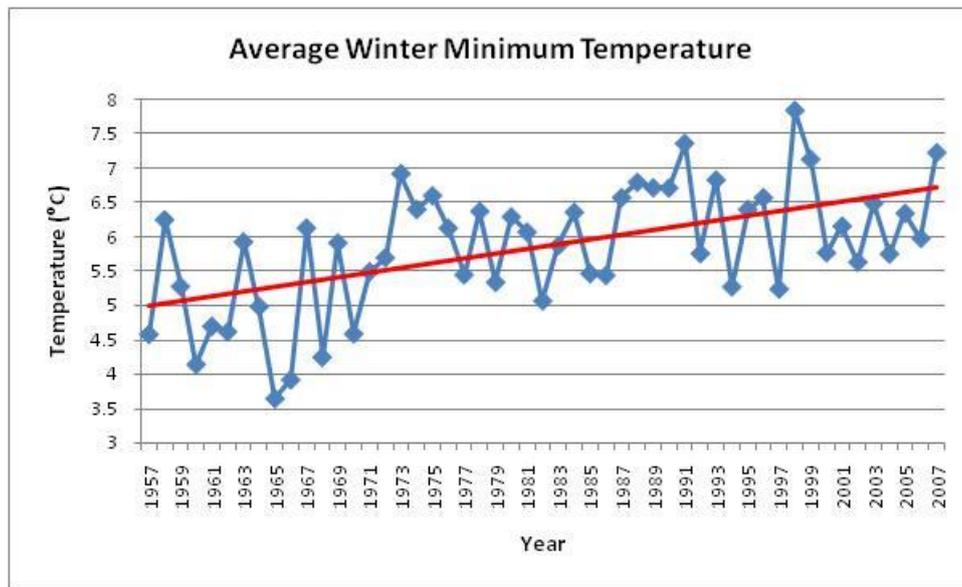


Figure 12 - Average winter minimum temperature (1957-2007)

## HARVEST MAXIMUM TEMPERATURE

The harvest period is calculated over two periods; firstly the months of December, January, February and March (DJFM) and then over the months of January and February (JF) from 1957 to 2008. Average harvest maximum temperature for DJFM ranges between 26.6°C and 32.5°C with an average of 29.0°C recorded in the study region over the designated time period (Figure 13). An observable increasing linear trend of approximately 0.5°C over this time period is evident however this trend is not statistically significant. The average for the JF harvest period is slightly lower at 28.3°C and no trend is evident.

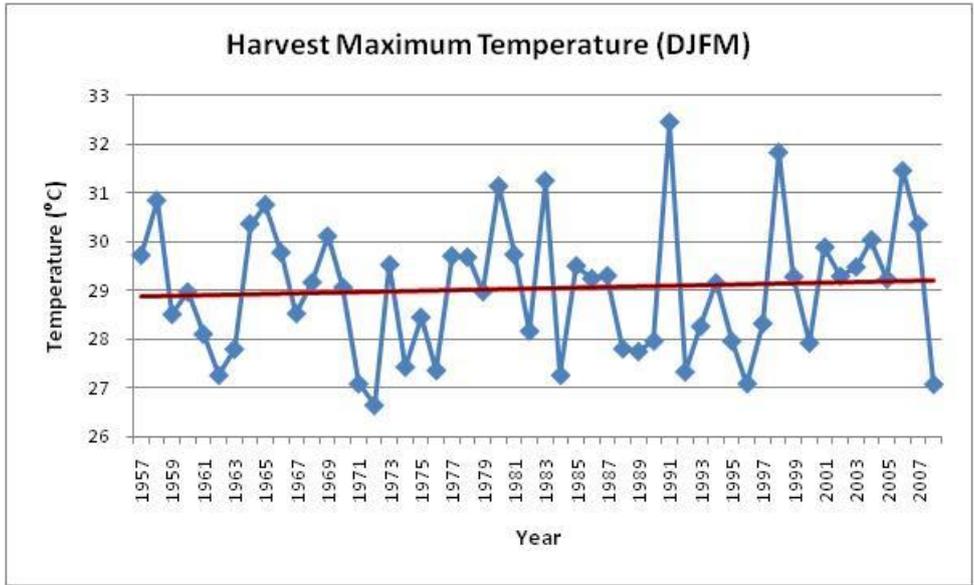


Figure 13 - Harvest maximum temperature (DJFM 1957 - 2008)

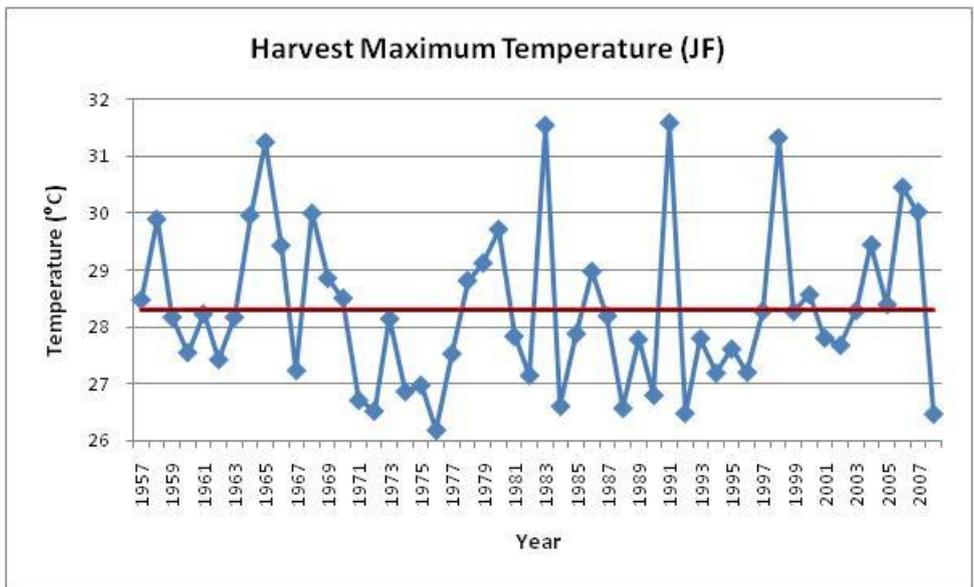


Figure 14 - Harvest maximum temperature (JF 1957-2008)

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## DIURNAL RANGE

The diurnal temperature range is obtained by subtracting the daily minimum temperature from the daily maximum temperature. These daily values are then averaged to obtain a mean diurnal range. In this analysis the mean diurnal range is calculated for January following the work of Webb et al. (2005).

