Understanding and managing the risks and opportunities from climate change on Cherry production.

Dane Thomas, Peter Hayman, Paul James

This project is supported by funding from the Australian Government Department of Agriculture, Fisheries and Forestry under FarmReady, part of Australia's Farming Future.

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CHERRY GROWERS AUSTRALIA INC

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Summary

This project focuses on managing weather and climate risks to cherry production in a warming climate. We held a series of meetings were risks from weather and climate where identified by cherry growers. Some of these risks were due to single weather events such as rain at harvest, frost, hail or heatwaves or weather events over weeks such as conditions for pollination. There are other risks such as winter drought or chill accumulation in winter or heat accumulation in summer that are due to seasonal conditions.

We used a cherry phenological calendar to show when the risks may impact the orchard. We then analysed the risks using historic weather and climate information for 25 cherry producing locations in Australia. This provided the current risk level.

To understand how the risk may change in a warmer climate we analysed the risk if the climate was 0.5, 1.0, 1.5 or 2.0°C warmer or 10% drier. These temperature increases are within expected ranges by 2050 for many parts of Australia although it is expected that mean temperature in coastal mainland locations and Tasmania will increase less than inland locations. We then provide some options that could be used by cherry growers to reduce the impact of increased risks from climate change.

It is conceivable that cherry producers could use a ‘space as a proxy for time’ approach when treating the risks of a warmer climate. That is, examine how risks are managed by cherry producers in a location warmer or drier than yours currently is. This approach is likely to be a useful first step in identifying options for managing risks for many locations. This is because the 25 cherry producing locations we examined had mean summer temperature ranging from 15 to 25°C, and mean winter temperature ranging from 5 to 12°C, which for many locations allows for the identification and examination of a warmer location. However this approach should be treated with some caution as production of high quality cherries requires several climatic conditions to be met or managed, not just mean summer and winter temperature.

Our findings were:

Locations with warmer winter temperatures are more likely to have less chill accumulation. Insufficient chill accumulation can result in physiological damage to trees including non-synchronous bud burst and flowering. Chill accumulation declines dramatically when mean winter temperature is warmer than 9°C. **The risk of insufficient chill accumulation is addressed in risk 1 – page 19**

Locations with warmer summer temperature have higher heat accumulation and faster crop development. Heat accumulation after harvest can affect the following years' crop. A major impact of a warmer climate is likely to be faster crop development, affecting all phenological stages and changing the time of harvest. **The risk of higher heat accumulation is addressed in risk 2 – page 28.**

Locations with warmer summer temperature are more likely to have temperatures that are too high for pollination, while locations with cooler temperature in winter or summer are likely to have temperature too cold for pollination. Warming reduces the risk of temperatures being too cold, but increases the risk of temperatures being too hot. **The risk of temperatures being too cold or too hot for pollination are addressed in risk 3 – page 36.**

Locations with a warm mean summer temperature are subject to heatwaves. The risk of heatwaves increases dramatically when mean summer temperature is warmer than 20°C. The Queensland locations are somewhat unusual in that they have high mean summer temperature but low risk of heatwaves. Risks of heatwaves increases in a warmer climate. **The risk of heatwaves is addressed in risk 4 – page 42.**

The locations with cool winter temperatures are more likely to have higher frost risk. Temperatures likely to cause frost may be rarer in a warmer climate, but faster plant development could negate this positive effect by shifting critical stages of plant development to colder parts of the year. **The risk of frost is addressed in risk 5 – page 49.**

Cherry producing locations cover a large range of rainfall zones with considerable seasonal variability. Climate science has less certainty on impacts on rainfall so the risk of insufficient rain for irrigation as a consequence of climate change is difficult to measure. **The risk of insufficient rain for irrigation is addressed in risk 6 – page 58.**

The seasonality of rainfall contributes to the risk of rainfall near harvest. Rain near harvest is detrimental to cherry production as it is associated with fruit 'cracking'. Fruit cracking is also affected by management practices. We used several metrics to assess the chance of fruit being wet. Generally locations with cooler summer temperature have greater risk of wet fruit. Climate science has less certainty on changes to rainfall so how the risk of wet fruit may be impacted is difficult to measure. **The risk of rain near harvest is addressed in risk 7 – page 62.**

Risks of wind and hail are addressed on page 68 and page 69 respectively.

Introduction

Growing high quality cherries is risky and weather is a major source of risk. Of course there are other sources of risk such as marketing and prices, bio-security and government policies. This project focuses on managing weather and climate risks.

Figure 1 shows a generic framework for risk management used by the Australian Department of Climate Change developed by the Australia New Zealand Standard AS/NZS 4360. This has been used by the Australian Department of Climate Change and follows the logic of establishing the context, identifying, analysing and evaluating the risks before considering ways to treat the risk.

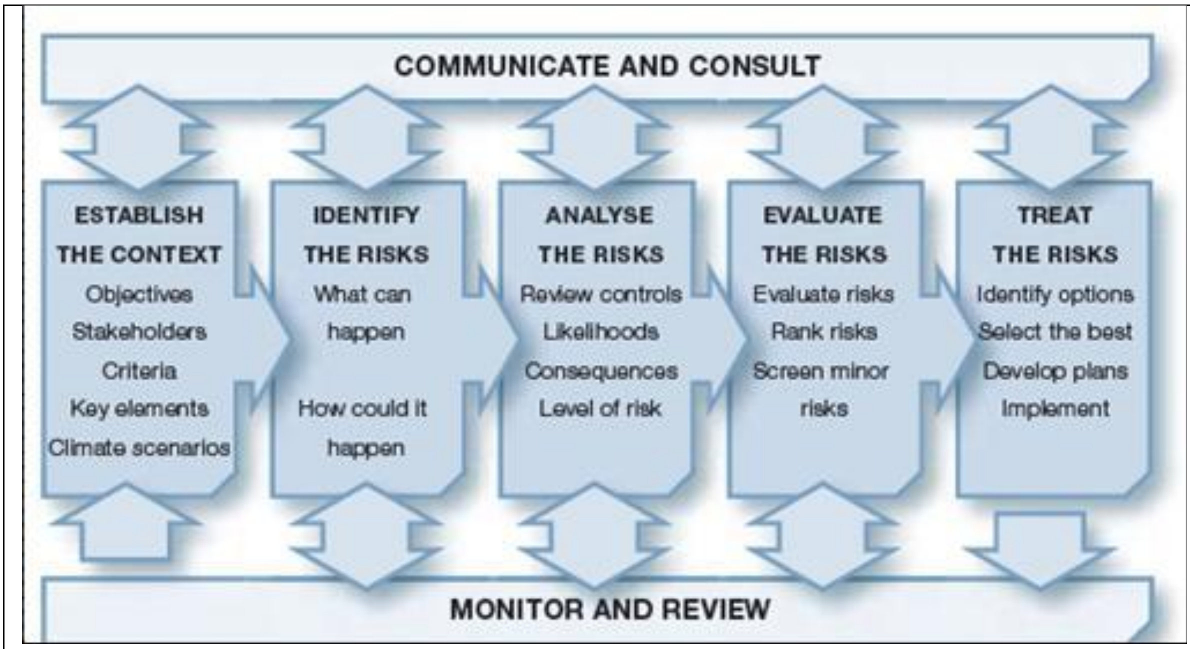


Figure 1. Risk Management Framework. Australia New Zealand Standard AS/NZS 4360

To establish the context and identify the risks we held a series of meetings with cherry growers including a survey at the annual conference in 2010. From these meetings, the main risks were identified as follows:

1. *Insufficient chill accumulation*
2. *Heat accumulation hastening development possibly leading to crop maturing at less desirable times*
3. *Temperatures being too hot or too cold for effective pollination*
4. *Heatwaves affecting crop growth*
5. *Frost damage*
6. *Insufficient rain or irrigation water for growth*
7. *Rainy days near harvesting leading to fruit spoilage (cracking)*
8. *Wind damage to trees and flowers*
9. *Hail damage to trees, flowers and fruit*

Some of these risks are due to single weather events (eg rain at harvest, frost, hail or heatwaves) or weather events over weeks such as conditions for pollination. There are other risks such as winter drought or chill accumulation in winter or heat accumulation in summer that are due to seasonal conditions. Not surprisingly, different regions have varying ranks in terms of the likelihood of these risks and the consequences on high quality cherry production. In general terms cooler regions were unconcerned with chilling and heatwaves but more concerned with frost and temperatures being too cold for pollination. Warmer locations had the opposite concerns such as insufficient chilling, heatwaves and temperatures too hot for pollination. In some regions the dominant concern was winter drought and access to irrigation water, this last risk highlights the complex interaction between climate risk and policy risk.

This toolkit addresses the nine risks listed above. Each risk is identified and placed in context by defining the risk in biological and climate terms. We then present a summary of our analysis and evaluation of the risk for 25 locations before discussing how the risk can be treated. We are asking what methods are available to manage cherry orchards for the variability experienced in the current climate and for similar “shocks”. In answering this question we tackle a number of separate questions.

Are there any systems in place that warn cherry producers that the extreme climate/weather is likely to occur?

This ‘forewarned is forearmed’ approach uses historic records to explore the chance of an event occurring. Sources of historical Information include forecasts of frost, rain, heatwave events from the Bureau of Meteorology, on-farm weather stations. Government departments can provide information such as next seasons availability of irrigation water.

Can the undesired climate/weather be avoided?

Is it possible to manage the climate around the plants or the climate perceived by the plant such that the undesired conditions are avoided?

Examples include the use of irrigation for evaporative cooling and avoidance of heatwaves, use of netting, and ground covers.

Can the impact be reduced?

Can appropriate management systems be put in place that reduce the impact of a future event (pre-managed) or of a past event (post-managed)?

Examples include methods of improving pollination; use of sun-protection agents or particle film technology such as refined kaolin or calcium carbonate crystals; chemical (hormones) to assist bud break, control of vegetative growth for delayed ripening.

Climate Change

Figure 2 shows that Australia, like most places in the world is getting warmer. Individual years such as 2011 are slightly cooler than the 1961 to 1990 average, but each decade since the 1950s is warmer than the previous decade (as shown by the grey bars).

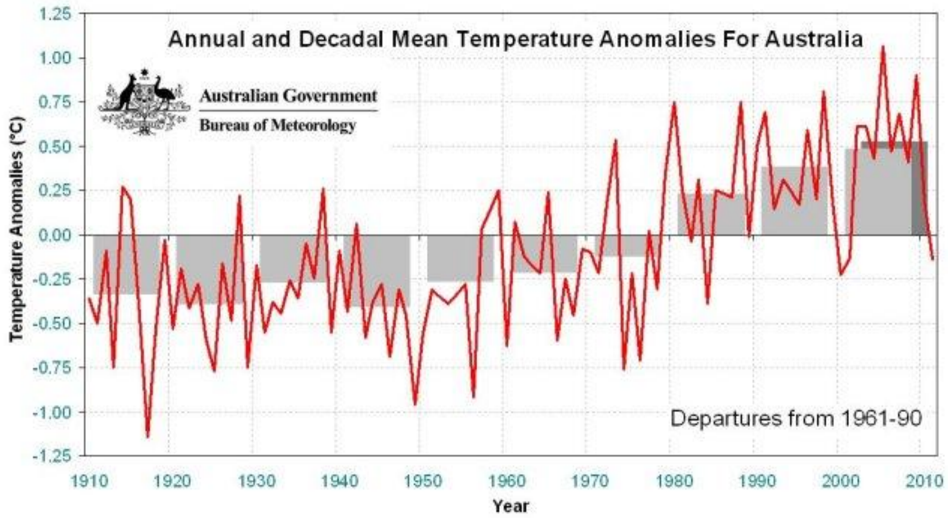


Figure 2. Annual and decadal mean temperature anomalies for Australia

There are many books and pamphlets dealing with climate change. The Australian Academy of Science released a report available at www.science.org.au/policy/climatechange.html which answers the following seven questions.

1). What is climate change?

2). How has Earth's climate changed in the distant past?

3). How has climate changed during the recent past?

4). Are human activities causing climate change?

5). How do we expect climate to evolve in the future?

6). What are the consequences of climate change?

7). How do we deal with the uncertainty in the science?

For cherry growers the main changes to consider are as follows:

1. Changes to mean temperature - which will affect phenology (the timing of events, such as flowering) through changes to chill and heat accumulation which may influence tree growth and fruit ripening processes. Advanced phenology is also likely to advance ripening processes (earlier). The spectrum of weeds, pests and diseases is also likely to change with warmer temperatures.

2. Changes to extreme high temperatures and extreme low temperature. These events may be observed as frosts and heatwaves.

3. Changes to the timing and amount of rainfall - which will influence the soil and plant water balance and have an impact on disease and fruit quality.

4. Changes to the quality and quantity of water available for irrigation.

Higher confidence in changes to temperature than to rainfall.

While the cherry industry wants to know about changes to temperature and rainfall in orchards, the information from climate science is currently at a much broader scale.

There will be improvements in climate modelling and prediction, but there will always be a mismatch between the level of accuracy needed by decision makers, and what can be delivered by climate science. What is relatively certain is that we know enough to plan for a warmer future, and that it is prudent to consider a future where water is more limiting than in the past.

Uncertainty in modelling extreme events.

The likelihood of more extreme events (particularly drought and heat) arises from the impacts of an increase in mean temperature as well as the possible increase in temperature variation (IPCC 2001a). The effect of global warming on the incidence of extreme heat is demonstrated in Figure 3. For a normally distributed variable such as temperature a small increase in its long-term mean can produce substantial changes in the probability of extreme heat events. When this increase in mean temperature is combined with an expected increase in the variance then there would be expected to be much more extreme hot temperatures. When we have modelled how risks change with 0.5, 1.0, 1.5 and 2.0°C warmer climate we have not included the expected increase in variance. That is, we have examined the less extreme situation shown by Figure 3a not Figure 3c.

We used a range of temperature increases when examining how climate change may alter risks to cherry production as there is some uncertainty about absolute increases in mean temperature. However it is expected that mean temperature in many parts of Australia may be 2°C warmer than current by 2050 (*CSIRO and Bureau of Meteorology 2007*). It is expected that mean temperature in coastal mainland locations and Tasmania will increase less than inland locations. There is also uncertainty about seasonal differences in warming, as the seasonality of warming will be related to seasonality of rainfall changes which less well understood by climate science.

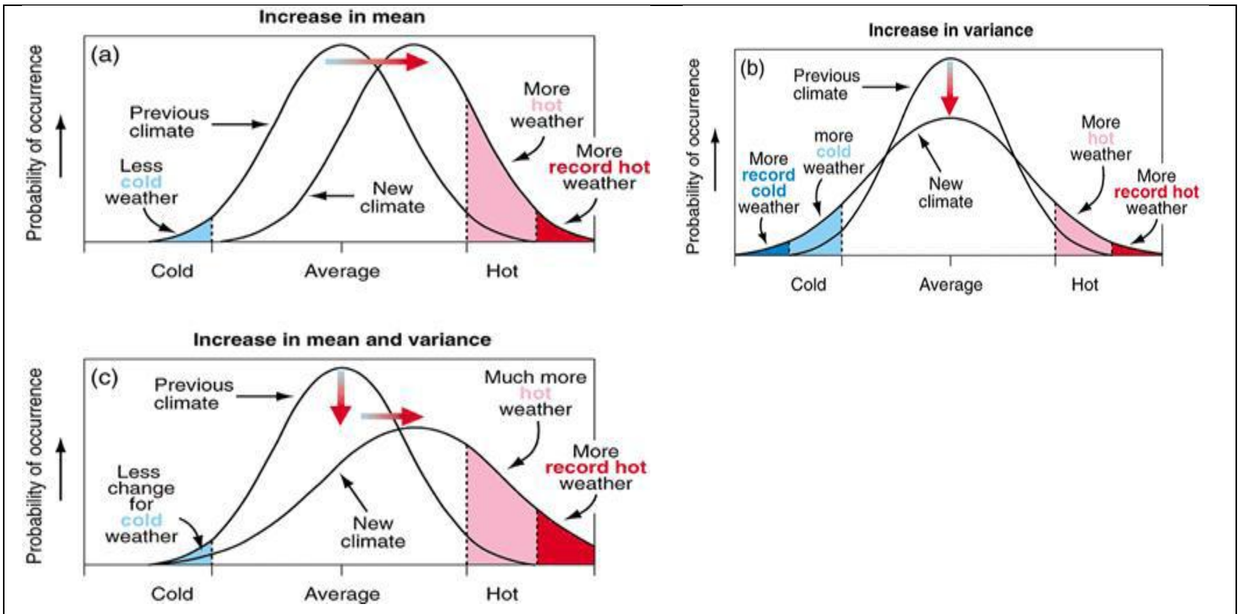


Figure 3. Illustration of effects on extreme temperature when (a) the mean increases, leading to more hot weather, (b) the variance increases, and (c) when both the mean and variance increase, both leading to much more hot weather. *Source: IPCC (2001a, 2001b)*

For other variables that may not follow a normal distribution, like frost or rainfall, the situation is more complex, especially for dry climates. For rainfall, changes in the mean total rainfall can be accompanied by other changes like the frequency of rainfall or its distribution, including its variability and the probability of extremes.

The locations we examined

A total of 25 locations that cover most cherry growing regions in Australia were examined in this analysis. Table 1 lists these locations from the coolest to the warmest mean summer temperature. ***Mean temperature is the average of daily maximum and daily minimum temperature.*** Summer was designated as December to February. This table also lists average daily maximum and daily minimum temperatures during each season. Autumn was designated as March to May, winter as June to August, and spring as September to November.

Mean summer temperatures ranged from 15.5°C at Geeveston, Tasmania to 25.1°C at Hillston, NSW. Mean winter temperatures ranged from 4.7°C at Batlow, NSW, to 11.8°C at Donnybrook, WA. Annual rainfall ranged from 261 mm at Loxton, SA, to 1267 at Mt Dandenong, Vic.

There is a close relationship between the ranking of summer, autumn and spring temperatures but a weaker relationship between summer and winter temperatures (Figure 4). The strength of the relationship is indicated by the R^2 value, with a high value signifying a stronger relationship. A location with a warm mean summer temperature was very likely to have a warm mean autumn or mean spring temperature but not necessarily a warm mean winter temperature. Inland sites such as Hillston or Loxton tend to have warm summers and cool winters.

Mean summer temperature was related to mean spring and mean autumn temperature (top and middle figures), but not mean winter temperature (lower figure).

Locations are categorised by state.

In general locations in WA and SA have warmer mean winter temperature while locations in NSW and Victoria have cooler mean winter temperature than expected from their mean summer temperature.