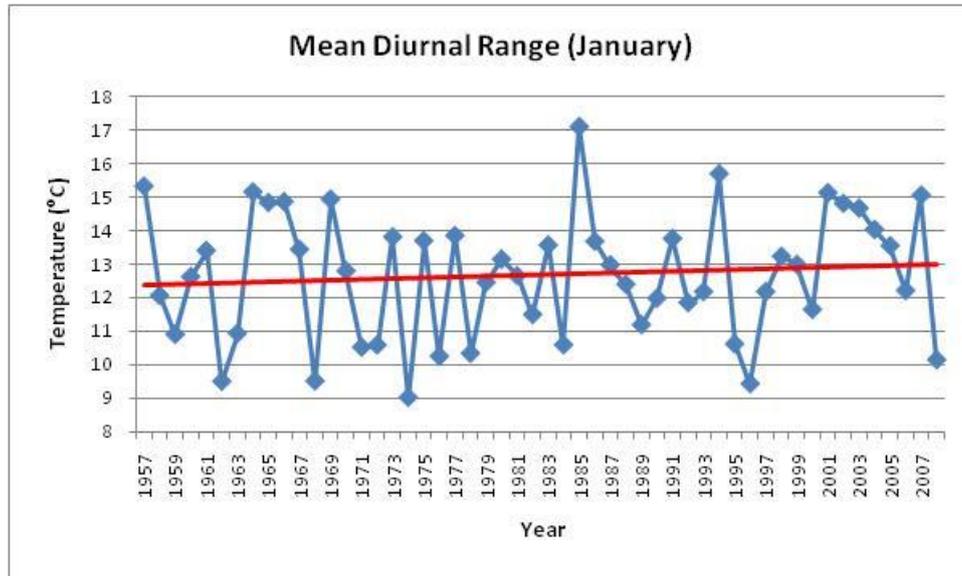


Figure 15 - Mean diurnal range (January 1957 - 2008)

The mean January diurnal range for the study region for the period from 1957 to 2008 is 12.6°C (Figure 15). The diurnal range varies between 9.0°C and 17.1°C during this time period. An observable increasing linear trend of approximately 0.6°C is evident although this trend is not statistically significant. Globally, diurnal temperature ranges have reportedly decreased over the last half century (Englehart and Douglas 2005). The regional increase observed here indicates that maximum temperatures are warming at a faster rate than minimum temperatures.

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## CONTINENTALITY

Continentality is a measure obtained by subtracting the mean temperature of the coldest month (July) from the mean temperature of the warmest month (January). Continentality for the study region for the period from 1957 to 2007 averages 11.0°C and ranges between 8.8°C and 12.8°C (Figure 16). An observable decreasing linear trend of 0.8°C is evident however this trend is not statistically significant. This change is a result of July temperatures warming at a higher rate than January temperatures (1.74°C increase over the time period versus 0.9°C increase).

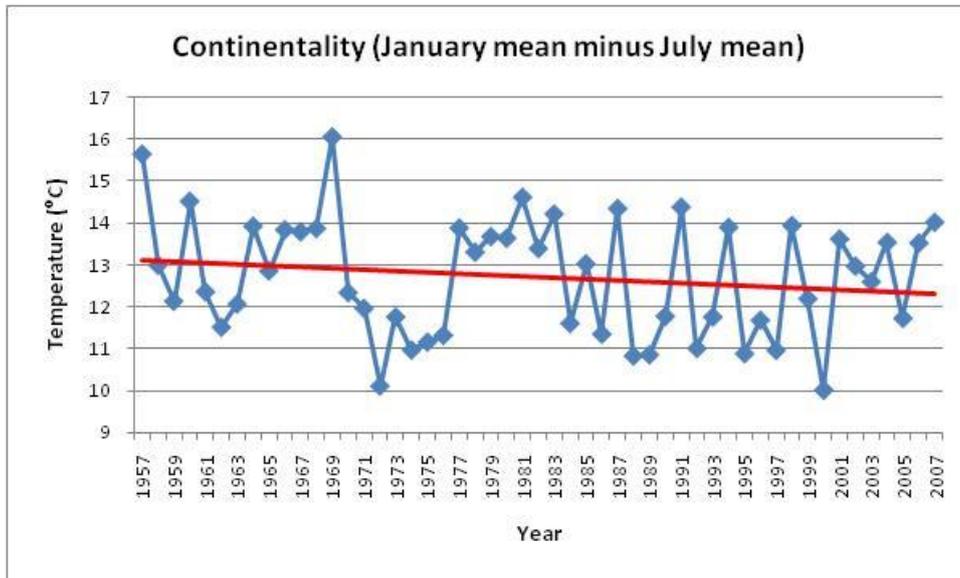


Figure 16 - Continentality (January mean minus July mean 1957 - 2007)

## FROSTS

Frosts were identified as a climate change concern by stakeholders albeit of a lower priority than other climate issues. Two degrees Celsius were added to frost threshold values to account for temperature recording platforms mounted above ground level. A threshold value of  $-6^{\circ}\text{C}$  (adjusted to  $-4^{\circ}\text{C}$ ) was identified by stakeholders for extreme frost events however they were not assessed due to lack of data (only one day during the period from 1957 to 2007 met this threshold). Frosts occurring during the growing season (September through to March) were also not assessed for change over time due to lack of data points. In all, only 28 frost days occurred during the growing seasons from 1957 to 2007, with each year receiving 0 to 5 spring frosts.

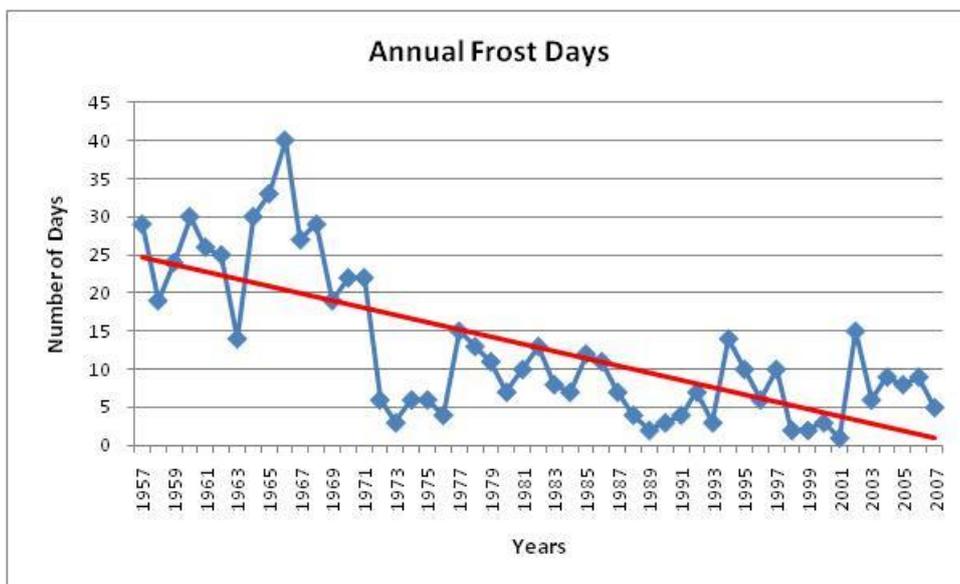


Figure 17 - Annual frost days (1957-2007)

Frost days were identified from daily minimum temperatures equal to or below 2°C. The number of frost days occurring per annum for the period from 1957 to 2007 is shown in Figure 17. An observable and statistically significant decreasing linear trend in the frequency of occurrence of frost days is evident. Although a linear trend line has been fitted to the data, observation suggests two distinct cycles, with the period from 1957 to 1971 experiencing more frost days on average than the period from 1972 to 2007.

This trend is particularly evident when considering the frequency of occurrence of spring frost days from 1957-2007 (Figure 18). Since 1971, only four years (1984, 1994, 1995 and 2004) have recorded frost days in the study region. Obviously localised frost hollows exist and establishing a relationship between a BOM recording station and a local site may provide additional data for analysis. For example, if minimum temperatures are known to be 4 degrees colder than the recorded BOM temperature at a particular vineyard, adjusted minimum temperature thresholds for frost could be applied.

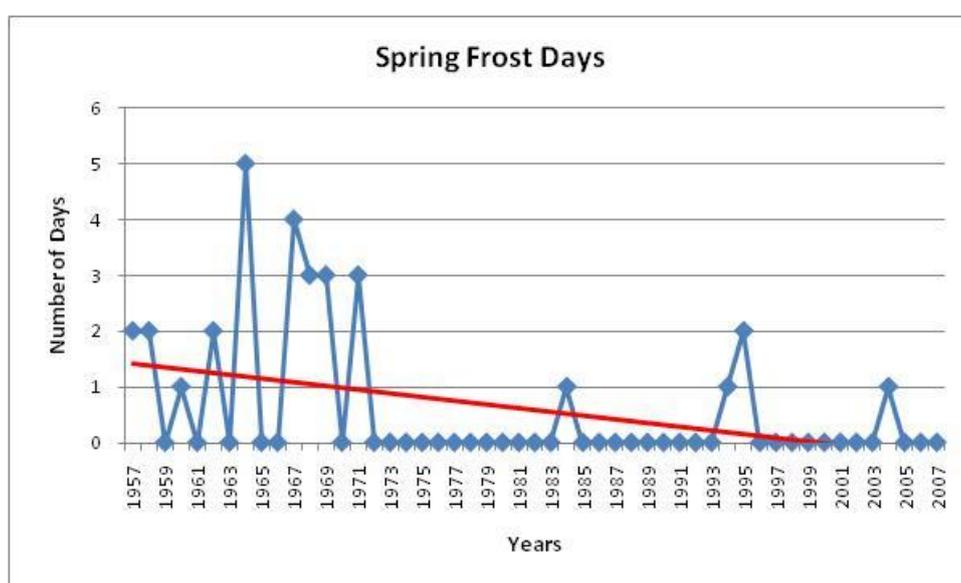


Figure 18 - Spring frost days (1957-2007)

## DAILY PAN EVAPORATION

Average seasonal daily pan evaporation for the study region for the period from 1970 to 2007 is shown in Figure 19. Decreasing linear trends are evident in all seasons, with autumn, winter and spring decreases statistically significant. A decrease of 0.5mm/24hr is recorded for summer. Decreases of 1mm/24hr are recorded for autumn and winter and 0.8mm/24hr for spring.

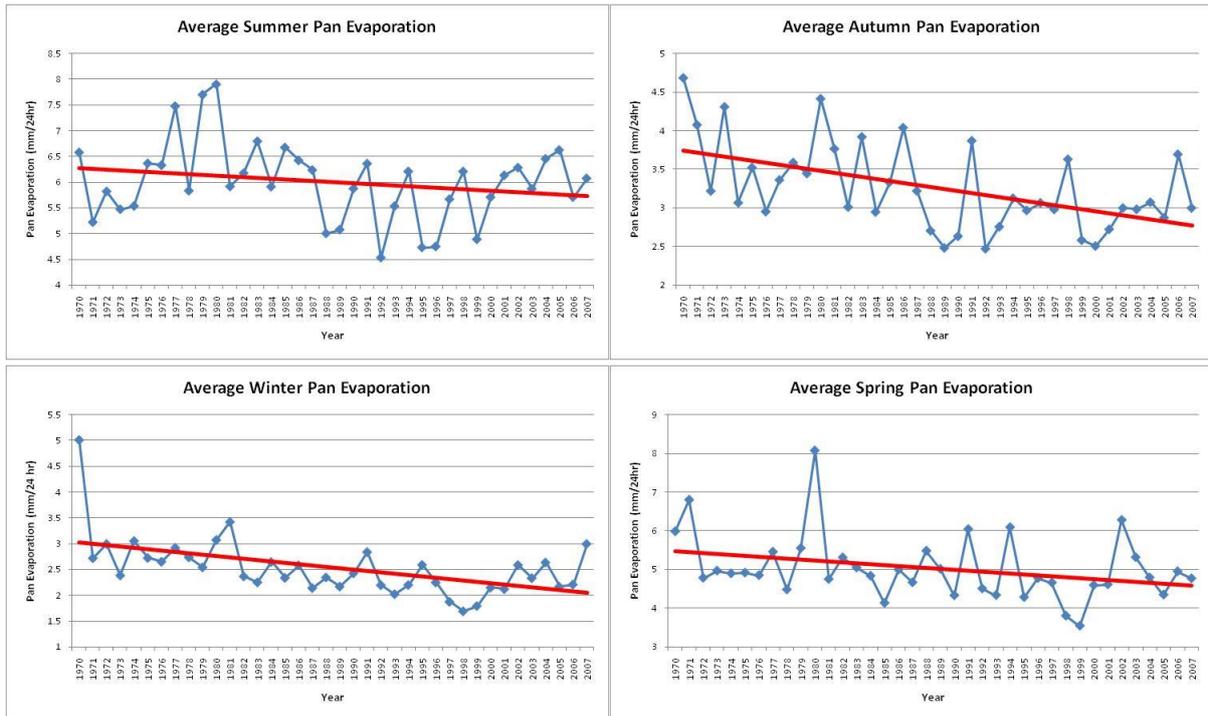


Figure 19 - Average seasonal pan evaporation (1970-2007)

## HUMIDITY

Average annual 9am and 3pm humidity for the period from 1973 to 2007 is shown in Figure 20. A decrease of approximately 2.2% in 9am humidity and an increase of approximately 5.5% in 3pm humidity over this period is evident. These decreasing linear trends in 9am humidity are not statistically significant, however the increasing trend in 3pm humidity is significant (P=0.0).