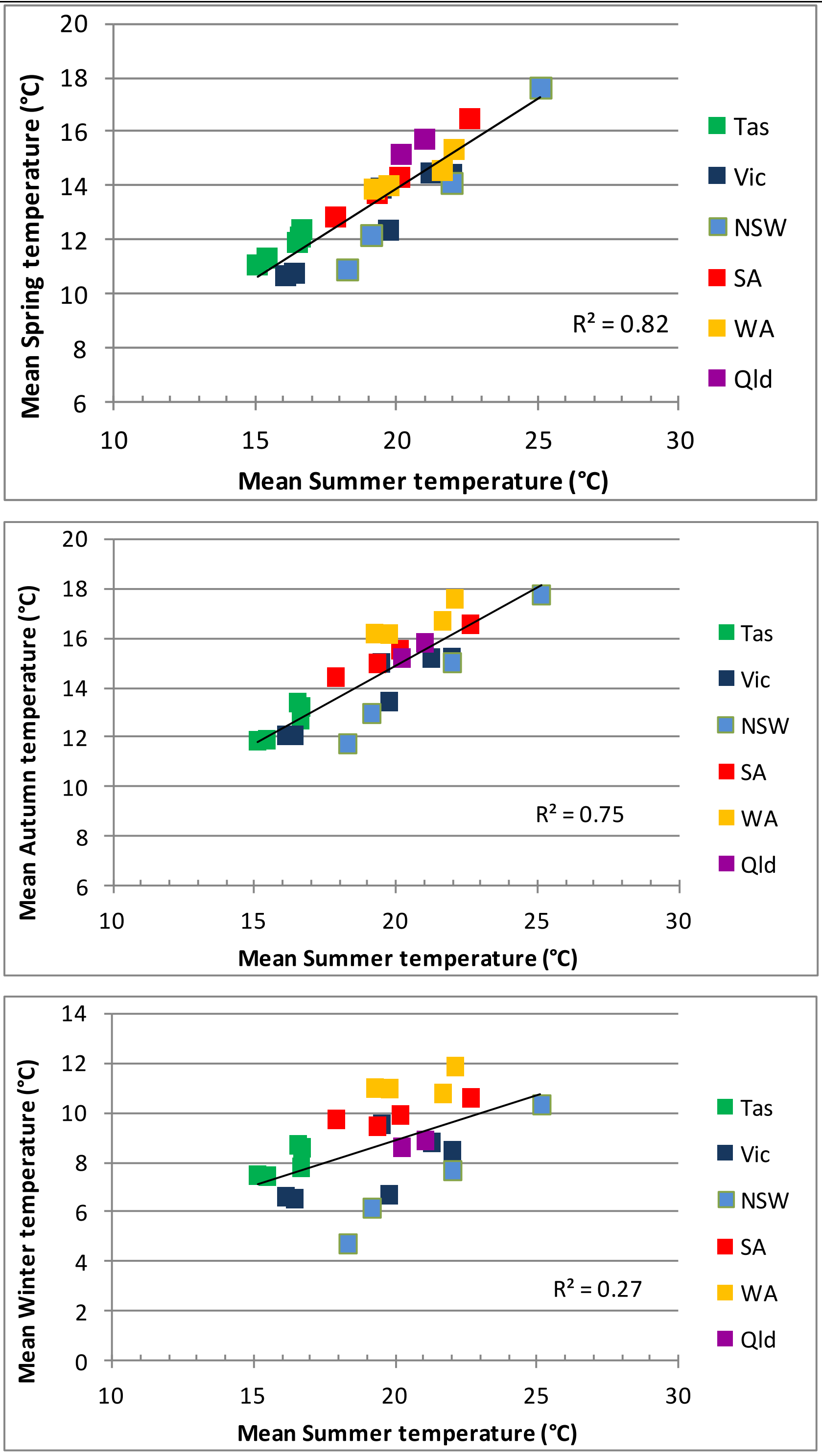


Figure 4. Relationship between mean temperature in summer and in other seasons for cherry producing locations.

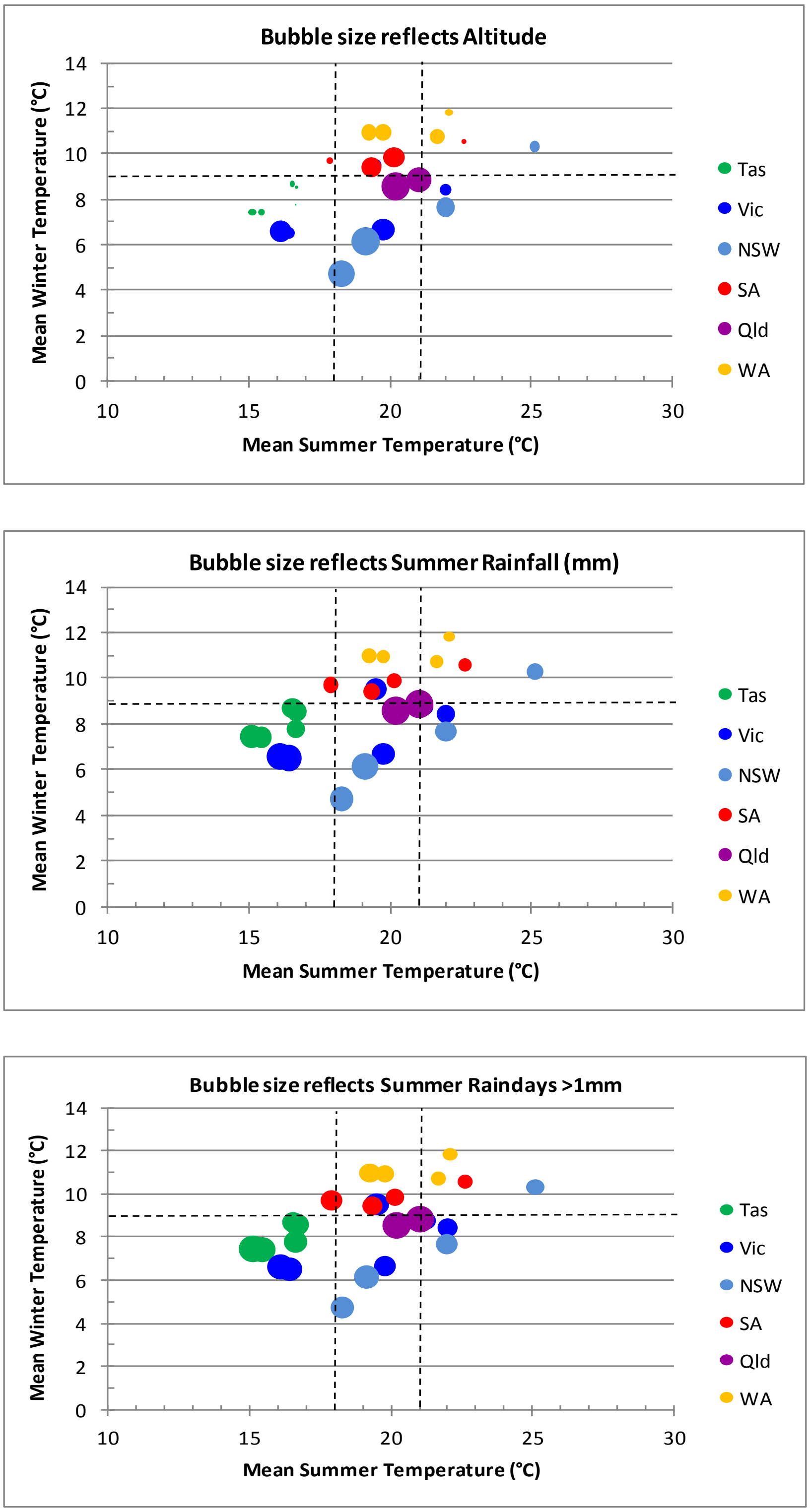
Table 1. The locations we examined showing for each the Bureau of Meteorology station number, altitude and seasonal average daily maximum (Tmax), minimum (Tmin) and mean temperature. Mean temperature is the average of maximum and minimum temperature. Summer rainfall (mm) and days with more than 1 mm of rain in summer are also shown. Locations are listed according to increasing mean summer temperature.

Location	State	Station number	Altitude (m ASL)	Summer Tmean	Winter Tmean	Autumn Tmean	Spring Tmean	Summer Tmax	Winter Tmax	Autumn Tmax	Spring Tmax	Summer Tmin	Winter Tmin	Autumn Tmin	Spring Tmin	Summer rain (mm)	Summer rainday >1mm
GEEVESTON	Tas	94137	63	15.1	7.4	11.8	11.1	20.7	11.8	16.7	16.0	9.5	3.1	6.9	6.1	182	25
GROVE	Tas	94069	55	15.5	7.4	11.9	11.3	21.7	12.4	17.5	16.8	9.2	2.4	6.2	5.8	155	22
MT DANDENONG	Vic	86243	600	16.1	6.6	12.1	10.7	21.5	9.1	15.8	14.8	10.7	4.1	8.3	6.5	245	23
HEALESVILLE	Vic	86050	131	16.4	6.5	12.0	10.7	22.5	9.3	16.3	15.3	10.4	3.7	7.8	6.2	231	21
BEACONSFIELD	Tas	91001	33	16.5	8.7	13.4	11.9	21.3	12.7	17.9	16.2	11.8	4.7	8.8	7.6	144	16
NEW NORFOLK	Tas	95105	5	16.6	7.8	12.7	12.1	22.8	12.4	18.0	17.5	10.5	3.1	7.3	6.7	113	18
RICHMOND	Tas	94012	10	16.7	8.6	13.2	12.4	22.1	12.9	18.0	17.4	11.3	4.2	8.4	7.4	123	17
MT GAMBIER	SA	26021	63	17.9	9.7	14.4	12.8	24.7	13.8	19.8	18.3	11.1	5.6	9.0	7.4	87	15
BATLOW	NSW	72004	780	18.3	4.7	11.7	10.9	25.5	9.3	17.9	16.9	11.1	0.2	5.6	4.9	204	16
ORANGE	NSW	63254	947	19.1	6.2	13.0	12.2	25.9	10.7	18.8	18.0	12.4	1.7	7.1	6.3	238	19
MT BARKER	WA	9581	300	19.2	11.0	16.2	13.9	25.6	15.1	21.3	19.1	12.9	6.9	11.0	8.6	75	14
LENSWOOD	SA	23801	480	19.3	9.4	15.0	13.7	25.8	12.8	19.7	18.7	12.9	6.1	10.2	8.6	96	13
COLDSTREAM	Vic	NA	130	19.5	9.5	15.0	13.9	26.2	13.7	20.4	19.4	12.8	5.3	9.5	8.4	149	18
BEECHWORTH	Vic	82001	580	19.8	6.7	13.4	12.3	27.1	10.8	19.3	18.2	12.4	2.5	7.5	6.5	167	15
MANJIMUP	WA	9573	287	19.8	10.9	16.1	14.0	26.6	14.9	21.3	19.2	13.0	6.9	10.9	8.8	60	11
ASHTON	SA	23702	503	20.2	9.9	15.5	14.3	26.8	13.6	20.7	19.7	13.5	6.1	10.3	8.9	83	11
APPLETHORPE	Qld	41175	872	20.2	8.6	15.2	15.1	25.8	14.7	20.9	21.6	14.6	2.4	9.5	8.7	280	26
STANTHORPE	Qld	41095	784	21.0	8.9	15.8	15.7	26.9	15.6	21.8	22.5	15.2	2.1	9.7	8.9	277	25
TATURA	Vic	81049	114	21.3	8.8	15.2	14.4	28.9	13.9	21.7	21.0	13.6	3.7	8.6	7.8	94	10
DWELLINGUP	WA	9538	267	21.7	10.7	16.7	14.5	29.2	15.6	22.7	20.5	14.2	5.9	10.6	8.6	58	7
YOUNG	NSW	73056	440	22.0	7.7	15.0	14.1	30.0	13.3	22.1	21.3	14.0	2.1	7.9	6.9	153	14
WANGARATTA	Vic	82138	153	22.0	8.4	15.2	14.4	30.3	13.7	22.3	21.3	13.7	3.2	8.1	7.5	119	13
DONNYBROOK	WA	9534	63	22.1	11.8	17.6	15.3	30.0	17.3	24.1	21.8	14.2	6.4	11.0	8.8	43	6
LOXTON	SA	24024	30	22.6	10.6	16.5	16.5	30.9	16.5	23.6	23.9	14.4	4.6	9.4	9.0	56	7
HILLSTON	NSW	75032	122	25.1	10.3	17.7	17.6	32.6	16.2	24.4	24.8	17.7	4.5	11.1	10.5	94	10

The locations were grouped according to mean winter temperature and mean summer temperature. Obviously any boundary has the problem of points that are close to either side. Locations with mean winter temperature cooler than 9°C were classified as having cool winters and those with mean winter temperature warmer than 9°C were classified as having mild winters. Locations with mean summer temperature cooler than 18°C were classified as having cool summers; those with mean summer temperature between 18 and 21°C were classified as having mild summers; and those with mean summer temperature warmer than 21°C were classified as having hot summers.

The graphs in Figure 5 show the relationship between mean winter temperature and mean summer temperature for each location. The size of the bubble reflects either the locations' altitude (m ASL), average summer rainfall (mm), or the average number of days in summer that rain is more than 1 mm. In all cases a larger bubble reflects a larger value. Apart from locations in Tasmania, the locations with cool winters and cool or mild summers are at high altitude with the exception of Coldstream and Tatura in Victoria at 130 m and 114 m respectively. The locations in SA and WA had mild winters, and usually mild or warm summers. These locations had low summer rainfall and few raindays, reflecting their essentially Mediterranean climate. Many of the remaining locations, regardless of their mean temperatures during summer or winter had high rainfall during summer.

Cherry producers may be able to use a 'space as a proxy for time' approach when treating the risks of a warmer climate. This approach is based on ecological principles to examine the impact of environmental conditions such as temperature, rainfall or altitude. Commonly the production or species diversity is examined along a transect differing in one or more environmental conditions.   The examination of the 25 cherry producing locations showed mean summer temperature ranged from 15 to 25°C, and mean winter temperature ranged from 5 to 12°C.   This suggests one method of treating risks of a warmer climate is to examine how risks are managed by cherry producers in a location warmer or drier than yours currently is. This approach is likely to be a useful first step in identifying options for managing risks for many locations. However this approach should be treated with some caution as cherry production is not simply a function of mean summer and mean winter temperature. Weather and climate consists of many variables that influence the production of high quality cherries. For example chill accumulation depends on hourly temperature, heat waves are a function of daily maximum temperatures, rainfall is associated with fruit cracking but is necessary for supply of irrigation.



Classification of locations based on mean winter temperature and mean summer temperature.

The horizontal line shows the thresholds of 9°C in winter that differentiates locations with cool winters from those with mild winters.

The vertical lines shows the thresholds of 18°C in summer than differentiates locations with cool summers from those with mild summers; and of 21°C in summer that differentiates locations with mild summers from those with hot summers.

The graphs each have a third variable of altitude (top), summer rainfall (middle) or days in summer with more than 1 mm rain (lower). A larger bubble signifies high altitude, more rainfall or more days with rain.

Locations are categorised by state. Individual locations can be identified by using Table 1.

Figure 5. Relationship between mean summer temperature and mean winter temperature for the 25 cherry producing locations. The size of the point reflects the additional characteristic of the locations altitude, rainfall in summer, or number of days of more than 1mm rain in summer.

Further reading

- James, P. (2010) Australian Cherry Production Guide. Is an up-to-date comprehensive guide to cherry production offering practical and useful information. This book can be obtained by a link from Cherry Growers Australia http://www.cherrygrowers.org.au/images/File/Production%20Guide%20-%20Final.pdf

Information on climate change and stocktaking to assist in decision making in an Australian context can be found in

- Hayman PT, Leske P, and Nidumolu U. (2009) Climate change and Viticulture. Informing the decision making at a regional level. South Australian Wine Industry Association and South Australian Research and Development Institute. GWRDC Project SAW 06/01. Version 1.0, October 2009. http://www.sardi.sa.gov.au/__data/assets/pdf_file/0005/123476/Climate_Change_Booklet_-_web.pdf

HAL report AP09019 provides information on risks relating to climate for some closely aligned horticultural crops.

- Putland D, Deuter P, Hayman P, Hetherington S, Middleton S, Nidumolu U, Nimmo P, Thomas D**,** Wilkie J, Williams D. (2011) The apple and pear industry's response to climate change and climate variability: a desktop study. HAL project AP09019. 176 pages.

Climate data: Obtaining the data and cautions in interpreting the analysis.

Historical climate data (1957-Present) for selected locations was obtained from the SILO database (http://www.nrw.qld.gov.au/silo/). The data we obtained consisted of daily values of maximum and minimum temperatures, rainfall, and evaporation. For most locations we used Patched Point Data (PPD). The PPD contains ‘Observed’ data of historical weather records from the particular Meteorological station and ‘Patched’ data. Observed data are the actual measured data. Patched data are used where no data exists. In effect, missing data are patched. Missing data may occur for several reasons including intermittent days when weather data was not observed, periods prior to opening a meteorological station or after its closure, or patching data for a climate variable that is not directly measured at the meteorological station (eg. Most stations do not record evaporation, and some stations do not record temperature). Information on which data is ‘Observed’ and which is ‘Patched’ and has been interpolated at each location is available from the SILO website.

DataDrill data was obtained from the SILO database (http://www.nrw.qld.gov.au/silo/) for the location of Coldstream as Patched Point data from a meteorological station near Coldstream was not available. Obtaining climate information from Coldstream was considered important as an outcome from the Yarra Valley climate change workshops in March 2010 identified that local producers used a combination of climate conditions at the warmer site of Coldstream and the colder site of Mt Dandenong when estimating climate for their orchards.

The Data Drill accesses grids of data interpolated from point observations by the Bureau of Meteorology. The data in the Data Drill are all synthetic; there are no original meteorological station data left in the calculated grid fields. Interpolations are calculated by rigorous techniques (described in Jeffery et al. 2001). DataDrill dataset are available for grids located at intervals of 3 minutes latitude and 3 minutes longitude (equivalent to 5 km by 5 km).

The grid location the DataDrill dataset used for Coldstream was located at latitude 37.70°S, longitude 145.35°E, is approximately 3 km North of Coldstream and 2 km West of Coldstream meteorological station (station number 86386).

Climate change scenarios have been modelled by adjusting the values of the historic climate and recalculating variables such as temperature, rainfall, evaporation, chill and heat accumulation. Chill accumulation models typically require hourly temperature. The hourly temperature data was not available for most locations so it had to be calculated from daily maximum and minimum temperature. This was done using the equations detailed in Linvill (1990) but using the minimum temperature of the following day to determine the cooling of temperature during the afternoon and overnight. This simulated a more natural course of temperature. Calculated hourly temperature will approximate but are unlikely to fully match actual readings of hourly temperature. This means that additional calculations based on hourly temperature such as chill accumulation are likely to have some discrepancies compared with calculations based on actual readings of hourly temperature.

The data from historic records and climate change scenarios were used to calculate risks for climate events. It should be noted that these risks using the historic record or for climate change scenarios are a guide to future climate risk. The calculated 'risks' are simply a method of examining and presenting what has already happened, and what is likely to, but not necessarily will, happen again. It is also important to recognise that each block on a cherry orchard will have a climate that is unique and in many cases quite different to the nearest recording station.