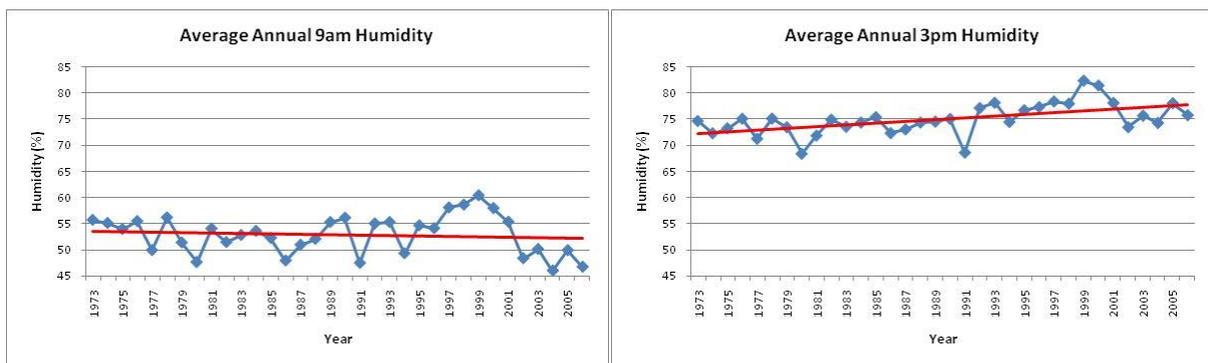


Figure 20 - Average annual 9am and 3pm humidity (1973-2007)

## WATER BALANCE

Simple water balance for the region is calculated by subtracting the average daily pan evaporation (mm/24hr) from the average daily precipitation for each season. Annual average water balance for the study region, calculated from simple water balance, for each season for the period from 1970 to 2008 is shown in Figure 21.

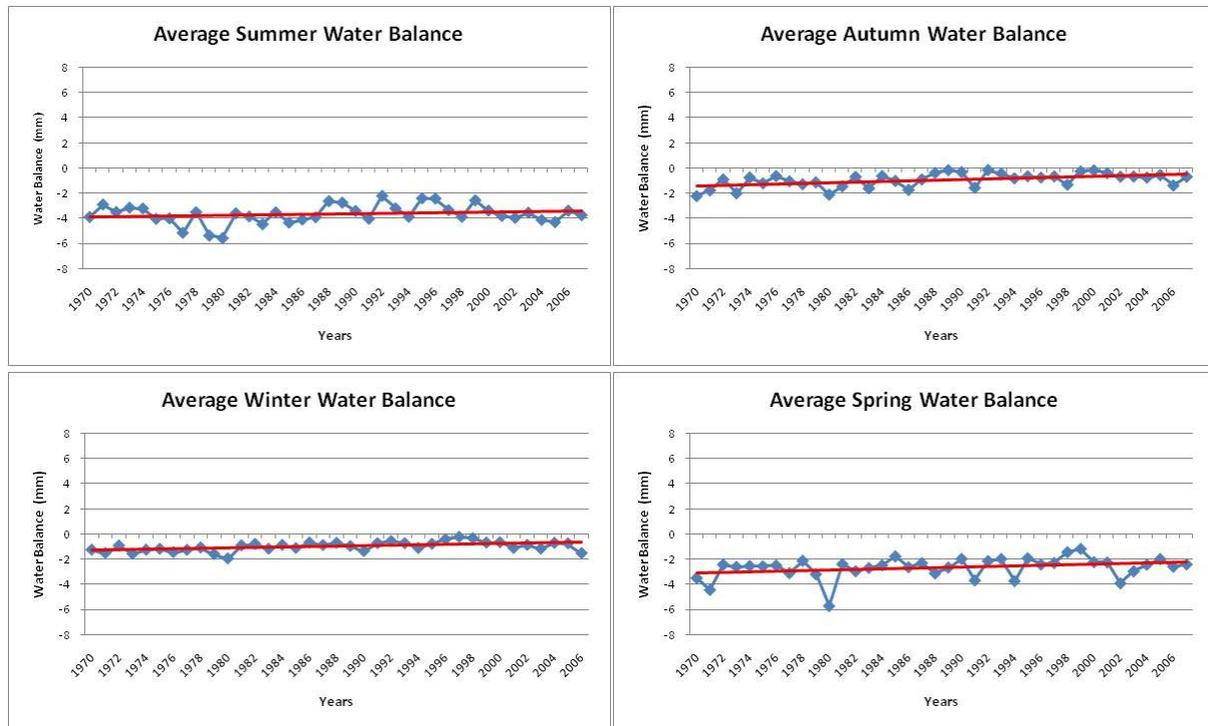
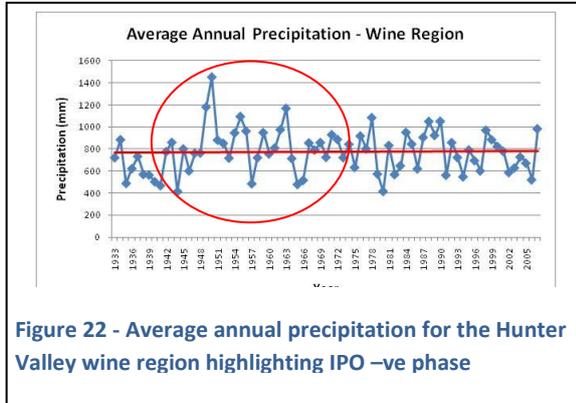


Figure 21 - Average Seasonal Water Balance (1970-2007)

Historical records indicate a negative water balance exists in each season. The largest negative water balance occurs during summer; this season together with spring appears most variable. Increases of 0.5mm in summer, 0.95mm in autumn, 0.6mm in winter and 0.9mm in spring are evident. The linear trends in autumn and winter are statistically significant (i.e.  $P < 0.05$ ).

## PROJECTED CHANGES IN CLIMATE

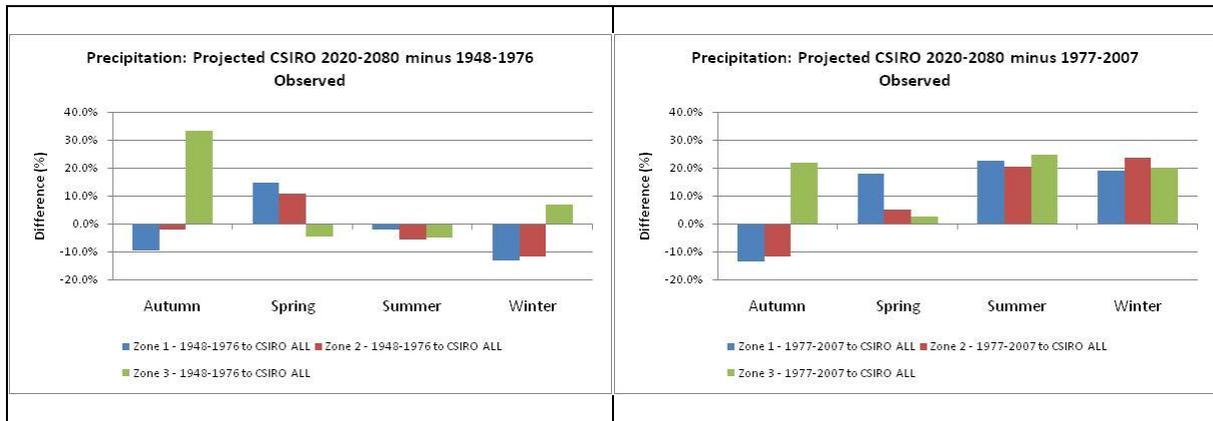
### PRECIPITATION PROJECTIONS



Historical records for the study region show no trend in average annual precipitation for the period from 1933 to 2007. However analysis of CSIRO Mk3.5 global climate model data shows some seasonal and zonal changes in precipitation are projected.

Although no regional increase in precipitation is projected for the period from 2020-2080, a return to precipitation patterns similar to those experienced during the 1948-1977 IPO period (La Nina like –ve phase) is projected. Precipitation during this period was more variable than that experienced during the latter +ve phase (1977-2007) (see Figure 22).

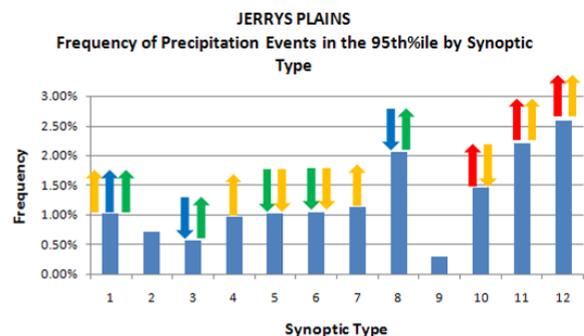
Some seasonal shifts in precipitation are also projected, with decreases of approximately 12.5% for the coastal and central zones during winter and increases of approximately 13% in these zones during spring (Figure 23). A significant 33% increase in autumn rainfall in the western zone (within which the Hunter Wine Growing region is primarily located) is also projected.



**Figure 23 - Estimates of projected precipitation shifts relative to the 1948-1976 and 1977-2007 epochs**

Summer and autumn synoptic patterns associated with high rainfall events (i.e. rainfall in the 95<sup>th</sup>ile) in the wine growing region are projected to increase during the period from 2020-2080. This suggests an increase in the frequency of occurrence of high rainfall events in summer and autumn is likely to occur. Changes in the frequency of a synoptic pattern associated with high rainfall events in winter and spring are also projected.

These include a decrease in frequency during winter and increases during spring, indicating a corresponding shift to



**Figure 24 - Shifting synoptic patterns associated with high rainfall events at Jerrys Plains**

occur in high rainfall events. An example of these shifting synoptic patterns is provided in Figure 24. Coloured arrows indicate the direction of seasonal shifts (i.e. red = summer, yellow = autumn, blue = winter and green = spring). The frequency of shifts is reported as a proportion.

## TEMPERATURE PROJECTIONS

The Hunter Valley wine region is located in both the western and central climatic zones and thus projected changes in minimum temperature for both of these zones will affect the study region (Figure 25). Minimum temperatures in the wine region are projected to be warmer, particularly in the west of the region. Projections (2020-2080) in the central zone for summer are for decreases in average minimum temperature of  $\sim 0.8^{\circ}\text{C}$  relative to the 1970-2007 period. A significant increase of  $\sim 4.2^{\circ}\text{C}$  in average minimum temperature for summer is projected in the western zone. Increases in all zones are projected for autumn;  $\sim 1.4^{\circ}\text{C}$  in the central zone and again a significant  $\sim 4.8^{\circ}\text{C}$  in the western zone. Winter projections are for warmer average minimum temperatures in the central zone ( $\sim 1.2^{\circ}\text{C}$ ) and lower temperatures in the western zone ( $\sim 0.8^{\circ}\text{C}$ ). The region is likely to experience lower average spring minimum temperatures with a decrease of  $\sim 0.2^{\circ}\text{C}$  projected for the central zone, and  $\sim 1.2^{\circ}\text{C}$  in the western zone.

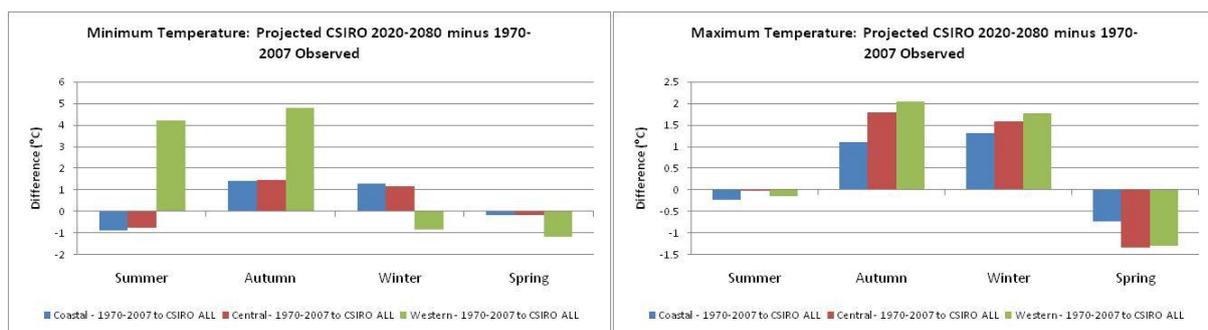


Figure 25 - Estimates of projected minimum and maximum temperature shifts ( $^{\circ}\text{C}$ ) relative to the 1970-2007 period

The most significant changes in average maximum temperatures are projected to occur during autumn and winter in the region. Projections (2020-2080) in the western zone for summer are for decreases in average maximum temperature of  $\sim 0.2^{\circ}\text{C}$  relative to the 1970-2007 period (Figure 25). No change for summer is projected in the central zone. Increases in all zones are projected for autumn;  $\sim 1.8^{\circ}\text{C}$  in the central zone and  $\sim 2.0^{\circ}\text{C}$  in the western zone. Winter projections are for warmer average maximum temperatures,  $\sim 1.6^{\circ}\text{C}$  in the central zone and  $\sim 1.8^{\circ}\text{C}$  in the western zone. The region is likely to experience lower spring average maximum temperatures with a decrease of  $\sim 1.3^{\circ}\text{C}$  in the central and western zones.