Jeffrey SJ, Carter JO, Moodie KB, Beswick AR (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling Software* **16**: 309–330.

The Cherry Calendar

A cherry calendar is a useful way to link the orchard to weather and climate risks. For example, when analysing the risk of rain near harvest we need to know when harvest occurs. The likelihood of the event occurring is the estimated risk. Likewise many other risks are associated with particular development or phenological stages. The risks are listed in Table 2. The table also describes the development stages we have used to define when the risk occurs.

We have developed an Excel® spreadsheet that allows the dates of these development stages to be adjusted by ‘users’ so that they match the growers orchard. Users can define The month (1 to 12, with 1 being January and 12 being December) and in which week or quarter of the month (1 to 4) the phenological stage is reached. In this spreadsheet we have segregated the days in a month in quarters of a month, which is a close approximation of week number in the month. Users can adjust the month and quarter to suit the phenological development of varieties in their orchard. The risks are then calculated for phenological development corresponding to the ‘user’.

We have attempted to find out the likely time that particular phenological events occur for many cherry producing regions in Australia. We do not have all this information as yet. For this reason we have used the same periods to analyse the risks. Individual ‘users’ can adjust the dates for their or other regions to increase the accuracy of the estimated risk. The dates (month and quarter) that we have used as a common date for all locations that the phenological events occur and therefore the common dates when the risk occurs is shown in the table.

Table 2. The Cherry Calender showing the phenological stages and the Risks

		July				August				September				October				November				December				January				February				March				April				May				June			
		7	7	7	7	8	8	8	8	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	12	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	6
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
						X Bud swell																																											
									X Bud burst																																								
											X Flowering starts																																						
																X Flowering ends																																	
																				X Harvest starts																													
																											X Harvest ends																						
																																												X 100% leaf fall				
RISK	**Period**																																																
1. Insufficient chill accumulation	100% leaf fall to bud swell	🟪	🟪	🟪	🟪																																								🟪	🟪	🟪	🟪	🟪
2. Heat accumulation hastening development leading to crop maturing in less desirable times	1 = bud burst to end harvest.								🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																						
	2 = end of harvest to 100% leaf fall.																											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
3. Temperatures being too hot or too cold for effective pollination	Start of flowering to end of flowering										🟨	🟨	🟨	🟨	🟨	🟨																																	
4. Heatwaves affecting crop growth	1 = last flowering to end of Harvest.															🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																						
	2 =end of harvest for two months.																											🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩													
5. Frost damage	1= Bud burst to start of flowering.								🟦	🟦																																							
	2 = Start of flowering to end flowering.										🟦	🟦	🟦	🟦	🟦	🟦																																	
	3 = End of flowering for three weeks.																🟦	🟦	🟦																														
6. Insufficient rain or irrigation water for growth	seasonal	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
7. Rain at harvest	three weeks prior to harvest to end of harvest																🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪																						

Sources of information about risks from climate or weather

Climate

Many reports on climate projections are available. The report *Climate Change in Australia (CSIRO and Bureau of Meteorology 2007)* released October 2007 contains a technical summary of the current understanding of trends and projections for climate in Australia. Further information on climate change for individual regions can be obtained from http://www.climatechangeinaustralia.gov.au). This website has tools that show the expected differences that are projected to occur in each season. The Ozclim tool developed by CSIRO (http://www.csiro.au/OzClim) is an interactive site that allows an individual to examine climate projections from many global circulation models.

The Bureau of Meteorology website contains a page titled Climate and past weather (http://www.bom.gov.au/climate/) that contains information of seasonal forecasts, climate change, extreme events, and weather and climate summaries.

Weather

The Bureau of Meteorology manages numerous stations for which rainfall and temperature data may be recorded. A quick and freely available way to check data observation records for sites around Australia is through the Bureau of Meteorology's Weather Station Directory (www.bom.gov.au/climate/cdo/about/sitedata.shtml). Drop-down menus allow you to select the weather element you're after, such as air temperature, as well as confining the search to a specific state, and searching via place name (useful if you have a location in mind) or station number (useful if you want to look at sites in a particular region). The lists provide the dates within which the observations have been recorded at each site, along with the percentage complete as a crude guide to the quality of the data (where 50% would suggest only half of the observations during the recording period were actual recordings from that station).

Some cherry growers are fortunate to be close to a recording station, but finding representative stations for a parameter as location specific as temperature will always be challenging.

Many cherry growers have installed automatic weather stations, which provide valuable data to assist in making decisions. However, if detailed comparisons are to be made, any monitoring equipment must have had regular calibration for its outputs to be considered valid.

Information available from the Bureau of Meteorology includes daily records and long term averages. The information from each current year could be used as a predictor of the current years' chill accumulation, or heat accumulation, or rainfall. One page on the Bureau of Meteorology web site titled Water and the Land (http://www.bom.gov.au/watl/) contains forecasts for frost potential throughout Australia. Currently this forecast is for up to 2 days in advance. This web page also has links to detailed historical values of potential evapotranspiration which is useful for estimating irrigation.

A further resource provided by the Bureau of Meteorology are the warnings of forecasted severe weather events. These include storm, hail, frost and heatwaves. These warnings are additional to the daily weather forecasts.

In addition the Bureau of Meteorology is testing a new tool called Forecast Explorer. This tool provides 3 hourly forecasts of temperature and rainfall for the forthcoming week, and has the potential to be used to gauge the possibility of frost or rain events or heatwaves. Currently this tool is available for Victoria, NSW/ACT, Tasmania and South Australia with other states being included by 2015 (WA in 2013, Qld in 2014, NT in 2015). The tool can be obtained from the Bureau of Meteorology's home page http://www.bom.gov.au/index.shtml

or alternatively for:

- Victoria http://www.bom.gov.au/forecasts/graphical/public/vic/
- NSW/ACT http://www.bom.gov.au/forecasts/graphical/public/nsw/
- Tasmania http://www.bom.gov.au/forecasts/graphical/public/tas/
- South Australia http://www.bom.gov.au/forecasts/graphical/public/sa/

In WA, the department of Agriculture and Food has developed Statistical Seasonal Forecasts for rainfall. For more info go to: http://www.agric.wa.gov.au/PC_94509.html

Information on current dam levels (if this is a source of irrigation water) can be obtained from Government water boards. Although it should be noted that Federal and State departments have Policy arrangements determining irrigation water supply.

Risk 1. Insufficient chill accumulation

Identifying the risk of insufficient chill accumulation and placing it in context.

Chill accumulation is vitally important to deciduous tree crops. Insufficient chill accumulation can result in physiological damage to trees including non-synchronous bud burst and flowering.

Chill accumulation is a risk associated more with changes in mean temperature and in particular minimum temperature rather than changes in extreme minimum temperature. This is because chill accumulation occurs from a series of many events rather than a few single extreme events. There is high confidence that climate change will affect chill accumulation because there is high confidence in general warming. There is higher confidence that warming will be greater for inland regions than coastal regions, and that warming will be greater at higher latitudes than in the tropics. There is lower confidence in the seasonal pattern of warming and although nights have warmed more than days, it is not clear that this will be a strong trend in the future.

Perhaps the largest uncertainty surrounding chill accumulation is how to measure it as there are several methods for calculating chill accumulation. It is also important to recognise that each model used for calculating chill accumulation is likely to give a different answer for a specific location and time period, so it is important to gather information on how much chill has accumulated and which model was used to calculate the chill accumulation. It should be noted that the current scientific opinion is that the Dynamic model (sometimes referred to as Erez model) is thought the most appropriate chill accumulation model.

All methods rely on temperatures being within a physiologically active range. In addition even when temperatures are within the physiologically active range the amount of chill accumulation calculated by the different models may not be the same. That is, when using some methods of calculating chill accumulation, some temperatures give more chill accumulation than others. This is relatively simple when considering chill accumulation models of chill hours less than 7.2°C or the slightly more complex model that assumes only temperatures above 0°C but below 7.2°C have a positive effect on chill. In both these models each hour that the temperature is within these ranges gives one hour of chill accumulation. The Utah vernalisation model (or Richardson model) recognises the relative contribution that different temperatures have on chill with both positive and negative chilling units able to be accumulated. The Dynamic model calculates chilling accumulation as ‘chill portions’ using a range of temperatures from about 2 to 13°C, and accounts for chill cancellation due to fluctuating warm temperatures. The Dynamic model assumes that chill results from a two-step process where cold temperatures initially form an intermediate product in the buds and warm temperatures can destroy this intermediate product. When a certain quantity of the intermediate product has accumulated, it is transformed irreversibly into a chill portion, which can no longer be destroyed.

In addition to these reasonably complex formulas, rules of thumb can be applied for calculating chill hours based on mean minimum temperature of the coldest month. The simplest of these is based on United States data and assumes a linear increase in chill hours with a reduction in mean minimum temperature (Byrne and Bacon, unknown year, Cambell, 2007). This model has been refined for Australian conditions by George and Nissen (cited in Cambell et al. 1999) using mean minimum temperature but is modified such that estimated chill hours are based on a curved relationship with mean winter temperature, meaning that more chilling accumulates at cooler mean minimum temperatures than at warmer mean minimum temperatures.

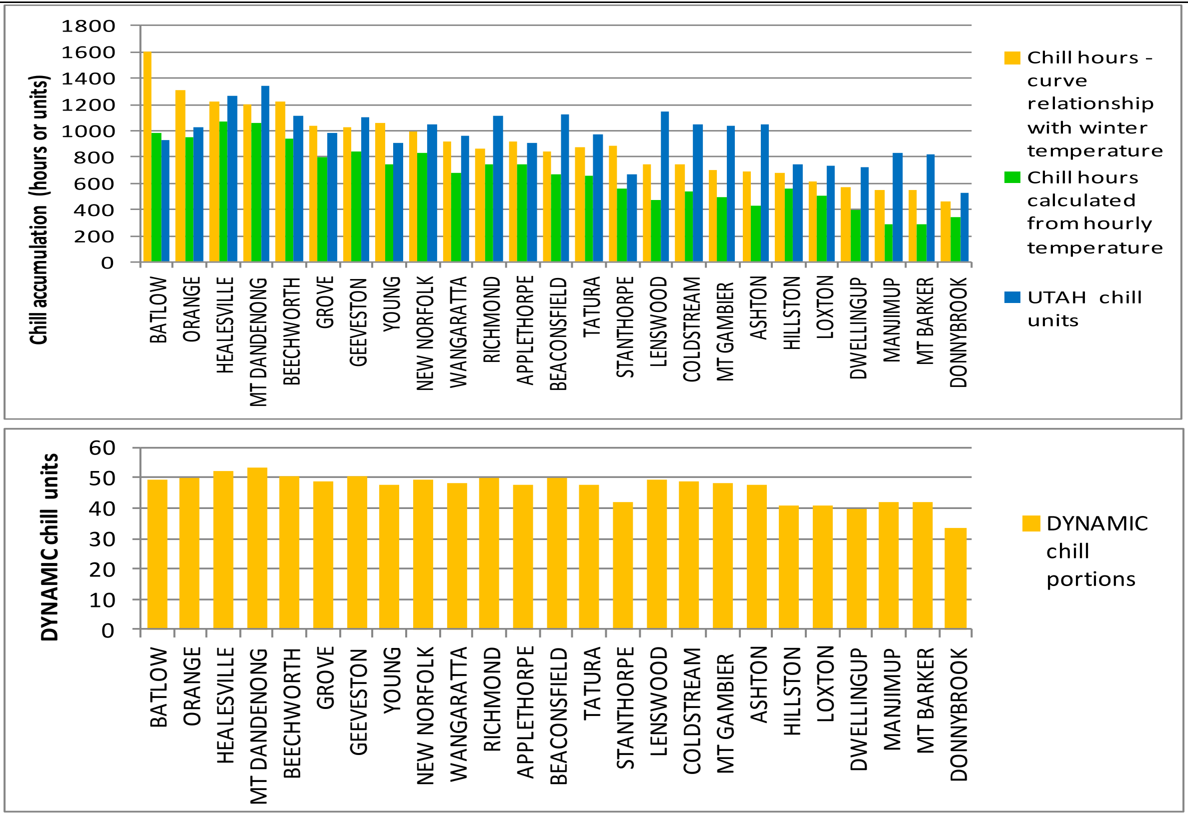
Analysing and evaluating the risk of insufficient chill accumulation.

We assessed chill accumulation from the time of 100% leaf fall to bud swell. It is important to note that different chill models give different amounts of chill accumulation, but that all models show a reduction in chill accumulation in a warmer climate.

Chill accumulation could generally be said to be larger in locations with cooler mean winter temperatures. However, as noted there are many ways of calculating chill accumulation and these determine the exact responses to temperature at a locations and when temperature changes due to a warmer climate are calculated.

The bar charts in Figure 6 display chill accumulation using the historic climate from the coldest (on left) to warmest locations using four methods. In the first graph a simple chill accumulation calculated based on mean temperature of the coldest month (named *chill hours – curve*) shows chill accumulation declines as mean winter temperature becomes warmer.

Chill accumulation calculated by the remaining two methods shown on this graph and the method shown on the second graph use hourly temperature. Chill accumulation calculated by these methods generally declines with increasing mean winter temperature although there are some location specific effects. The reason for this is that these more advanced methods of calculating chill accumulation rely on temperatures being within a physiologically active range, and the relative importance that different temperatures contribute the chill accumulation.



The risks associated with insufficient chill accumulation were higher in locations having warmer mean winter temperature. This can be seen by generally higher chill accumulation at locations to the left had side in the bar graphs (above) and also the scatter plots (to right). In the scatter plots each location is shown by an individual point coloured according to state.

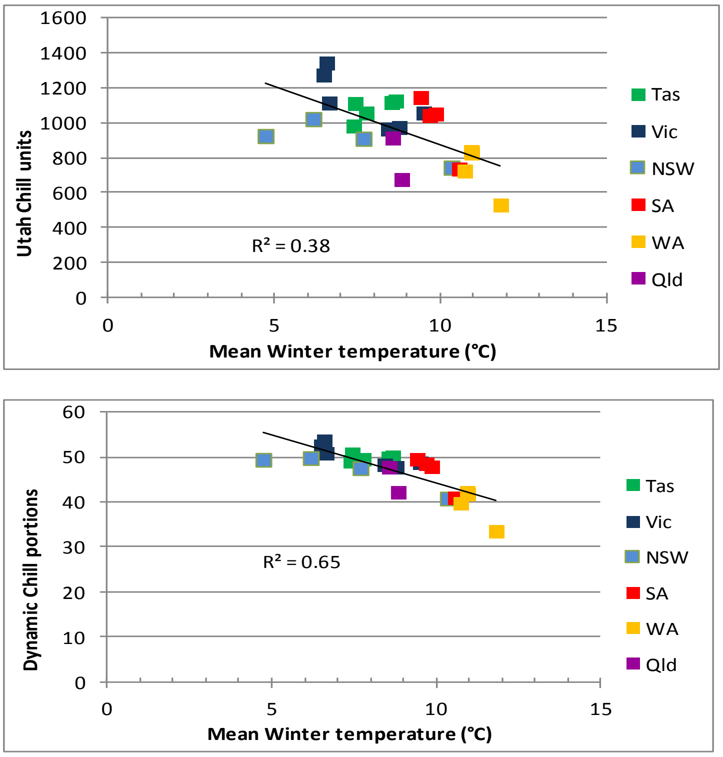


Figure 6. Chill accumulation and its relationship with mean winter temperature in the current climate.

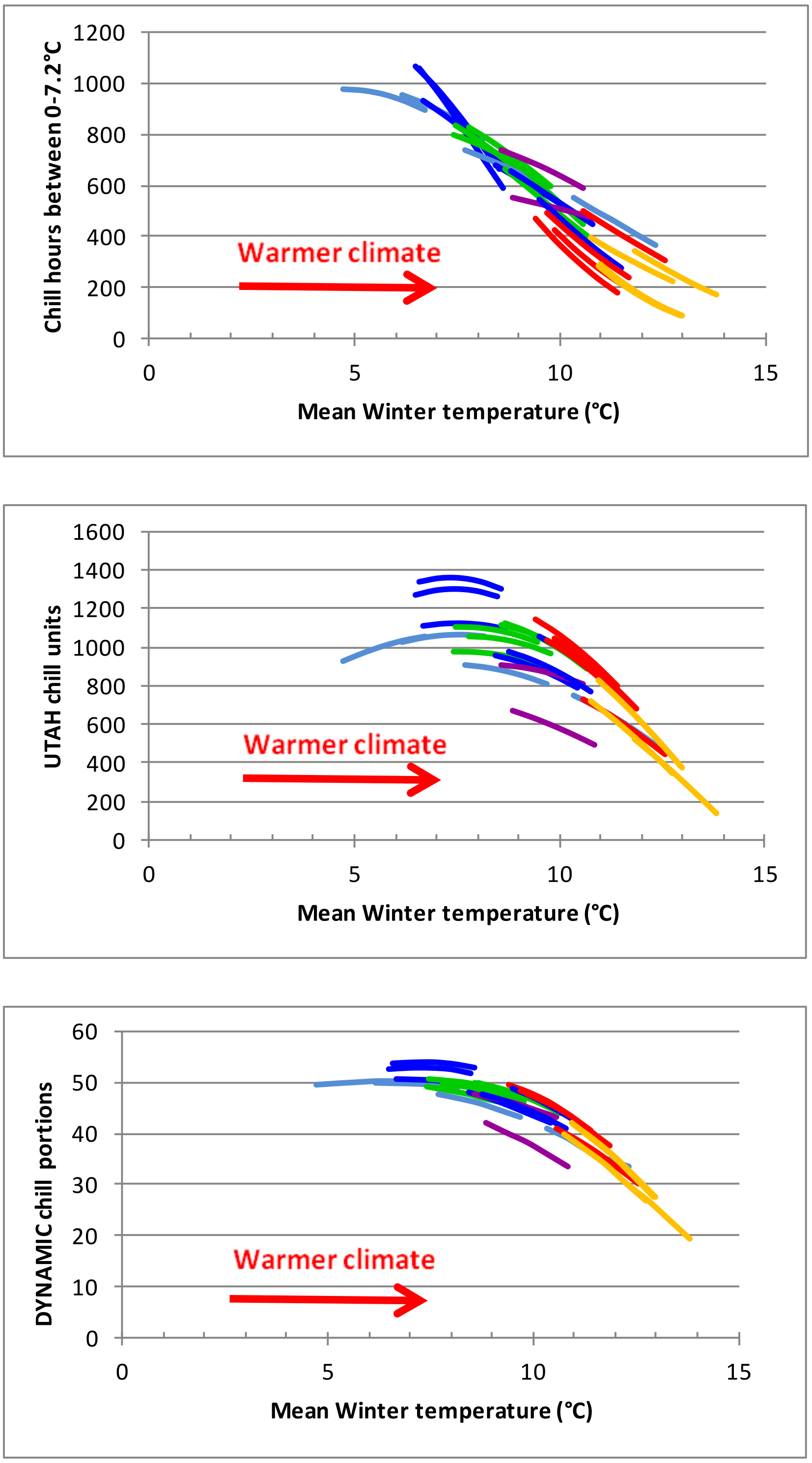
Table 3 lists three methods of calculating chill accumulation that are determined from hourly temperature. The table shows the average chill accumulation using the historic climate records and the chill accumulation if temperatures were 0.5, 1.0 or 2.0°C warmer than the historical record. It is expected that mean temperature in many parts of Australia may be 2°C warmer than current by 2050 (*CSIRO and Bureau of Meteorology 2007*). The table lists locations from coldest to warmest mean winter temperatures. When the impact of a warmer climate on the amount of chill accumulation is analysed the chill accumulation in some sites was more responsive to temperature changes than others, and the method of determining chill accumulation affected these responses (Figure 7).

In most sites we examined there are no or relatively few times when temperature is under-utilised such that there was a definite net movement out of the zone of physiological activity and any warming will decrease chill accumulation. These include locations in WA, Qld, SA, and some locations in Victoria and NSW. The decline is most apparent when using models of chill hours calculated as hours less than 7.2°C or hours between 0 and 7.2°C. The Utah model showed chill accumulation in some cold locations in Victoria and NSW to initially increase or remain stable in a warmer climate before declining as further temperature increases were included. The Dynamic model showed more uniformity with mean winter temperature than the other more complex models, and showed chill accumulation to remain stable at mean winter temperatures below 9°C, but to decline at warmer mean winter temperature.

Table 3. Risks associated with insufficient chill accumulation.

These risks were calculated as chill accumulation for the period from 100% leaf fall to bud swell. This table shows these risks for all locations assuming 100% leaf fall and bud swell occur on the same date. Chill accumulation is shown for three methods calculated from hourly temperature: chill hours between 0 and 7.2°C (0-7.2°C), chill units calculated by the Utah model (UTAH) and chill portions calculated by the Dynamic model (DYNAMIC). Calculations have been done for the climate using the historic record, and also for several warming scenarios. These are a 0.5°C, a 1.0°C and a 2.0°C warmer climate. Locations are listed from the coldest mean winter temperature to the warmest mean winter temperature.

				Historic record				0.5°C warmer				1°C warmer				2°C warmer		
Location	**State**	**Start**	**End**	0-7.2°C	UTAH	DYNAMIC		0-7.2°C	UTAH	DYNAMIC		0-7.2°C	UTAH	DYNAMIC		0-7.2°C	UTAH	DYNAMIC
BATLOW	NSW	24 May	31 Jul	978	926	50		973	970	50		958	1008	50		898	1057	50
ORANGE	NSW	24 May	31 Jul	955	1023	50		924	1047	50		884	1061	50		780	1057	49
HEALESVILLE	Vic	24 May	31 Jul	1067	1271	53		983	1293	53		885	1299	53		666	1264	52
MT DANDENONG	Vic	24 May	31 Jul	1063	1340	54		956	1357	54		835	1357	54		588	1308	53
BEECHWORTH	Vic	24 May	31 Jul	935	1113	51		879	1126	51		818	1128	50		679	1095	49
GROVE	Tas	24 May	31 Jul	802	978	49		771	976	48		733	965	48		643	914	46
GEEVESTON	Tas	24 May	31 Jul	839	1108	51		786	1105	50		727	1090	50		597	1023	48
YOUNG	NSW	24 May	31 Jul	741	911	48		709	899	47		675	879	46		591	813	43
NEW NORFOLK	Tas	24 May	31 Jul	829	1054	50		779	1048	49		723	1031	48		597	962	46
WANGARATTA	Vic	24 May	31 Jul	680	961	48		634	933	47		587	895	45		488	791	42
RICHMOND	Tas	24 May	31 Jul	745	1115	50		671	1088	49		595	1047	48		448	928	45
APPLETHORPE	Qld	24 May	31 Jul	741	911	48		709	899	47		675	879	46		591	813	43
BEACONSFIELD	Tas	24 May	31 Jul	663	1122	50		597	1083	49		531	1031	48		400	889	44
TATURA	Vic	24 May	31 Jul	656	972	48		605	936	47		551	890	45		444	768	41
STANTHORPE	Qld	24 May	31 Jul	555	672	42		536	634	40		517	591	38		473	491	34
LENSWOOD	SA	24 May	31 Jul	471	1142	50		381	1074	48		304	993	46		175	794	41
COLDSTREAM	Vic	24 May	31 Jul	542	1054	49		471	995	47		401	924	45		279	749	40
MT GAMBIER	SA	24 May	31 Jul	490	1040	48		418	972	47		351	893	45		236	703	38
ASHTON	SA	24 May	31 Jul	425	1049	48		348	973	46		282	885	44		176	676	38
HILLSTON	NSW	24 May	31 Jul	554	746	41		504	693	39		459	633	37		363	491	33
LOXTON	SA	24 May	31 Jul	500	733	41		450	671	39		401	602	36		307	443	30
DWELLINGUP	WA	24 May	31 Jul	392	721	40		344	637	37		301	546	34		222	344	27
MANJIMUP	WA	24 May	31 Jul	284	832	42		220	732	39		167	622	36		87	380	28
MT BARKER	WA	24 May	31 Jul	288	824	42		222	724	39		168	616	36		87	376	28
DONNYBROOK	WA	24 May	31 Jul	340	526	33		292	437	30		248	342	27		169	140	19



Chill accumulation measured using three methods calculated from hourly temperature: chill hours between 0 and 7.2°C top); Utah chill units (middle); and Dynamic model chill units (lower).

Each line is the response in chill accumulation at a single location for the historic climate and under conditions of temperature increases of 0.5°C steps to a maximum of 2°C and replotting these risks with the new mean winter temperature for the location. The mean winter temperature of each location would also increase in 0.5°C steps to a maximum of 2°C warmer than the current mean temperature. That is, in all cases the calculated chill accumulation is plotted against the locations mean winter temperature in the historic or in a warmer climate.

The different coloured lines represent locations in Queensland (maroon), NSW (sky blue), Victoria (navy blue), Tasmania (green), SA (red) and WA (gold).

Figure 7. Impact of a warmer climate on chill accumulation differs depending on the method used to calculate chill accumulation but all decline in a warmer climate.

Treating the risk of insufficient chill accumulation

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology and local grower meteorological stations may provide daily or hourly temperature. It is possible to interpolate the hourly temperatures required for chill accumulation models if they are not readily available from daily maximum and minimum temperature (as was done in this report). These data could be used to calculate chill accumulation in the current season. Historical data could be used to calculate historical chill accumulation. This information can be used by producers to assess the risks for their orchard and to make management decisions accordingly.
- The University of California Fruit Tree Physiology web site http://ucanr.org/sites/fruittree/How-to_Guides/Dynamic_Model_-_Chill_Accumulation/ is a useful source of information about use of the Dynamic model. It is possible to download an excel spreadsheet containing the Dynamic model from this site.

Can the undesired climate be avoided or the impact reduced?

- Chemicals to break dormancy are in use, and their use is likely to expand. It would be prudent to seek specific information on the use and efficacy of these chemicals in cherry production.
- Varietal (scion and rootstock) selection is an option but market acceptance of new varieties should be investigated. There is abundant information on low-chill stonefruit, and varieties of pome fruit differ in chilling requirements. Information on chill requirements of cherry varieties are not readily available. A recent HAL report Cherry cultivar selection: chill hours and climate change (report CY11010) suggests cultivars on Gisela rootstocks had lower chill requirements than Colt or F12/1 growing in the same location.

  It should be noted that chill accumulation and can differ for the same variety depending on the method used to determine chill accumulation and with the source of information. There is also considerable debate and uncertainty surrounds the elasticity (or tolerance) of individual varieties to chilling. This same HAL report lists chill accumulation for at least 50% bud break for many varieties grown in Australia. Chill accumulation was calculated by several models including grower rating when no other information was available. A selection of these varieties that are listed by James (2011) as major and significant minor varieties in Australia are shown in Table 4. Many cherry growing locations are categories as accumulating a high chilling using the HAL groupings in the current climate, but the likelihood of this occurring in a warming climate is reduced. We have therefore shown are other varieties rated by growers as requiring low, low-medium, medium-high and high chill accumulation (Table 5).

Table 4. Chilling requirements of several major and significantly minor cherry cultivars. Data from Darbyshire et al., 2012.

Variety	Rating (see below)	Dynamic chill portions	Utah chill units	Positive Utah chill units	Chill hours (0-7.2°C, but possibly less than 7.2°C)
Bing	H		683	320-880	700-1100
Brooks	LM	36.7		539	441
Early burlat	LM / MH	48	1326	683	518 -1119
Garnet	VH				
Kordia (Attika)	H				<1320
Lapins	L / LM	35	539 -683		441-700
Merchant	MH /H				
Rainier	LM	45			
Regina	H				
Rons	MH				
Simone	MH				
Stella	MH			200-310	400-1100
Sweet georgia	MH				
Sweetheart	MH				
Sylvia	VH				1800
Van	MH		330-1357	435	398-1200

L (low) = 20-40 chill portions, 600-800 chill units, 300-500 chill hours;
LM (low - medium) = 40-50 chill portions, 800-1000 chill units, 500-7520 chill hours;
MH (medium – high) = 50-60 chill portions, 1000-1200 chill units, 750-1000 chill hours;
H (high) = 60-80 chill portions, 1200-1400 chill units, 1000-1500 chill hours;
VH (very high) = >80 chill portions, >1400 chill units, >1500 chill hours.

Table 5. Ratings of cherry cultivars currently of minor commercial importance in Australia.

Low	Low-Medium	Medium High	High
Minnie Royal, Royal dawn, Royal lee, Tulare	Celeste, Christabalina, Newstar (also rated as medium high), Ruby, Somerset	Black star, Grace star, Marvin, Sam, Samba (sumste), Skeens, Sonata, Sunburst	Chelan (also rated as very high), Index, Norwunder, Summit, Ulster

- Shading / Netting may reduce temperature by reducing incoming sunlight.
- Evaporative cooling through use of sprinklers may enhance chill accumulation.
- Qld DEEDI (Cambell et al., 1998) produced the “low chill” stonefruit information kit with a section on manipulating flowering and fruiting. It would be prudent to seek information to determine if these practices are suitable to your orchard. Methods listed in the Qld DEEDI manual to cope with insufficient chill included:
    - Not allowing the tree to enter dormancy and manipulating flowering by bending branches, defoliation. This method is most relevant in subtropical and tropical areas receiving insufficient chilling.

- Pre-conditioning the flower buds in summer and autumn by water management and use of growth regulators, followed by the use of rest breaking chemicals during dormancy. A proposed monthly plan was provided. This is suitable for areas where chilling is obtained but the grower wants to advance flowering by reducing the amount of chilling required to break dormancy.

Further reading

Information on chill requirements of cherry varieties were obtained from

- Darbyshire R, Brunt C, Chapman S. (2012). Cherry cultivar selection: chilling and climate change. HAL report CY11010. 31 pages.

The following publications from the current leading world experts on chill accumulation describe our current understanding of the impact of climate change on chill accumulation.

- Campoy JA, Ruiz D, Egea J. (2011). Dormancy in temperate fruit trees in a global warming context: a review. *Scientia Horticulturae* **130**: 357-372.
- Luedeling E, Brown PH. (2011). A global analysis of the comparability of winter chill models for fruit and nut trees. *International Journal of Biometeorology*. **55**: 411-421
- Luedeling E, Girvetz EH, Semenov MA, Brown PH. (2011). Climate change affects winter chill for temperate fruit and nut trees. *PLoS ONE*. May: e20155

The following publications detail studies on the impact of climate and climate change on chill accumulation for Australian locations.

- Darbyshire R, Webb L, Goodwin I, Barlow S. (2011). Winter chilling trends for deciduous fruit trees in Australia. *Agricultural and Forest Meteorology* **151**:1074-1085.
- Hennessy KJ, Clayton-Greene K. (1995). Greenhouse warming and vernilisation of high-chill fruit and southern Australia. *Climate Change* **30**: 327-348.

The publication by Cambell et al. (1998) contains information on low chill stonefruit production. A relationship between mean winter temperature and estimated chill hours is described.

- Campbell J, George A, Slack J, Nissen B, Vock N. (1998). *Low chill stonefruit information kit. Agrilink, your growing guide to better farming series.* Manual. Agrilink Series QAL9705. Department of Primary Industries, Queensland Horticulture Institute. Brisbane, Queensland. Main site: http://era.deedi.qld.gov.au/1661/ Specific chapter on key issues: http://era.deedi.qld.gov.au/1661/10/4key-lcstone.pdf

The following publications detail the development of several chill models.

- Cambell J. (2004) Winter chill: apples and pears for warmer districts. *Australian Fruitgrower* May 2007 pp18-19.
- Erez A, Fisherman S, Linsley-Noakes GC, Allan P. (1990). The dynamic model for rest completion in peach buds. *Acta Horticulturae* **276**:165-174.
- Fisherman S, Erez A, Couvillon GA. (1987a). The temperature-dependence of dormancy bud breaking in plants – mathematical analysis of a two-step model involving a cooperative transition. *Journal of Theoretical Biology*. **124**:473-483.
- Fisherman S, Erez A, Couvillon GA. (1987b). The temperature-dependence of dormancy bud breaking in plants – computer simulation of processes studied under controlled temperatures. *Journal of Theoretical Biology*. **126**:309-321.
- Linvill, DE. (1990). Calculating chilling hours and chill units from daily maximum and minimum temperature observations. *Hortscience* **25**:14-16.
- Richardson EA, Seeley SD, Walker DR. (1974). A model for estimating the completion of rest for ‘Redhaven’ and ‘Elberta’ peach trees. *Hortscience* **9**:331-332.

Risk 2. Heat accumulation hastening development

Identifying the risk of heat accumulation hastening development and placing it in context.

A major impact of a warmer climate is likely to be faster crop development, affecting all phenological stages and changing the time of harvest. Heat accumulation after harvest can affect the following years' crop. While there is considerable debate and uncertainty surrounding the elasticity (or tolerance) of individual varieties to heat, it should be appreciated that there are likely to be interactions between varieties, temperature and irrigation regimes. Global warming is likely to result in a slow shift in the climate in each growing district that will affect the ideal varieties that can be grown in that district. What is less certain is the relationship between climate and fruit quality. However, a reduction in fruit quality is likely to occur if there are increases in temperature. These relationships are highlighted by recent research on the impact of temperature on skin quality and then the effect of reduced skin health on increasing fruit 'cracking' (see http://www.tia.tas.edu.au/__data/assets/pdf_file/0020/149402/cherry-cracking-fact-sheet.pdf). A warmer climate is also likely to see an expansion in the ranges of weed species, diseases and pests, such as fruit fly, that are now limited by temperature. For pests such as codling moth it is anticipated there would be an increase in the number of breeding cycles per year, leading to increased insect pressure on the host tree.

Accumulated heat is influenced more by mean daily temperature than by temperature extremes. We have greater certainty in predicting the mean daily temperature of a location than of temperature extremes. There is high confidence that climate change will affect heat accumulation because there is high confidence in general warming. There is lower confidence in the seasonal pattern of warming and although in the recent past nights have warmed more than days, it is not clear that this will be a strong trend in the future.

Heat sums of growing degree days can be used as a measure of plant development. Calculations of growing degree days require a minimum and/or a maximum temperature threshold between which plant development occurs. These thresholds are useful indicators rather than absolute values owing to acclimation to local conditions. A minimum threshold of between 5 and10°C is frequently used for horticultural crops although a range of values are used, while different models use optimal and/or critical (maximum temperatures) (eg. Rattigan and Hill, 1987; Black et al., 2008; Legave et al., 2008).

Some more recent advances in the calculation of heat accumulation use shorter time intervals (eg. hourly or 3 hourly averages of temperature) to gain a better estimate of heat accumulation. These approaches are similar to those used to estimate chill accumulation.

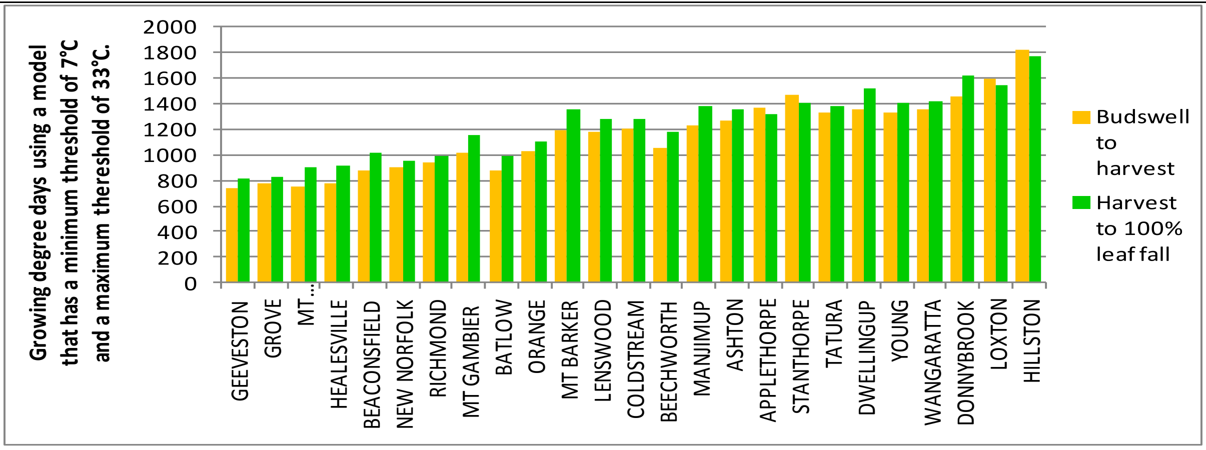
Unfortunately a requirement of calculating heat accumulation is a better understanding of the responses of cherry crops to temperature. This information is not available for Australia and reports from Europe show unreasonably low temperatures. For these reasons we used heat accumulation models that only rely only on daily temperatures. The first heat sum model required only a minimum temperature threshold of 7°C, while a second model assumed a minimum temperature threshold of 7°C and a maximum temperature threshold of 33°C (P.James Pers Comm).

Analysing and evaluating the risk of heat accumulation hastening development.

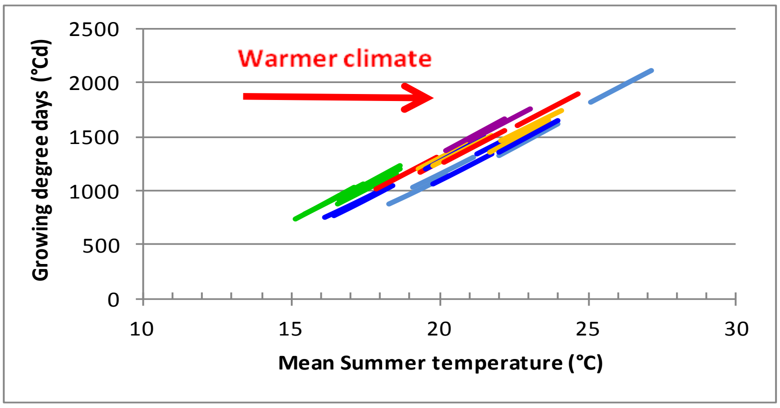
We assessed heat accumulation using two models for two periods. The first period was from bud swell to harvest, and the second from end of harvest to 100% leaf fall. For most locations the calculated growing degree days was similar for both periods irrespective of heat accumulation model. This highlights the fact that growth and heat accumulation after harvest is equally important as the growth to harvest.