## PROJECTED IMPACTS ON KEY CLIMATE ISSUES / INDICES

Stakeholder consultation and scientific review identified a number of key climate issues and indicators of relevance to the viticulture industry with the potential to be affected by climate change. The impacts of projected changes in climate on each of these issues/indicators are outlined in the following table.

Issue / Indicator	Projected Change
<b>Extreme Heat Events</b>	Although no trend in extreme heat days (EHDs) is evident from the historical data, analysis of projected data indicates increases are likely to occur in the region. A clear relationship between synoptic patterns and extreme heat days (EHDs) exists. This relationship is strongest in the west of the Hunter region where ~72% of all EHDs (daily temperature greater than or equal to 38°C) occur under the dominant monthly synoptic pattern (ST12). Projected increases in this synoptic pattern during summer and autumn are likely to result in increased frequency of EHDs in the wine region during the period from 2020-2080.
<b>Heat Degree Days</b>	Increases in the mean daily temperature are likely to continue following the statistically significant trend observed from 1958-2008. Increases are likely to occur as a result of the projected increases in both average minimum and maximum temperatures.
<b>Mean January temperature</b>	Historical records show an increase in mean January temperature (MJT) of 0.8°C which is not statistically significant. Projections for summer are for a significant increase of ~4.2°C in average minimum temperature in the western zone and slight decreases in the central and coastal zones. A slight increase in average summer maximum temperature (~0.2°C) is projected in the western zone with no change to occur in the central zone. Given that the study region lies predominantly within the western zone, increases in MJT are likely to continue, driven primarily by increases occurring in minimum temperatures.
<b>Winter Minimum Temperature</b>	Historical records show a statistically significant increase in winter minimum temperature of 1.7°C over the period from 1957-2007. As previously discussed, a significant increase in average minimum temperature of ~4.2°C in the western zone is projected for the period from 2020-2080. Thus recorded increases are likely to continue.
<b>Harvest Maximum Temperature</b>	Given minimal projected changes in average summer maximum temperature, no significant change in harvest maximum temperature is projected to occur.
<b>Diurnal Range</b>	The diurnal range is obtained by subtracting the daily minimum temperature from the daily maximum temperature. These daily values are then averaged to obtain a

	<p>mean diurnal range. In this case study, the mean diurnal range is calculated for January following the work of Webb et al. (2005). Given that monthly data has been used from the GCM output, meaningful analysis of projected changes in the January diurnal range is not possible. Projected changes in the summer average minimum and maximum temperature suggests a slight increasing linear trend is likely to continue.</p>
<b>Continentality</b>	<p>Higher increases in average minimum and maximum temperature are projected to occur in winter rather than summer. On this basis, the decreasing linear trend in continentalty observed from historical records (<math>\sim 0.8^{\circ}\text{C}</math>) is likely to continue.</p>
<b>Frost</b>	<p>An observable historical and statistically significant decreasing linear trend in the frequency of occurrence of frost days is evident. Although a linear trend line has been fitted to the data, observation suggests two distinct cycles (see Figure 17), with the period from 1957 to 1971 experiencing more frost days on average than the period from 1972 to 2007. Winter projections suggest minimal change is expected during this season. However projected increases in the frequency of occurrence of synoptic patterns associated with frost events in spring are likely to see an increase in the frequency of minimum temperature events (<math>\leq 0^{\circ}\text{C}</math>) during this season. Similar changes are also likely to produce an increase in minimum temperature events (<math>\leq 0^{\circ}\text{C}</math>) in the projected period (2020-2080) during autumn.</p>
<b>QLD Fruit Fly</b>	<p>Projected increases in temperature within the bounds identified in the IPCC (2007b) assessment report are likely to impact on the range of QLD Fruit Fly. Increased frost incidence may impact on this species mortality rates and thus further analysis is required to fully qualify the potential climate change impacts on QLD Fruit Fly infestations in the study region.</p>

**Table 5 - Projected climate change impacts on viticulture issues/indicators**

## ASSESSING RISK TO THE HUNTER VALLEY WINE INDUSTRY

In addition to providing an analysis of historic and projected climate change as it relates to the Hunter Valley Wine Industry, this Case Study also aims to demonstrate the applicability of this climate data to industry risk assessment and adaptation planning processes. For this purpose, a broad scale industry risk assessment process has been completed and is documented below. This process was completed collaboratively by representatives of the Hunter Valley Wine Industry Association, Industry and Investment NSW and HCCREMS staff. The level of risk identified relates to the likelihood and consequences of the identified impact occurring given the projected change in climate.

The Risk Assessment Framework used as the basis for this process is included in Figure 26. The climate data and indices that have informed the assessment of risk, the potential impacts arising from changes in these indices, and the potential adaptation strategies identified for managing such impacts are included in Table 6. The risk assessment process that has been applied is consistent with that included in *'Climate Change Impacts and Risk Management: A Guide for Business & Government, Commonwealth of Australia 2006'*.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium

Figure 26 - Risk Assessment Matrix (source: Commonwealth of Australia 2006. *Climate Change Impacts and Risk Management: A Guide for Business & Government*).

**NB When determining the Consequence ratings during the risk assessment process, it was assumed that no current management practices are in place.**

Risk priority levels have been interpreted as the following:

**Extreme** risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without executive sanction.

**High** risks are the most severe that can be accepted as a part of routine operations without executive sanction but they will be the responsibility of the most senior operational management and reported upon at the executive level.

**Medium** risks can be expected to form part of routine operations but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at senior management level.