Accumulation growing degree days was higher in locations having a warmer summer temperature (Table 6, Figure 8).

The heat accumulation in the current climate and in warmer climates are shown in the tables and lower graph of Figure 8. A warmer climate was modelled by adding either 0.5, 1.0, 1.5 or 2.0°C to each daily temperature and recalculating heat accumulation. It is expected that mean temperature in many parts of Australia may be 2°C warmer than current by 2050 (*CSIRO and Bureau of Meteorology 2007*). The accumulation of heat increases in a warmer climate irrespective of which heat accumulation model was used.



The risks associated with heat accumulation were higher in locations having warmer mean summer temperature. This can be seen by the increase in growing degree days at locations to the right hand side in the bar graph (above).



The increase in growing degree days for each location are shown as a line joining growing degree days in the current climate and in climates up to 2°C warmer. The graph above uses growing degree days from bud swell to harvest calculated by Model 2 (thresholds of 7°C for minimum temperature and 33°C for maximum temperature. The different coloured lines represent locations in Queensland (maroon), NSW (sky blue), Victoria (navy blue), Tasmania (green), SA (red) and WA (gold).

Figure 8. Heat accumulation increases with mean summer temperature in the current climate, and is projected to increase in a warmer climate.

Table 6. Risks associated with heat accumulation hastening development.

These risks were calculated for two periods. The first period from common date bud burst until the end of common date harvest is shown in the first table; the second period from the end of common date harvest until 100% leaf fall is shown in the second table. The risks were calculated as growing degree days (C°d). Model 1 uses a threshold of minimum temperature of 7°C, while Model 2 uses thresholds of 7°C for minimum temperature and 33°C for maximum temperature. Calculations have been done for the climate using the historic record, and also for warming scenarios of a 0.5°C, 1.0°C, 1.5°C and 2.0°C warmer climate. Locations are listed from the coolest mean summer temperature to the warmest mean summer temperature.

Risk of Heat accumulation from bud burst until end of harvest

				Historic record		0.5°C warmer		1°C warmer		1.5°C warmer		2°C warmer	
				Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Location	**State**	**Start**	**End**	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd
GEEVESTON	Tas	24 Aug	15 Jan	771	742	835	811	900	881	967	953	1035	1024
GROVE	Tas	24 Aug	15 Jan	820	782	883	851	948	921	1014	992	1081	1064
MT DANDENONG	Vic	24 Aug	15 Jan	767	746	828	810	891	877	957	946	1024	1016
HEALESVILLE	Vic	24 Aug	15 Jan	796	771	856	835	919	902	983	970	1049	1039
BEACONSFIELD	Tas	24 Aug	15 Jan	888	872	956	944	1025	1017	1095	1089	1166	1161
NEW NORFOLK	Tas	24 Aug	15 Jan	930	906	996	977	1064	1049	1132	1121	1201	1193
RICHMOND	Tas	24 Aug	15 Jan	952	936	1019	1007	1088	1079	1158	1152	1228	1224
MT GAMBIER	SA	24 Aug	15 Jan	1030	1015	1097	1086	1165	1158	1233	1229	1302	1301
BATLOW	NSW	24 Aug	15 Jan	919	875	978	937	1038	1002	1100	1069	1163	1136
ORANGE	NSW	24 Aug	15 Jan	1063	1031	1126	1098	1190	1166	1255	1236	1322	1306
MT BARKER	WA	24 Aug	15 Jan	1201	1196	1271	1269	1342	1341	1413	1414	1484	1486
LENSWOOD	SA	24 Aug	15 Jan	1181	1174	1249	1246	1319	1318	1389	1390	1459	1463
COLDSTREAM	Vic	24 Aug	15 Jan	1207	1198	1277	1271	1346	1343	1416	1416	1487	1488
BEECHWORTH	Vic	24 Aug	15 Jan	1089	1058	1152	1126	1217	1196	1283	1266	1350	1337
MANJIMUP	WA	24 Aug	15 Jan	1232	1227	1302	1300	1373	1372	1444	1445	1515	1517
ASHTON	SA	24 Aug	15 Jan	1273	1268	1342	1341	1412	1413	1482	1486	1553	1558
APPLETHORPE	Qld	24 Aug	15 Jan	1392	1373	1461	1445	1530	1517	1600	1589	1670	1662
STANTHORPE	Qld	24 Aug	15 Jan	1482	1462	1551	1534	1620	1607	1690	1679	1760	1751
TATURA	Vic	24 Aug	15 Jan	1349	1333	1416	1405	1484	1477	1553	1549	1621	1622
DWELLINGUP	WA	24 Aug	15 Jan	1371	1362	1440	1434	1509	1506	1579	1579	1649	1651
YOUNG	NSW	24 Aug	15 Jan	1358	1331	1423	1402	1489	1473	1556	1545	1623	1617
WANGARATTA	Vic	24 Aug	15 Jan	1375	1357	1442	1429	1509	1502	1577	1574	1645	1646
DONNYBROOK	WA	24 Aug	15 Jan	1464	1458	1534	1531	1603	1603	1673	1676	1743	1748
LOXTON	SA	24 Aug	15 Jan	1599	1599	1667	1671	1736	1744	1804	1816	1872	1889
HILLSTON	NSW	24 Aug	15 Jan	1814	1821	1881	1893	1948	1966	2015	2038	2081	2111

Risk of Heat accumulation from end of harvest until 100% leaf fall

				Historic record		0.5°C warmer		1°C warmer		1.5°C warmer		2°C warmer	
				Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Location	**State**	**Start**	**End**	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd	°Cd
GEEVESTON	Tas	16 Jan	23 May	827	809	886	872	946	935	1007	999	1069	1063
GROVE	Tas	16 Jan	23 May	857	830	914	892	973	955	1033	1018	1093	1082
MT DANDENONG	Vic	16 Jan	23 May	904	897	964	959	1025	1021	1087	1085	1150	1148
HEALESVILLE	Vic	16 Jan	23 May	920	911	979	972	1039	1034	1101	1097	1162	1160
BEACONSFIELD	Tas	16 Jan	23 May	1018	1011	1080	1075	1143	1139	1206	1203	1269	1267
NEW NORFOLK	Tas	16 Jan	23 May	966	951	1026	1014	1087	1078	1148	1142	1210	1205
RICHMOND	Tas	16 Jan	23 May	1000	992	1061	1056	1124	1120	1186	1184	1249	1248
MT GAMBIER	SA	16 Jan	23 May	1162	1159	1224	1223	1286	1287	1348	1351	1410	1415
BATLOW	NSW	16 Jan	23 May	1013	985	1070	1045	1127	1105	1185	1166	1244	1229
ORANGE	NSW	16 Jan	23 May	1121	1103	1180	1166	1240	1228	1300	1291	1362	1355
MT BARKER	WA	16 Jan	23 May	1359	1361	1422	1425	1486	1489	1549	1553	1612	1617
LENSWOOD	SA	16 Jan	23 May	1275	1276	1338	1340	1400	1404	1463	1469	1525	1533
COLDSTREAM	Vic	16 Jan	23 May	1286	1284	1348	1348	1411	1412	1473	1476	1535	1540
BEECHWORTH	Vic	16 Jan	23 May	1198	1182	1257	1245	1317	1307	1377	1371	1438	1434
MANJIMUP	WA	16 Jan	23 May	1385	1386	1448	1450	1511	1514	1574	1578	1637	1642
ASHTON	SA	16 Jan	23 May	1355	1357	1417	1421	1479	1485	1541	1549	1604	1614
APPLETHORPE	Qld	16 Jan	23 May	1322	1311	1384	1375	1446	1439	1509	1503	1572	1567
STANTHORPE	Qld	16 Jan	23 May	1413	1402	1475	1466	1538	1530	1600	1594	1663	1658
TATURA	Vic	16 Jan	23 May	1388	1381	1449	1445	1510	1509	1571	1573	1632	1637
DWELLINGUP	WA	16 Jan	23 May	1522	1523	1584	1587	1647	1651	1708	1715	1770	1780
YOUNG	NSW	16 Jan	23 May	1420	1407	1480	1470	1539	1534	1600	1598	1660	1662
WANGARATTA	Vic	16 Jan	23 May	1430	1421	1490	1485	1550	1549	1610	1613	1671	1677
DONNYBROOK	WA	16 Jan	23 May	1614	1617	1676	1682	1738	1746	1799	1810	1860	1874
LOXTON	SA	16 Jan	23 May	1545	1550	1605	1614	1665	1678	1726	1742	1786	1806
HILLSTON	NSW	16 Jan	23 May	1760	1771	1820	1835	1879	1899	1938	1963	1996	2027

Treating the risk of heat accumulation hastening development

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology and local grower meteorological stations may provide daily or hourly temperature. These data could be used to calculate heat accumulation in the current season. Historical data could be used to calculate historical heat accumulation. This information can be used by producers to assess the risks for their orchard and to make management decisions accordingly.

Can the undesired climate be avoided or the impact reduced?

- Varietal (scion/rootstock) combinations can alter phenology and move development to different time of the year.
- Netting / shading would reduce solar radiation passing to the orchard. This would be expected to reduce temperature of the leaves, buds, and fruit because the temperature of these organs will be a combination of air temperature, solar radiation heating the organ and cooling by evaporation (especially of and by the leaves). The literature provides conflicting information on relationships between netting and temperature – some saying leaf temperature is reduced, other saying air temperature is both reduced and increased under netting. This may have to do with the relative amounts by which the netting reduces solar radiation and wind speed.
- Plant growth regulators could be used to advance the commencement of crop growth. However it is important to seek specialist assistance when considering this option.
- Sprinklers can cool the orchard and delay flowering. Operating sprinklers during warm days in the winter cools the crop and can delay bloom and hence provide a measure of frost protection. Budding in cherry was delayed for 15 days when the orchards were sprinkled whenever the air temperature exceeded 6.2°C between breaking rest and bud break. However, the benefits of sprinkling depend on the humidity as well as temperature. When the sprinklers are operated, the temperature will drop to near the wet-bulb temperature, so there is little benefit in attempting to cool by sprinkling in humid environments where the dew-point temperature is close to the air temperature. However this procedure is not universally recommended as the increased sensitivity of buds to frost injury counteracts the benefits of bloom delay.
- Another possibility might be to fog or mist the air rather than use sprinklers. This could cool the air without adding water to the soil. The availability of water for irrigation (see Risk 6) will be an important consideration if using this option.
- Surfactants (kaolin clays or similar) application to leaves and fruit will reduce temperature thereby delaying crop development and fruit maturation. However it is

important to consider any impact of these surfactants on fruit quality attributes such as colour development and market requirements. Consider issues with removing surfactant from fruit after harvest and market acceptability of any remaining surfactant on fruit.

Further reading

The following publication describes the impact of temperature on ‘doubling’ in cherries, and some practical methods to reduce ‘doubling’. These include shade and surfactants.

- Whiting M, Martin R. (2008). When and how to reduce doubling in sweet cherry. *The Compact Tree Fruit* **41**:22-24.

Further information on surfactants and methods to reduce sunburn damage (consequence of light and temperature) in apples are provided in the following DPI Vic agfact.

- http://www.dpi.vic.gov.au/agriculture/horticulture/fruit-nuts/pome-fruit/sunburn-protection-for-apples

Some information on temperatures under netting can be found in the publications listed in Risk 4 with the most comprehensive being

- Rigden P. (2008). To net or not to net. 3rd edition. Queensland Government Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/documents/BusinessAndTrade_BusinessDevelopment/Orchard-Netting-Report.pdf

These publications describe heat accumulation models in European conditions. Their usefulness for Australian conditions is uncertain.

- Black B, Frisby L, Lewers K, Takeda F, Finn C. (2008). Heat unit model for predicting bloom dates in *Rubus. HortScience* **43**:2000-2004.
- Ladányi M, Persely S, Szabó T, Soltész M, Nyéki J, Szabó, Z. (2009). The application of a heat sum submodel for the budburst of sour cherry varieties grown at Újfehértó. *International Journal of Horticultural Science* **15**:105–112.
- Legave JM, Farrera I, Almeras T, Calleja M. (2008). Selecting models of apple flowering time and understanding how global warming has had an impact on this trait. *Journal of Horticultural Science and Biotechnology*. **83**: 76-84.
- Snyder RL, Spano D, Cesaraccio C, Duce P. (1999). Determining degree-day thresholds from field observations. *International Journal of Biometeorology*. **42**:177–182.

Risk 3. Temperatures being too hot or too cold for effective pollination

Identifying the risk of temperatures being too hot or too cold for effective pollination and placing it in context.

This section deals mainly with the vector of pollen, namely bees. However effective pollination also requires viable pollen, pollen tube growth, ovule viability. Pollination must occur within a given period, the effective pollination period, in order for the pollen tube to reach the ovule and for fertilisation to occur while the ovule is still receptive. The length of the effective pollination period varies with cultivar, tree conditions and temperature. As the temperature following pollination rises, the pollen-tube grows more rapidly but the time during which the ovule is receptive is reduced. Very high temperatures are detrimental to fruit set. Few absolute thresholds for pollen viability, pollen tube growth or ovule viability are reported. It is conceivable that the temperature restrictions we have used in this analysis to assess the risk of low bee activity, namely the chance (or percentage of days) when temperatures are colder than 13 or hotter than 28°C as optimal for bee activity; and the risk of reduced nectar production and flower attractiveness, namely the chance (or percentage of days) hotter than 24°C could also be used to assess risks.

It should be recognised that the classification of acceptable temperatures for bee activity as those being between 13 and 28°C is subject to uncertainty. Some reports indicate bee activity increases between 13°C and remain stable above 19°C. Others suggest the honey bee needs an internal body temperature of 35°C to fly, and that the optimal air temperature for foraging is 22-25°C and that air temperatures below 10 or above 38°C slows activity. Bee internal temperature can be regulated by shivering before flight and stopping flight for additional shivering, passive body temperature regulation in a comfort range that is a function of work effort, and finally, active heat dissipation by evaporative cooling from regurgitated honey sac contents. This highlights faults when using daily maximum temperature to classify a day into one suitable for pollination or one that is not suitable as it does not take into account the part of the day where pollination may occur but at a less than optimum rate. That is, a day with a daily maximum temperatures of 29°C would be considered unsuitable for bee foraging regardless of the fact that for most of the day the temperature will be less than 28°C and therefore acceptable for bee foraging. Unfortunately this theory of periods of unsuitable days being acceptable for bee foraging doesn’t work for days considered too cold for pollination.

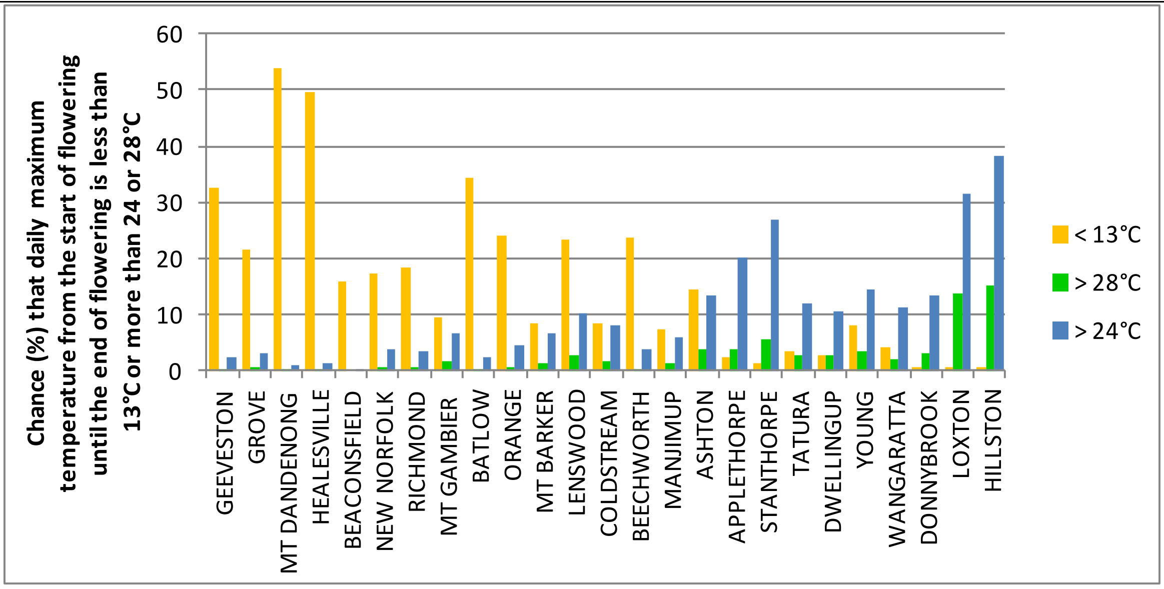
While the risk as defined above deals only with temperature, there is considerable knowledge on promoting the effectiveness of pollination. The Agnote (Agnote DAI/126. Honey bees in cherry and plum pollination NSW DPI 1999) is a useful source of information.

Analysing and evaluating the risk of temperatures being too hot or too cold for effective pollination.

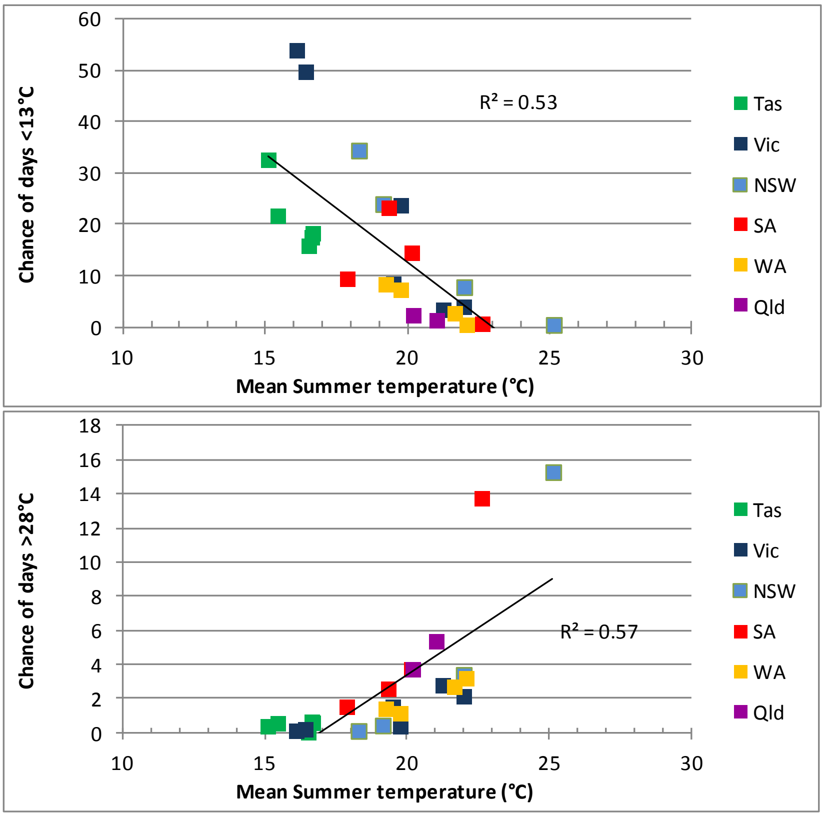
We assessed the risk of temperatures being too hot or too cold for effective pollination from the start to the end of flowering.

The risks associated with pollination temperature being too low were higher in locations having cooler mean summer temperature, while the risks of pollination temperature being too high or temperatures being too high for nectar production were higher in locations having warmer mean summer temperature. This can be observed in Figure 9 and Table 7. However, it is unlikely that conditions are sub-optimal for bee activity during all daylight hours or on all days that the orchard is in bloom. It should also be noted that many conditions determine bee activity and effective pollination.

In a warmer climate the chance of days being too cold for pollination declined while the chance of temperatures being too hot for pollination increased. This can be observed in Figure 10 and data is also shown in Table 5. The warmer climate was projected by adding either 0.5, 1.0, 1.5 or 2.0°C to the daily maximum temperature for each day and recalculating the chance of daily maximum temperatures being below 13°C or above either 24 or 28°C. The table shows these chances for each location in the historic climate and in warmer climates. The line graphs use this data to show how the chances change in the warmer climate.



There is a higher chance of cool days at cooler locations to the left hand side in the bar graph (above) and greater chance of temperatures being too at warm locations to the right hand side of the bar chart.



In the scatter plots the chance of temperatures being too low (less than 13°C) or the chance of temperatures being too high (more than 28°C) is shown for each location by an individual point coloured according to state.

Figure 9. Chance that temperatures will be too cold or too hot for effective pollination varied with location. Those with cooler mean summer temperatures had higher chance of temperatures being too cold, while those with warmer mean summer temperature had higher chance of temperatures being too hot. Data is from current climate.

The top graph shows the risk of daily maximum temperature being less than 13°C while the lower graph shows the risk of daily maximum temperature being more than 28°C during the period from the start of flowering until the end of flowering. Each line is for one location using the historic climate records and recalculating the risks if temperature increased in 0.5°C steps to a maximum of 2°C and replotting these risks with the new mean summer temperature for the location. The mean summer temperature of each location would also increase in 0.5°C steps to a maximum of 2°C warmer than the current mean temperature. The different coloured lines represent locations in Queensland (maroon), NSW (sky blue), Victoria (navy blue), Tasmania (green), SA (red) and WA (gold).

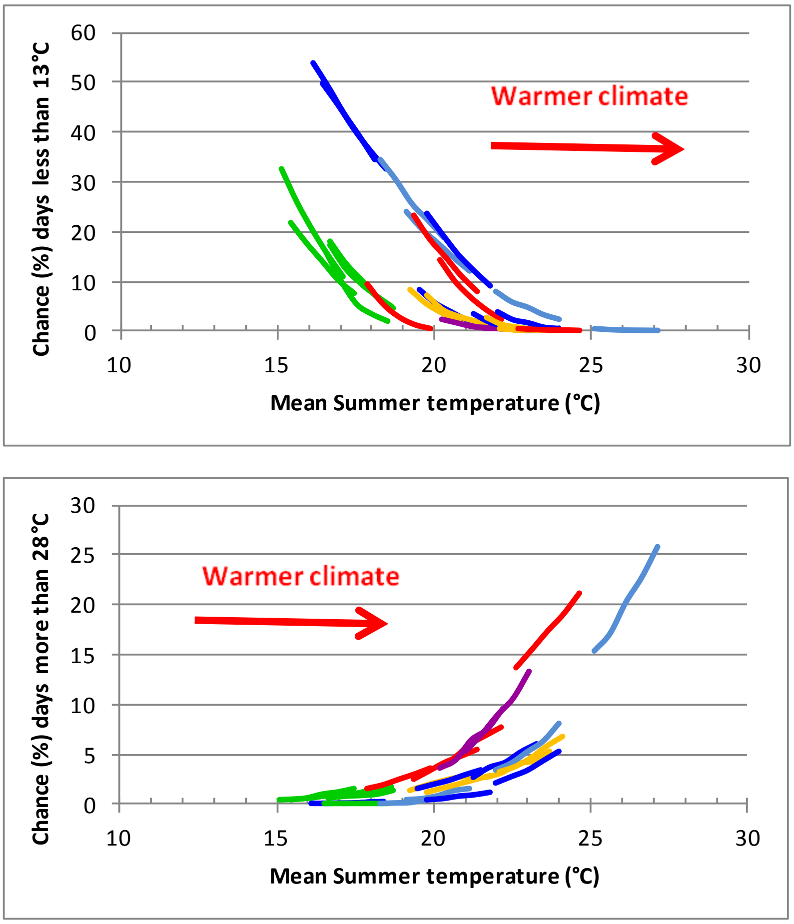


Figure 10. Impact of a warmer climate on the chance that temperatures will be too cold or too hot for effective pollination

Table 7. Risks associated with temperatures being either too cold or too hot for effective pollination.
The risks were calculated for the period from the start to the end of flowering. The risks are calculated as the chance (or percentage of days) that any day in this period is either colder than 13°C, warmer than 28°C or warmer than 24°C. Calculations have been done for the climate using the historic record, and also for several warming scenarios. These are a 0.5°C, a 1.0°C and a 2.0°C warmer climate. Locations are listed from the coolest mean summer temperature to the warmest mean summer temperature.

				Historic record			0.5°C warmer			1°C warmer			2°C warmer		
Location	**State**	**Start**	**End**	days<13°C	days>28°C	days>24°C	days<13°C	days>28°C	days>24°C	days<13°C	days>28°C	days>24°C	days<13°C	days>28°C	days>24°C
GEEVESTON	Tas	9 Sep	23 Oct	33	<1	2	26	<1	3	20	<1	3	11	1	5
GROVE	Tas	9 Sep	23 Oct	22	<1	3	18	<1	4	14	1	5	8	2	7
MT DANDENONG	Vic	9 Sep	23 Oct	54	<1	1	49	<1	2	44	<1	2	34	<1	3
HEALESVILLE	Vic	9 Sep	23 Oct	50	<1	1	45	<1	2	40	<1	3	32	<1	5
BEACONSFIELD	Tas	9 Sep	23 Oct	16	<1	<1	10	<1	<1	5	<1	<1	2	<1	<1
NEW NORFOLK	Tas	9 Sep	23 Oct	17	<1	4	13	<1	4	10	1	5	5	2	8
RICHMOND	Tas	9 Sep	23 Oct	18	<1	3	14	<1	4	10	<1	5	5	1	7
MT GAMBIER	SA	9 Sep	23 Oct	9	1	6	5	2	7	3	2	8	<1	4	11
BATLOW	NSW	9 Sep	23 Oct	35	<1	2	30	<1	3	26	<1	4	19	<1	6
ORANGE	NSW	9 Sep	23 Oct	24	<1	5	20	<1	6	18	<1	7	12	2	10
MT BARKER	WA	9 Sep	23 Oct	8	1	6	6	2	7	4	2	9	2	3	13
LENSWOOD	SA	9 Sep	23 Oct	23	3	10	18	3	12	15	4	14	8	6	18
COLDSTREAM	Vic	9 Sep	23 Oct	8	1	8	6	2	10	4	2	12	2	3	17
BEECHWORTH	Vic	9 Sep	23 Oct	24	<1	4	19	<1	5	15	<1	6	9	1	8
MANJIMUP	WA	9 Sep	23 Oct	7	1	6	4	2	7	3	2	9	1	3	12
ASHTON	SA	9 Sep	23 Oct	14	4	13	10	5	15	7	6	17	2	8	21
APPLETHORPE	Qld	9 Sep	23 Oct	2	4	20	2	4	23	<1	6	27	<1	10	36
STANTHORPE	Qld	9 Sep	23 Oct	1	5	27	<1	7	30	<1	9	34	<1	13	43
TATURA	Vic	9 Sep	23 Oct	3	3	12	2	4	14	<1	4	16	<1	6	21
DWELLINGUP	WA	9 Sep	23 Oct	3	3	10	1	3	11	<1	4	14	<1	5	19
YOUNG	NSW	9 Sep	23 Oct	8	3	14	6	4	17	5	5	20	2	8	27
WANGARATTA	Vic	9 Sep	23 Oct	4	2	11	2	3	14	2	3	16	<1	5	22
DONNYBROOK	WA	9 Sep	23 Oct	<1	3	13	<1	4	15	<1	5	18	<1	7	24
LOXTON	SA	9 Sep	23 Oct	<1	14	32	<1	15	35	<1	17	38	<1	21	45
HILLSTON	NSW	9 Sep	23 Oct	<1	15	38	<1	17	41	<1	20	46	<1	26	54

Treating the risk of temperatures being too cold or too hot for effective pollination

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology may provide daily or hourly temperature or forecast of daily temperature either for the next few days, next week or seasonal outlooks. These data could be used to assess the likely chances of temperatures not being optimal. This information can be used by producers to assess the risks for their orchard and to make management decisions accordingly.

Can the undesired climate be avoided or the impact reduced?

- Use of managed bees (instead of relying on feral hives).
- Colony strength, hive deployment, orchard preparation will influence bee activity.
- Provide water sources close to the hive.
- Netting will reduce wind which should benefit bee foraging, but net design and construction impacts on bee foraging. For example it may be worth considering placement of hives inside enclosed netting, or ensuring the size of net holes allow movement of bees to and from the flowers. Growers should actively seek information on pollination under nets as there is a large amount of current research being conducted around the world.

Further reading

The following NSW DPI publication provides comprehensive information about increasing the effectiveness of bees as pollinators.

- NSW DPI (1999). Honey bees in cherry and plum pollination Agnote DAI/126. Revised August 1999 Doug Somerville District Livestock Officer (Apiculture) Goulburn. Edited by Robert West Produced by Information Delivery Program, Orange. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/117109/bee-cherry-plum-pollination.pdf

Some information on bee foraging under netting can be found in

- Rigden P. (2008). To net or not to net. 3rd edition. Queensland Government Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/documents/BusinessAndTrade_BusinessDevelopment/Orchard-Netting-Report.pdf

These publications detail additional, quite specific information on bee foraging.

- Corbet SA, Fussell M, Ake R, Fraser A, Gunson C, Savage A, Smith K. (1993). Temperature and the pollinating activity of social bees. *Ecological entomology* **18**:17-30.
- Heinrich, B.(1996).How the honey bee regulates its body temperature. *Bee world*.**77**:130-137.
- Heinrich, B.(1979).Keeping a cool head: honeybee thermoregulation.*Science*.**205**:1269-1271.
- Johansson TSK, Johansson MP.(1978).Providing honeybees with water.*Bee World*. **59**:11-17.
- Waller GD.(1980).Beekeeping in the United States. Agricultural handbook number 335 pages 73-77.

Risk 4. Heatwaves affecting crop growth

Identifying the risk of heatwaves and placing it in context.

There is considerable circumstantial evidence that heat waves affect the phenology and quality of cherries, but there are few data from controlled experiments. Heatwaves can influence cherry production both before and after harvest. Damage to the current years' crop could arise through impacts on pollination, flower and fruit development and retention, or leaf damage. Damage to the following years' crop can occur after harvest of the current year because high temperatures can influence 'doubling'.

An increase in mean temperature is likely to increase the chance of extreme hot temperatures. We have greater certainty for the mean daily temperature of a location than of temperature extremes that may be experienced at a location. Saying this there is high confidence that climate change will affect heatwaves because there is high confidence in general warming. All things considered there is moderate confidence of an increase in frequency and intensity of heatwaves in summer.

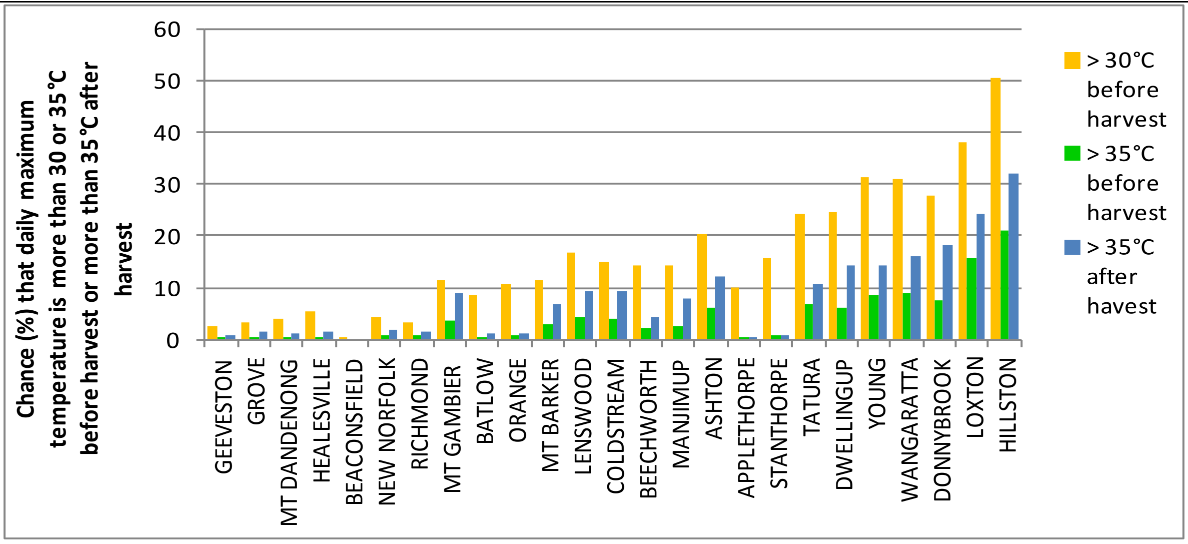
It should be noted that hot days usually have high evapotranspiration, thus heatwaves are usually accompanied by dry days, so damage can occur because of excessive heat combined with lack of water.

Analysing and evaluating the risk of heatwaves.

We assessed heat accumulation for two periods. The first period was from budburst to harvest, and the second for 2 months after harvest. For most locations the calculated risks increased after harvest.

The risk of heatwaves was assessed by the chance (or percentage of days) above 30, 35 or 40°C. The risk of days above 30 or 35°C was higher in already warm locations. The risk of maximum temperatures above 40°C is zero or close to zero for almost all locations except a few already hot inland locations. In all locations there is as great or greater risk of daily maximum temperatures being above 35°C in the 2 months after harvest as the period from end of flowering to harvest. This information can be seen in Figure 11 and in Table 8.

A warmer climate increases the chance of hot days more in already warm locations (Figure 12). In many already warm locations the chance of extremely hot days over 40°C rises by 50% or doubles in a 2°C warmer climate. These increases in hot days are observed in the period from flowering to harvest and in the 2 months following harvest. For most locations, apart from those in Tasmania and cooler locations in NSW and Vic, the chance of daily maximum temperature above 35°C increases by 10% in a 2°C warmer climate. Research has shown that the critical temperature causing ‘doubling’ in cherry crops is 35°C (Whiting and Martin, 2008). It is unknown for how many days this temperature must be reached before ‘doubling’ is affected.



There is a higher chance of heatwaves at warmer locations to the right hand side in the bar graph (above).
The scatter plots show the chance of temperatures being above 30 or 35°C is related to mean summer temperature with some inland locations in SA and NSW and some in WA having already high chance of hot days. However, for some locations such as those in Tas, Qld and some in Vic and NSW there is almost no chance of temperatures being above 35°C. The locations in Qld are unusual in that this occurs despite high mean summer temperature. Each location is shown by an individual point coloured according to state.

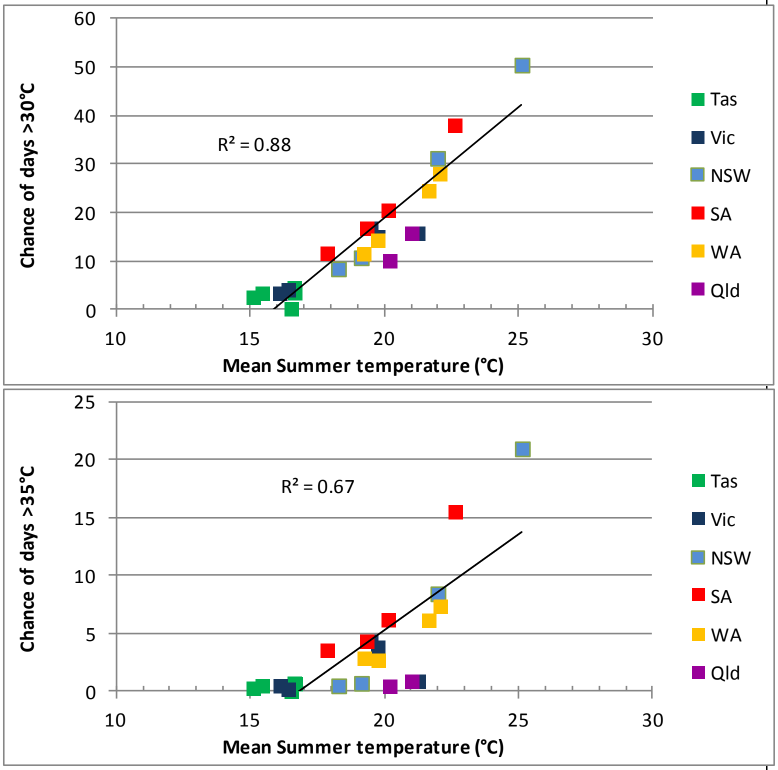
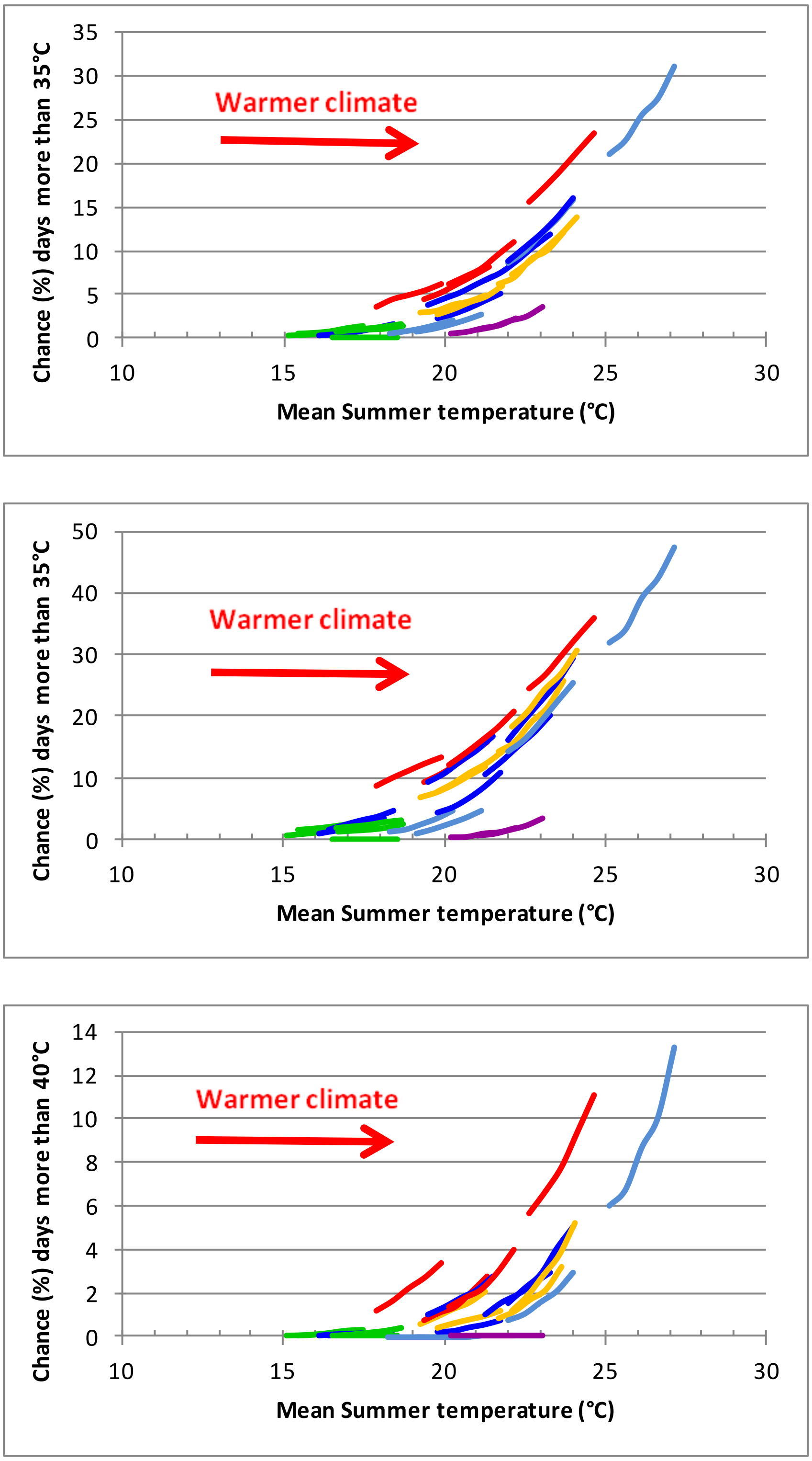