**Low** risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe.

TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
Extreme Heat Events (38°C or greater)	<p><u>Historical trend</u> No trend in extreme heat days (EHDs) is evident.</p> <p><u>Projected change</u> Increased frequency (~1%) of EHDs in the wine region during the period from 2020-2080.</p>	Leaf burn on vines (Report by the Grape and Wine Research and Development Corporation (Australian Government 2008) identifies Semillon can be used as a guide for assessing heat impacts due to its relatively low heat tolerance. The report identifies that leaf burn becomes evident at 38°C).	Almost Certain	Major	Extreme	<p>Leaf loss / sunburn of fruit</p> <p>Increased difficulty in harvesting and processing fruit</p> <p>Chemical and physical changes in fruit composition</p> <p>Increased water usage by vines</p>	<p>While EHD's are not predicted to significantly increase in frequency, they will remain an ongoing management issue requiring implementation of best practice management approaches including:</p> <ul style="list-style-type: none"> <li>• Site selection / row orientation to influence microclimate (ie decrease exposure to afternoon sun and maximise breezes)</li> <li>• Mulching</li> <li>• Water use efficiency and maintaining security of water supply</li> <li>• Research and application of anti stress agents / strategies for reducing exposure / damage and to decrease leaf transpiration rates.</li> </ul>
Heat Degree Days	<p><u>Historical trend</u> Statistically significant increasing trend in HDD for the study region. A total 152.58°C (approximately 3°C per year) increase in the HDD</p>	Condensed growing season	Likely	Moderate	High	<p>Potential changes to fruit composition</p> <p>Increased management and resource inputs required to maintain appropriate fruit composition</p> <p>Increased stress on harvest and wine making infrastructure</p>	<p>Wine maker consultation and education to enhance understanding of the potential risks and opportunities of a condensed growing season on grape production and winemaking practices (eg in relation to fruit ripening patterns and infrastructure needs).</p> <p>Potential need for greater infrastructure</p>
		Condensed ripening period	Likely	Moderate	High		

TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
	<p>summation was recorded from 1957 to 2008.</p> <p><u>Projected Change</u></p> <p>Increases in the mean daily temperature likely to continue following the historical statistically significant trend</p> <p>Increases likely to result due to projected increases in both average minimum and maximum temperatures.</p> <p>Autumn and winter increases will be most significant.</p>	Shift in growing seasons	Likely	Moderate	High	<p>Potential for increased damage from frosts where growing season commences earlier.</p> <p>Longer post harvest period and management of vines required where growing season extends later into Autumn.</p>	<p>in winemaking processes to increase throughput within a more condensed period</p> <p>Implementation of existing best practice management approaches to vineyard site selection and vine management practices to reduce potential impacts of frost (earlier growing season) or extended post harvest period (later growing season).</p> <p>More information / research needed to identify potential impacts of change. The focus of this research should include:</p> <ul style="list-style-type: none"> <li>• identification and analysis of alternative grape varieties and propagation materials; and</li> <li>• quantifying impacts of shifts in growing seasons on wine production, thereby evaluating current perceptions in regard to potential impacts.</li> </ul>
Mean January temperature (MJT)	<p><u>Historical trend</u></p> <p>Increase in MJT of 0.8°C (not</p>	Changes in fruit (grape) acidity	Possible	Moderate	Medium	Changes in fruit composition	Explore potential for staggering harvest dates

TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
	<p>statistically significant).  <u>Projected change</u>                      Increases in MJT are likely to continue, driven primarily by increases occurring in summer minimum temperatures.                      Projected changes in average minimum temperature in the region include a significant increase of ~4.2°C in the western zone and slight decreases in the central and coastal zones in summer.</p>	Changes to harvest date	Possible	Moderate	Medium	Increased management and resource inputs required to maintain appropriate fruit composition Potentially increased stress on harvest and wine making infrastructure	
		Increases in overnight minimum temperature have potential to increase amount of pest and diseases (eg fruit fly & bacteria)	Possible	Major	High	Crop loss and spoilage Additional management resources and viticultural inputs required for pest monitoring and management.	Increase level of pest monitoring and management programs
Winter Minimum Temperature	<p><u>Historical trend</u>                      Statistically significant increase in winter minimum temperature of 1.7°C over the period from 1957-2007.  <u>Projected change</u>                      Warmer, increase of ~0.3°C</p>	Vines going into dormancy later in the season	Likely	Moderate	High	Timing of pruning would be delayed due to deferred leaf loss Increased capacity for vines to carry disease later in the season Longer post harvest period requires increase in management resources and viticultural inputs.	Pruning later in the season Mulching to reduce soil temperature and increase moisture content. More research & information needed in this particular area. Changes to selection of propagation materials and varieties
		Erratic bud burst	Possible	Moderate	Medium	Earlier bud burst leading to greater potential for frost damage Variation in fruit composition within a vine	

TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
		Reducing chilling hours	Possible	Major	High	Changes in carbohydrate storage levels Changes in fruit composition	
Harvest Maximum Temperature (HMT)	<p><u>Historical trend</u> Average HMT for DJFM ranges between 26.6°C and 32.5°C with an average of 29.0°C recorded in the study region from 1957 to 2008. Observable increasing linear trend of approximately 0.5°C is evident; however this trend is not statistically significant. The average for the JF harvest period is slightly lower at 28.3°C and no trend is evident.</p> <p><u>Projected change</u> Given minimal projected changes in average summer maximum temperature, no significant change in harvest maximum temperature is projected to occur.</p>	In light of no historical or projected trend being identified for this parameter, no risk assessment has been completed.					

TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
Diurnal Range	<p><u>Historical trend</u> The mean January diurnal range (1957 to 2008) is 12.6°C, and varies between 9.0°C and 17.1°C.</p> <p>An observable increasing linear trend of approximately 0.6°C is evident although not statistically significant. Indicates that maximum temperatures are warming at a faster rate than minimum temperatures.</p> <p><u>Projected change</u> Projected changes in the summer average minimum and maximum temperature suggests a slight increasing linear trend is likely to continue.</p>	Changes in fruit composition	Likely	Moderate	High	Increased management and resource inputs required to maintain appropriate fruit composition	<p>Explore potential for staggering harvest dates</p> <p>Changes to selection of propagation materials and varieties</p> <p>More information / research needed to identify:</p> <ul style="list-style-type: none"> <li>• potential alternative grape varieties and propagation materials; and</li> <li>• quantitative impacts of shifts in growing seasons on wine production.</li> </ul> <p>Increase level of pest monitoring and management programs.</p>
		Changes to harvest date	Possible	Moderate	Medium	Increased management and resource inputs required to maintain appropriate fruit composition Potentially increased stress on harvest and wine making infrastructure	
		Increases in overnight minimum temperatures have potential to increase amount of pest and diseases (eg fruit fly & bacteria)	Possible	Major	High	Crop loss and spoilage Additional management resources and viticultural inputs required for pest monitoring and management	
Frost	<p><u>Historical trend</u> An observable statistically significant decreasing linear trend in the frequency of occurrence of frost days is</p>	Increased incidence of frosts in Spring	Likely	Major	High	Crop loss and vine damage Growers who have entered the industry since 1970's will not have experienced conditions of high frost frequency. These growers	<p>Critical factor to be included in selection and design of new blocks</p> <p>Changes to selection of propagation materials and varieties</p> <p>Encourage implementation of best</p>