Figure 11. The chance of hot days is greater in locations with warmer mean summer temperature in the current climate.



The chance of days being above 35°C in the period from flowering to harvest (above), or for the period of 2 months after harvest (above right). The chance of days being above 40°C for the period of 2 months after harvest (right) is also shown. Each line in the graphs is for a single location using the historic climate records and recalculating the risks if temperature increased in 0.5°C steps to a maximum of 2°C and replotting these risks with the new mean summer temperature for the location. The mean summer temperature of each location would also increase in 0.5°C steps to a maximum of 2°C warmer than the current mean temperature. The different coloured lines represent locations in Queensland (maroon), NSW (sky blue), Victoria (navy blue), Tasmania (green), SA (red) and WA (gold).

Figure 12. Chance of heatwaves increases in a warmer climate.

Table 8. Risks associated with heatwaves.

These risks were calculated for two periods. The first period from the end of flowering until the end of harvest is shown in the first table; the second period from the end of harvest for 2 months is shown in the second table. The risks are calculated the chance (or percentage of days) that the maximum temperature for any day in the period is warmer than 30°C, or warmer than 35°C, or warmer than 40°C. Calculations have been done for the climate using the historic record, and also for several warming scenarios. These are a 0.5°C, a 1.0°C and a 2.0°C warmer climate. Locations are listed from the coolest mean summer temperature to the warmest mean summer temperature.

Risk of heatwaves from bud burst until the end of harvest

				Historic record				0.5°C warmer				1°C warmer				2°C warmer		
Location	**State**	**Start**	**End**	days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C
GEEVESTON	Tas	16 Oct	15 Jan	2	<1	<1		3	<1	<1		3	<1	<1		5	<1	<1
GROVE	Tas	16 Oct	15 Jan	3	<1	<1		4	<1	<1		4	<1	<1		6	1	<1
MT DANDENONG	Vic	16 Oct	15 Jan	4	<1	<1		5	<1	<1		6	<1	<1		7	1	<1
HEALESVILLE	Vic	16 Oct	15 Jan	5	<1	<1		6	<1	<1		7	<1	<1		10	2	<1
BEACONSFIELD	Tas	16 Oct	15 Jan	<1	<1	<1		<1	<1	<1		<1	<1	<1		<1	<1	<1
NEW NORFOLK	Tas	16 Oct	15 Jan	4	<1	<1		5	<1	<1		6	1	<1		7	2	<1
RICHMOND	Tas	16 Oct	15 Jan	3	<1	<1		4	<1	<1		5	<1	<1		6	1	<1
MT GAMBIER	SA	16 Oct	15 Jan	12	4	<1		13	4	<1		14	5	<1		16	6	1
BATLOW	NSW	16 Oct	15 Jan	8	<1	<1		10	<1	<1		12	1	<1		16	2	<1
ORANGE	NSW	16 Oct	15 Jan	11	<1	<1		13	1	<1		15	2	<1		19	3	<1
MT BARKER	WA	16 Oct	15 Jan	11	3	<1		13	3	<1		14	4	<1		17	5	<1
LENSWOOD	SA	16 Oct	15 Jan	17	4	<1		18	5	<1		20	6	<1		24	8	1
COLDSTREAM	Vic	16 Oct	15 Jan	15	4	<1		16	4	<1		18	5	<1		22	7	1
BEECHWORTH	Vic	16 Oct	15 Jan	14	2	<1		16	3	<1		18	3	<1		24	5	<1
MANJIMUP	WA	16 Oct	15 Jan	14	3	<1		16	3	<1		17	4	<1		21	6	<1
ASHTON	SA	16 Oct	15 Jan	20	6	<1		22	7	<1		24	8	<1		28	11	2
APPLETHORPE	Qld	16 Oct	15 Jan	10	<1	<1		12	<1	<1		16	1	<1		23	2	<1
STANTHORPE	Qld	16 Oct	15 Jan	16	<1	<1		18	1	<1		22	2	<1		31	4	<1
TATURA	Vic	16 Oct	15 Jan	24	7	<1		27	8	<1		30	9	1		35	12	2
DWELLINGUP	WA	16 Oct	15 Jan	24	6	<1		26	7	<1		30	9	<1		35	12	1
YOUNG	NSW	16 Oct	15 Jan	31	9	<1		34	10	<1		38	12	1		44	16	2
WANGARATTA	Vic	16 Oct	15 Jan	31	9	<1		34	10	1		37	12	2		42	16	3
DONNYBROOK	WA	16 Oct	15 Jan	28	7	<1		30	9	<1		33	10	<1		39	14	2
LOXTON	SA	16 Oct	15 Jan	38	16	3		41	17	4		43	19	5		49	23	6
HILLSTON	NSW	16 Oct	15 Jan	50	21	4		52	23	5		56	26	6		62	31	9

Risk of heatwaves from end of harvest for 2 months

				Historic record				0.5°C warmer				1°C warmer				2°C warmer		
Location	**State**	**Start**	**End**	days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C		days>30°C	days>35°C	days>40°C
GEEVESTON	Tas	16 Jan	15 Mar	5	<1	<1		6	<1	<1		7	1	<1		9	2	<1
GROVE	Tas	16 Jan	15 Mar	7	2	<1		8	2	<1		9	2	<1		12	3	<1
MT DANDENONG	Vic	16 Jan	15 Mar	10	1	<1		12	1	<1		13	2	<1		17	3	<1
HEALESVILLE	Vic	16 Jan	15 Mar	13	2	<1		15	2	<1		17	3	<1		21	5	<1
BEACONSFIELD	Tas	16 Jan	15 Mar	<1	<1	<1		<1	<1	<1		1	<1	<1		2	<1	<1
NEW NORFOLK	Tas	16 Jan	15 Mar	9	2	<1		10	2	<1		12	2	<1		15	3	<1
RICHMOND	Tas	16 Jan	15 Mar	6	1	<1		7	2	<1		8	2	<1		11	3	<1
MT GAMBIER	SA	16 Jan	15 Mar	22	9	1		24	10	2		25	11	2		28	13	3
BATLOW	NSW	16 Jan	15 Mar	17	1	<1		19	2	<1		23	2	<1		31	5	<1
ORANGE	NSW	16 Jan	15 Mar	18	1	<1		21	2	<1		24	3	<1		32	5	<1
MT BARKER	WA	16 Jan	15 Mar	22	7	<1		24	8	<1		26	9	1		32	12	2
LENSWOOD	SA	16 Jan	15 Mar	30	9	<1		32	10	1		34	12	1		38	16	3
COLDSTREAM	Vic	16 Jan	15 Mar	31	9	<1		33	11	1		36	13	2		41	17	3
BEECHWORTH	Vic	16 Jan	15 Mar	29	4	<1		33	5	<1		38	7	<1		47	11	<1
MANJIMUP	WA	16 Jan	15 Mar	30	8	<1		32	9	<1		35	11	<1		41	14	1
ASHTON	SA	16 Jan	15 Mar	34	12	1		36	14	2		38	16	2		43	21	4
APPLETHORPE	Qld	16 Jan	15 Mar	11	<1	<1		13	<1	<1		17	1	<1		25	2	<1
STANTHORPE	Qld	16 Jan	15 Mar	17	<1	<1		20	1	<1		25	2	<1		34	4	<1
TATURA	Vic	16 Jan	15 Mar	43	11	<1		47	13	2		51	15	2		59	20	3
DWELLINGUP	WA	16 Jan	15 Mar	48	14	<1		51	16	1		56	19	2		63	26	3
YOUNG	NSW	16 Jan	15 Mar	52	14	<1		56	16	1		60	19	2		68	25	3
WANGARATTA	Vic	16 Jan	15 Mar	57	16	2		62	19	2		66	22	3		73	29	5
DONNYBROOK	WA	16 Jan	15 Mar	54	18	1		57	21	2		61	24	3		70	31	5
LOXTON	SA	16 Jan	15 Mar	54	24	6		57	27	7		61	30	8		68	36	11
HILLSTON	NSW	16 Jan	15 Mar	71	32	6		73	34	7		77	39	9		82	48	13

Treating the risk of heatwaves

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology may provide forecast of daily temperature either for the next few days, next week or seasonal outlooks. They also issue warnings of chance of heatwaves. This information can allow producers to assess the risks and to prepare the orchard for heatwave conditions.

Can the undesired climate be avoided or the impact reduced?

- Ensure soil profile is wet as a well watered crop will be more able to cope with heatwaves than one experiencing a water deficit.
- Sprinkler / evaporative cooling during the heat event but similar issues regarding availability of irrigation water. Additionally consider plant health issues associated with increasing wetness of leaves or fruit.
- Surfactant sprays (particle film technology based either on refined kaolin clay or calcium carbonate crystals) on leaves and /or fruit can reflect light and heat thereby effectively avoiding heat damage. Consider issues with removing surfactant from fruit after harvest and market acceptability of any remaining surfactant on fruit.
- Netting / shading would reduce solar radiation passing to the orchard. This would be expected to reduce temperature of the leaves, buds, and fruit as the temperature of these organs will be a combination of air temperature, solar radiation heating the organ and evaporative cooling (especially of and by the leaves). The literature provides conflicting information on relationships between netting and temperature – some saying leaf temperature is reduced, other saying air temperature is both reduced and increased under netting.
- Varietal selection may be an option by changing to a variety (or scion – rootstock combination) that is more able to cope with extreme heat events or is likely to experience heat events at a less vulnerable time.

Further reading

The following publications describe experiments using surfactants, and/or netting on reducing temperature in orchards.

- Prive JP, Russell L., LeBlanc A. (2007). Gas exchange of apple and blackberry leaves treated with a kaolin particle film on adaxial, abaxial, or both leaf surfaces. *Hortscience* **42**: 1177-82.
- Gindaba J, Wand SJE. (2005). Comparative effects of evaporative cooling, kaolin particle film, and shade net on sunburn and fruit quality in apples. *Hortscience*. **40**:592-596.

Further information on the effectiveness of netting can be found in

- Rigden P. (2008). To net or not to net. 3rd edition. Queensland Government Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/documents/BusinessAndTrade_BusinessDevelopment/Orchard-Netting-Report.pdf

and

- George AP, Nissen RJ, Topp B, Brunn D. (2004). Producing super-sweet peaches and nectarines under sub-tropical climates in "Production technologies for low-chill temperate fruits. Reports from the Second International Workshop, 19–23 April 2004, Chiang Mai, Thailand" http://aciar.gov.au/files/node/641/TR61%20Part%201.pdf

The following publication describes the impact of temperature on 'doubling' in cherries, and some practical methods to reduce 'doubling'.

- Whiting M, Martin R. (2008). When and how to reduce doubling in sweet cherry. *The Compact Tree Fruit* **41**:22-24.

Risk 5. Frost damage

Identifying the risk of frost and placing it in context.

Frost risk is a complex event dependent on the phenology of the crop, the weather and climate, and orchard topography. The weather plays a role as conditions close to the frost event can affect its formation and severity. The climate can play a role as warm winters may result in an earlier spring budburst and this can lead to a higher risk of frost and damage to crops. This means that even if the frequency of frost stays the same or decreases, changes in phenology of the cherry crop may increase frost risk due to earlier budburst. This is somewhat similar to the higher frost risk of earlier budburst varieties that have new growth present when nights are more likely to be both longer and colder.

Frost depends not just on night temperature. Frosts will typically occur in a weather pattern of a cold, cloudy day followed by a still and cloudless night. The rates of day-time heating and night-time cooling can affect the development of frost. On cool cloudy days the soil or vegetation surface has had little opportunity to heat up, and on a still and cloudless night the soil will cool quickly after sunset.

Climate change is likely to cause greater warming at night which will reduce risk of frost. However, increased drying may counter this trend. This could be associated with either drier soils or clearer nights. Some regions have already observed high levels of frost risk in recent years arising from unusually dry conditions in spring. Wet soil can reduce the risk of frost. This is because wet soil stores more heat than dry soil during the day and loses this heat during the night to the surrounding air and plants.

Mean temperature for bud freeze-kill changes with bud development with warmer temperatures causing damage in more developed buds (cited in Thompson, 1996). Lower temperature for longer periods below the critical temperature will cause more damage to the plant. A bud freeze-kill temperature of between -2 and -3°C is reported as causing 10% damage and between -3 and -4°C as causing 50% damage during the later stages of development. Other reports indicate temperature less than -2°C causes frost damage to flowers and temperatures below -4°C cause 50% loss of flowers (cited in Marshall, 1954).

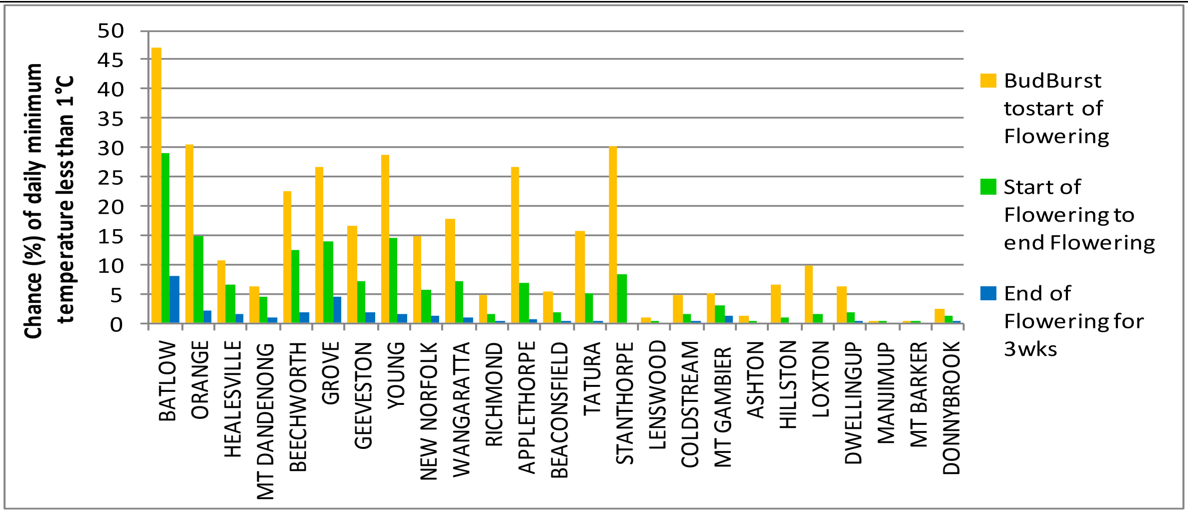
Analysing and evaluating the risk of frost.

Frost risk was assessed for three periods of the year. The three periods were from budburst to the 2nd week of flowering; from the 3rd week of flowering until the end of flowering; and for 3 weeks after flowering has ended.

We assessed frost risk as the chance (or percentage of days) that daily minimum temperature was cooler than 1°C, 0°C or -2°C during each period. The three temperatures were used as critical temperatures that can result in frost damage change with plant phenology. The warmer temperature threshold of 1°C is a conservative value used as an indicator of the potential for frost to occur. This is also the temperature used in the Bureau of Meteorology frost warnings. Thermometers for standard temperature measurements are located in a Stevenson screen shelter at a height of approximately 1.2 m above the ground. An observed temperature of about 2°C at Stevenson screen shelter height indicates that the temperature at ground level is approximating 0°C.

Table 9 and Figure 13 show the chance of days having daily minimum temperatures cooler than the three temperatures during the period from budburst to the start of flowering, and from the start of flowering until the end of flowering. The chance of minimum temperatures being less than 1°C were low for the third period of 3 weeks after flowering has ended in all but the coldest locations. In Table 9 each period is shown in a separate sub-table. The data in these tables show these chances in the historic climate and in climates that were 0.5, 1.0, 1.5 and 2.0°C warmer than the historic climate. We added these warming temperatures to the historic climate and then re-calculated the chance of days being colder than the three temperatures. A warmer climate reduces the chance of colder days. However, as mentioned earlier the risk of frost occurring is related to other events not just minimum temperatures so these risks based only on minimum temperature are a guide only.

The effect of a warming climate on the frost risk is also shown in Figure 14. A warming climate was projected by adding up to 2°C to the historic climate records. A warmer climate reduces the chance of colder minimum temperatures. In locations that are currently cool there is a dramatic decline in the chances of minimum temperature being less than 1°C, while in locations that are already warm such as those in WA, SA and some locations in other states, the chances of cold nights are already low and a warmer climate has only a small affect on reducing the chance of colder nights.