**TABLE 6 – CLIMATE CHANGE RISK ASSESSMENT AND ADAPTATION PLANNING OUTCOMES – HUNTER VALLEY WINE INDUSTRY**

Issue / Indicator	Historical & Projected Climate Change	Potential Impacts	Risk Assessment			Nature of Consequences	Potential Adaptation Strategies
			Likelihood	Consequences	Risk Priority		
	<p>evident.                      Observation suggests two distinct cycles, with the period from 1957 to 1971 experiencing more frost days on average than the period from 1972 to 2007.  <u>Projected changes</u>                      Minimal change expected during winter                      Increased frequency of frost events during autumn and spring</p>					<p>may not be adequately experienced / prepared for increased incidence of frost events occurring during Spring.</p>	<p>management cultural practice in both new and existing vineyards to reduce frost impacts occurring, and to maintain viability of vines that do become damaged from frost events.                      Research and application of anti stress agents / strategies for reducing exposure / damage.                      Capital investment in frost abatement techniques (eg fans, sprinklers)                      Awareness raising – collate existing information to include in a Frost Information Package for growers.</p>

**Table 6 - Climate change risk assessment outcomes : Hunter Valley Wine Industry**

## CONCLUSIONS

### CLIMATE ANALYSIS

Historical records indicate some statistically significant trends in key climate variables (Table 7). Heat degree days (summation), winter minimum temperatures and average annual 3pm humidity have recorded increases. Decreases in annual frost days and daily pan evaporation in winter and spring are also evident.

Climate Variable/Indicator	Historical Trend	Amount
Heat degree days (summation)	Increasing	~3°C per annum from 1958-2008
Winter minimum temperature	Increasing	~1.7°C from 1957-2007
Annual frost days*	Decreasing	~24 days between 1957-2007
Daily Pan Evaporation (winter and spring)	Decreasing	~1mm/24hr for winter, ~0.8mm/24hr for spring from 1970-2007
Average annual 3pm humidity	Increasing	~5.5% from 1973-2007

**Table 7 - Statistically significant trends in historical data from key climate variables/indicators**

\* Although a statistically significant decreasing linear trend is evident, two distinct cycles are present. The average frost days per annum for the period from 1957-1971 is ~26 whereas the latter period from 1972-2007 records only ~7 frost days per annum.

Changes in key climate variables are projected for the climate zones covering the Hunter Valley wine growing region (Table 8). A return to precipitation patterns similar to those experienced during the 1948-2007 period indicates increasing variability and thus high rainfall events are also likely to increase. Overall increases in minimum and maximum temperatures are projected however some seasonal decreases are also likely.

Climate Variable	Change
<b>Precipitation</b>	No trend however a return to precipitation patterns experienced during the 1948-1976 period is projected
<b>High rainfall events</b>	Increases during summer, autumn and winter. Decrease during spring.
<b>Minimum temperature</b>	Increases during summer, autumn and winter and a decrease during spring in the western zone Increases during autumn and winter and decreases during summer and spring in the central zone
<b>Maximum temperature</b>	Decrease during summer and spring and increases during winter and autumn

**Table 8 - Summary of projected climate changes**

## ASSESSMENT OF CLIMATE RISK

Identification of the historical changes in key climate variables and indices relevant to the viticulture industry, together with the projected changes in these parameters, has provided the basis for a broad scale assessment of risks for the Hunter Valley Wine Industry, and the identification of potential adaptation strategies in response to these.

The key findings of this process include:

- The most extreme level of risk identified is associated with the potential for increased extreme heat events to impact on fruit health and composition, harvesting and processing activities and water use efficiency. However, given the industry's already significant experience with and preparedness for events of this nature, and the relatively small projected increase in the frequency of such events, the continued implementation of existing best practice management techniques is considered adequate for the ongoing and effective management of this risk.
- Projected increases in winter minimum temperature and its potential impact on reducing chilling hours and increasing the prevalence of pest and diseases were identified as potentially major risks. Reduced chilling hours have the potential to cause changes in carbohydrate storage levels and fruit composition, while crop loss and spoilage can result from the increased prevalence of pests and disease. Potential adaptation strategies identified to manage these impacts include changes to vine management practices and the selection of propagation materials and varieties, along with increased levels of pest monitoring and management programs.
- Projected increases in the incidence of spring frosts were also identified as a potentially major risk due to potential crop loss and vine damage. Potential adaptation strategies identified include ensuring appropriate site selection and design of new vineyards, changes to the selection of propagation materials and varieties, implementation of best practice cultural practices, research into and application of anti stress agents, and investment in frost abatement technologies.
- High levels of risk were identified in association with increases in the level of heat degree days, winter minimum temperatures and diurnal range. There is potential for projected changes in these indices to influence fruit composition, condense growing seasons, increase crop loss and spoilage and defer the timing of annual pruning practices. Potential adaptation strategies identified include wine maker education and consultation to improve understanding of the potential risks and opportunities arising from condensed growing seasons, potential increases in winemaking infrastructure to increase throughput, and continued implementation of best practice management approaches to vineyard site selection and vine management practices.

Increases in these temperature related indices were also identified as having the potential to result in vines entering dormancy later in the season, and to cause erratic bud burst and changes to fruit composition and harvest dates. These were considered moderate level risks that would be addressed by the previously identified adaptation strategies relating to these indices.

The risk assessment and adaptation planning process that is documented in this case study provides an overall evaluation and prioritisation of the significance of the likely impacts of projected climate change on the Hunter Valley Wine Industry. Current best management practices already in place by the industry in response to an historically variable climate mean that it is already well placed to deal with some of these risks. In these circumstances the results of the analysis validate current practices and highlight the need to continue their implementation. They also highlight the need to educate new and existing industry members on their

importance. For other risks, implementation of the adaptation strategies identified may need to be integrated into future industry management and production practices.

In other instances, the potential impacts of climate change, and the nature of consequences, are not fully understood. In these instances, potential adaptation strategies include future research to further understand the potential impacts of climate change. For example, projected increases in the diurnal range in the wine growing region results in a requirement for additional information/research to explore potential alternative grape varieties and propagation materials and to quantify impacts of shifts in growing seasons on wine production.

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