The bar chart shows the chance of daily minimum temperature being cooler than 1°C for the three periods at each location. Not surprisingly The risks associated with frost were higher in locations having cooler mean winter temperature, and the chance of cooler temperatures decreases later in the year but some locations do not fit this trend. This can be seen by generally higher chance of cool nights at locations to the left hand side in the bar graph (above) and also the scatter plots (to right). In the scatter plot each location is shown by an individual point coloured according to state.

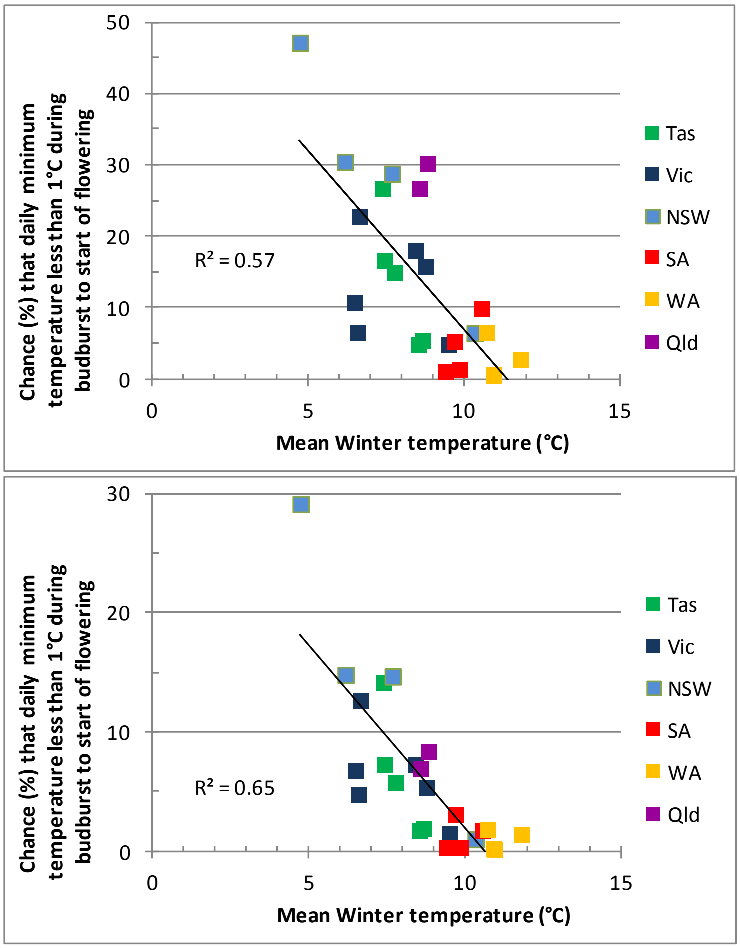


Figure 13. Riskof frost, measured as chance of days being cooler than 1°C, was higher in locations having cooler mean winter temperature in the current climate.

The top graph shows the risk of daily minimum temperature being less than 1°C during the periods from budburst to the start of flowering. The middle graph shows the same risk but for the period from start of flowering to the end of flowering. The lower graph shows the same risk but for the period from the end of flowering for 3 weeks. Each line is for one location using the historic climate records and recalculating the risks if temperature increased in 0.5°C steps to a maximum of 2°C and replotting these risks with the new mean winter temperature for the location. The mean winter temperature of each location would also increase in 0.5°C steps to a maximum of 2°C warmer than the current mean temperature. The different coloured lines represent locations in Queensland (maroon), NSW (sky blue), Victoria (navy blue), Tasmania (green), SA (red) and WA (gold).

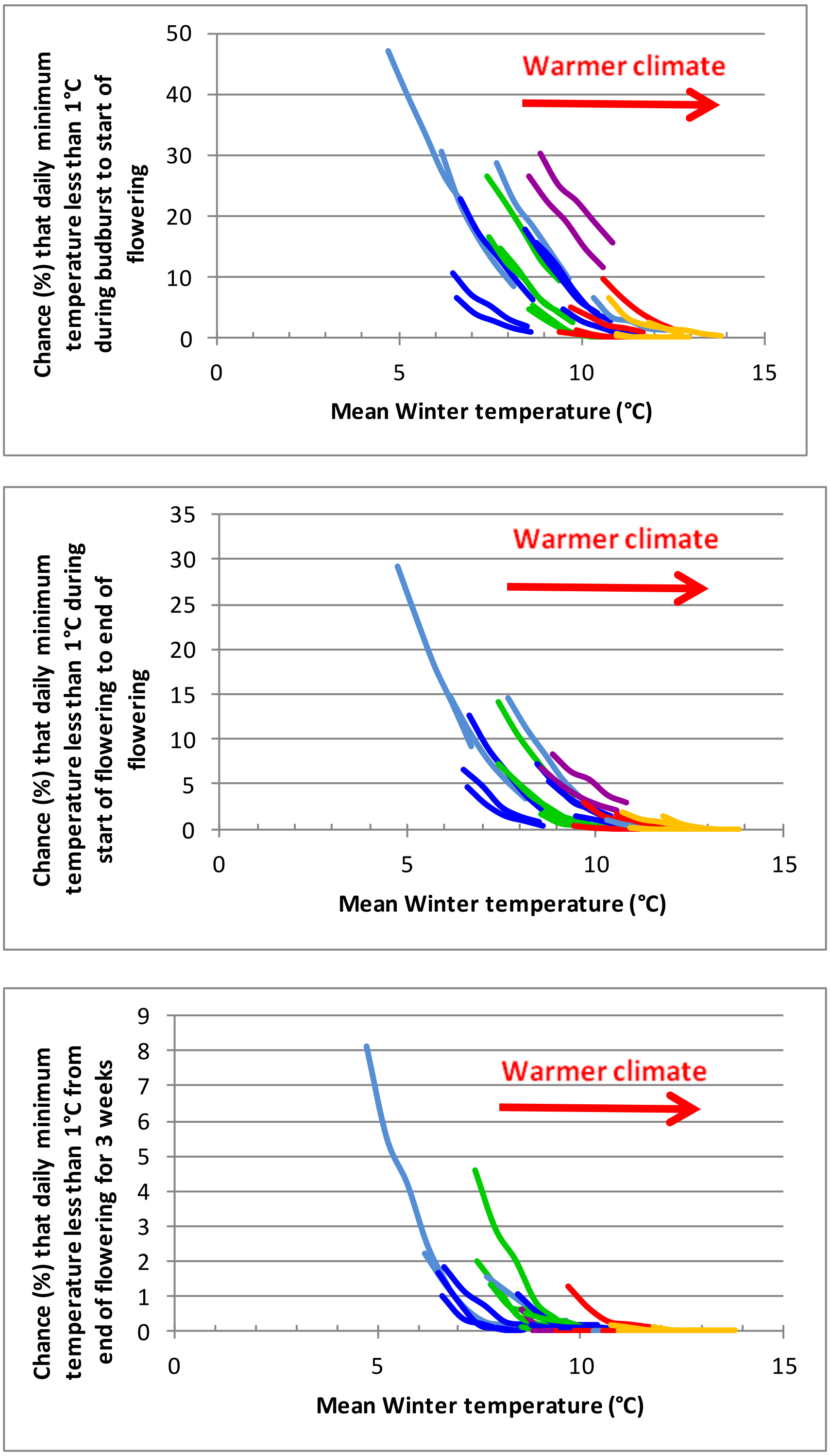


Figure 14. Frost risk measured as chance of days being cooler than 1°C is expected to decline in a warming climate

Table 9. Risks associated with Frost.

These risks were calculated for three periods. The first period from bud burst until the start of flowering is shown in the first table; the second period from the start of flowering until the end of flowering is shown in the second table; the third period from the end of flowering for 3 weeks in shown in the third table. The risks are calculated as the chance (or percentage of days) that the minimum temperature for any day in the period is less than 1°C, or less than 0°C, or less than -2°C. Calculations have been done for the climate using the historic record, and also for several warming scenarios. These are a 0.5°C, a 1.0°C and a 2.0°C warmer climate. Locations are listed from the coldest mean winter temperature to the warmest mean winter temperature.

Risk of Frost from bud burst until the start of flowering

				Historic record			0.5°C warmer			1°C warmer			2°C warmer		
Location	**State**	**Start**	**End**	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C
BATLOW	NSW	24 Aug	8 Sep	47	34	13	40	27	10	34	22	7	22	13	3
ORANGE	NSW	24 Aug	8 Sep	30	16	4	22	12	2	16	8	1	8	4	<1
HEALESVILLE	Vic	24 Aug	8 Sep	11	5	<1	7	3	<1	5	2	<1	2	<1	<1
MT DANDENONG	Vic	24 Aug	8 Sep	6	3	<1	4	2	<1	3	1	<1	1	<1	<1
BEECHWORTH	Vic	24 Aug	8 Sep	23	14	2	17	10	1	14	6	<1	6	2	<1
GROVE	Tas	24 Aug	8 Sep	27	18	4	22	13	2	18	9	2	9	4	<1
GEEVESTON	Tas	24 Aug	8 Sep	17	9	1	12	6	<1	9	4	<1	4	1	<1
YOUNG	NSW	24 Aug	8 Sep	29	18	4	22	14	3	18	10	<1	10	4	<1
NEW NORFOLK	Tas	24 Aug	8 Sep	15	7	<1	11	5	<1	7	2	<1	2	<1	<1
WANGARATTA	Vic	24 Aug	8 Sep	18	10	<1	14	6	<1	10	4	<1	4	<1	<1
RICHMOND	Tas	24 Aug	8 Sep	5	1	<1	3	<1	<1	1	<1	<1	<1	<1	<1
APPLETHORPE	Qld	24 Aug	8 Sep	27	19	5	22	15	4	19	12	2	12	5	1
BEACONSFIELD	Tas	24 Aug	8 Sep	5	1	<1	3	<1	<1	1	<1	<1	<1	<1	<1
TATURA	Vic	24 Aug	8 Sep	16	8	<1	12	4	<1	8	3	<1	3	<1	<1
STANTHORPE	Qld	24 Aug	8 Sep	30	22	7	25	19	4	22	16	3	16	7	1
LENSWOOD	SA	24 Aug	8 Sep	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
COLDSTREAM	Vic	24 Aug	8 Sep	5	2	<1	3	<1	<1	2	<1	<1	<1	<1	<1
MT GAMBIER	SA	24 Aug	8 Sep	5	2	<1	4	2	<1	2	1	<1	1	<1	<1
ASHTON	SA	24 Aug	8 Sep	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
HILLSTON	NSW	24 Aug	8 Sep	6	3	<1	3	2	<1	3	1	<1	1	<1	<1
LOXTON	SA	24 Aug	8 Sep	10	4	<1	7	3	<1	4	1	<1	1	<1	<1
DWELLINGUP	WA	24 Aug	8 Sep	6	2	<1	3	2	<1	2	<1	<1	<1	<1	<1
MANJIMUP	WA	24 Aug	8 Sep	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MT BARKER	WA	24 Aug	8 Sep	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
DONNYBROOK	WA	24 Aug	8 Sep	3	1	<1	1	<1	<1	1	<1	<1	<1	<1	<1

Risk of Frost from start of flowering until end of flowering

				Historic record			0.5°C warmer			1°C warmer			2°C warmer		
Location	**State**	**Start**	**End**	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C
BATLOW	NSW	9 Sep	23 Oct	29	18	4	24	14	3	18	6	2	9	4	<1
ORANGE	NSW	9 Sep	23 Oct	15	8	1	11	5	<1	8	2	<1	3	1	<1
HEALESVILLE	Vic	9 Sep	23 Oct	7	3	<1	5	1	<1	3	<1	<1	<1	<1	<1
MT DANDENONG	Vic	9 Sep	23 Oct	5	1	<1	3	<1	<1	1	<1	<1	<1	<1	<1
BEECHWORTH	Vic	9 Sep	23 Oct	13	6	<1	9	4	<1	6	1	<1	2	<1	<1
GROVE	Tas	9 Sep	23 Oct	14	8	1	11	5	<1	8	2	<1	3	1	<1
GEEVESTON	Tas	9 Sep	23 Oct	7	3	<1	5	2	<1	3	<1	<1	<1	<1	<1
YOUNG	NSW	9 Sep	23 Oct	15	8	1	11	6	<1	8	2	<1	3	1	<1
NEW NORFOLK	Tas	9 Sep	23 Oct	6	2	<1	4	1	<1	2	<1	<1	<1	<1	<1
WANGARATTA	Vic	9 Sep	23 Oct	7	3	<1	5	2	<1	3	<1	<1	1	<1	<1
RICHMOND	Tas	9 Sep	23 Oct	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
APPLETHORPE	Qld	9 Sep	23 Oct	7	4	<1	5	3	<1	4	1	<1	2	<1	<1
BEACONSFIELD	Tas	9 Sep	23 Oct	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
TATURA	Vic	9 Sep	23 Oct	5	2	<1	4	1	<1	2	<1	<1	<1	<1	<1
STANTHORPE	Qld	9 Sep	23 Oct	8	6	1	6	4	<1	6	2	<1	3	1	<1
LENSWOOD	SA	9 Sep	23 Oct	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
COLDSTREAM	Vic	9 Sep	23 Oct	1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
MT GAMBIER	SA	9 Sep	23 Oct	3	1	<1	2	<1	<1	1	<1	<1	<1	<1	<1
ASHTON	SA	9 Sep	23 Oct	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
HILLSTON	NSW	9 Sep	23 Oct	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
LOXTON	SA	9 Sep	23 Oct	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
DWELLINGUP	WA	9 Sep	23 Oct	2	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
MANJIMUP	WA	9 Sep	23 Oct	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MT BARKER	WA	9 Sep	23 Oct	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
DONNYBROOK	WA	9 Sep	23 Oct	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Risk of Frost from the end of flowering for 3 weeks

				Historic record			0.5°C warmer			1°C warmer			2°C warmer		
Location	**State**	**Start**	**End**	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C	days <1°C	days <0°C	days <-2°C
BATLOW	NSW	24 Oct	15 Nov	8	4	<1	6	2	<1	4	1	<1	1	<1	<1
ORANGE	NSW	24 Oct	15 Nov	2	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
HEALESVILLE	Vic	24 Oct	15 Nov	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MT DANDENONG	Vic	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
BEECHWORTH	Vic	24 Oct	15 Nov	2	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
GROVE	Tas	24 Oct	15 Nov	5	2	<1	3	<1	<1	2	<1	<1	<1	<1	<1
GEEVESTON	Tas	24 Oct	15 Nov	2	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
YOUNG	NSW	24 Oct	15 Nov	2	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
NEW NORFOLK	Tas	24 Oct	15 Nov	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
WANGARATTA	Vic	24 Oct	15 Nov	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
RICHMOND	Tas	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
APPLETHORPE	Qld	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
BEACONSFIELD	Tas	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
TATURA	Vic	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
STANTHORPE	Qld	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
LENSWOOD	SA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
COLDSTREAM	Vic	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MT GAMBIER	SA	24 Oct	15 Nov	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
ASHTON	SA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
HILLSTON	NSW	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
LOXTON	SA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
DWELLINGUP	WA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MANJIMUP	WA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
MT BARKER	WA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
DONNYBROOK	WA	24 Oct	15 Nov	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Treating the risk of frost

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology may provide forecast of daily temperature either for the next few days, next week or seasonal outlooks. They also issue warnings of chance of frost. This information can allow producers to assess the risks and to prepare the orchard for frost conditions.
- Local Meteorological stations on grower properties can be used to assess local temperature and hence provide an indication that frost events may occur.

Can the undesired climate be avoided or the impact reduced?

The FAO report of Frost prevention by Snyder, R., Paulo de Melo-Abreu, J. (2005) provides a number of methods by which the impact of frost may be prevented or reduced. They also provide informative explanations on why each method may be useful and practical methods for applying each technique including suggested rates of irrigation, if this method was used to reduce frost. Good local sources of information are the Departments of Agriculture or Department of Primary Industries. The Victorian Department of Primary Industry has produced a comprehensive and practical Agnote on frost prevention - Victorian DPI Agnote (2011) Be Prepared for frost AG1424.

Some options for managing frost include:

- Irrigation can be used to reduce frost risk as the water in the soil acts as a heat reservoir increasing daytime heat absorption and increasing night-time heat release. Additionally irrigation during the night can reduce frost risk. Overhead sprinklers can be used with good effect to prevent frost damage, but application rate has to be closely controlled. Too little water and plants freeze, too much water and orchards become waterlogged, thereby exchanging one damaging condition for another.
- Netting can reduce wind which may affect cold air drainage and therefore may affect frost risk. Netting can also affect air temperature and reduce solar radiation that passes through the net and to the soil. This could reduce heating of the soil and therefore the release of stored heat from the soil to the air during the night.
- Increasing wind movement limits cold air coming into contact with trees. Wind can be generated by wind machines or helicopters.

Further reading

The following Victorian DPI publication offers clear practical advice on frost risk

- DPI Victoria (2011). Be Prepared for frost AG1424 http://www.dpi.vic.gov.au/agriculture/horticulture/fruit-nuts/orchard-management/be-prepared-for-frost

The FAO publication offers detailed information on the causes of frost and details many passive and active control measures.

- Snyder R, Paulo de Melo-Abreu J. (2005). Frost Protection: fundamentals, practice and economics Volume 1. Food and Agriculture Organization of the United Nations Rome. http://www.fao.org/docrep/008/y7223e/y7223e00.htm

Risk 6. Insufficient rain or irrigation water for growth

Identifying the risk of insufficient rain or irrigation water for growth and placing it in context.

Knowledge of rainfall and evaporative demand is important as many cherry growing regions rely on water stored in the soil over the winter and spring period and irrigation in the summer growing period. Additionally many horticultural pests and diseases are very sensitive to rainfall, humidity and temperature (both day and night temperature). Some simple models exist and could be run under climate change projections.

There is low to medium confidence in rainfall projections. However it is generally anticipated to be drier in winters and springs with lower confidence in projections for summer. Although rainfall intensity is likely to increase, it is difficult to identify the timing. Generalised circulation models (GCM's) are uncertain on how daily rainfall events will be affected. For example, will only low rainfall days be lost or will each rain event be reduced. This has implications for water run-off because run-off is a function of the size of the rain event. A rule of thumb that applies to most inland areas of Australia is that a 10% decline in rainfall may result in a 20 to 30% decline in runoff (Chiew 2006).

Evaporation is the counter balance to rainfall. There is medium to high confidence in an increase in evaporative demand with rising temperatures. This increase is approximately 2 to 3% in potential evapotranspiration (ETo) for each 1°C rise in temperature (Lockwood 1999). Associated with changes in ETo is the observation that a higher concentration of CO_2 in the atmosphere will impact on the transpiration efficiency and canopy growth and hence will change the water balance. Rainfall varied considerable both between locations and between seasons.

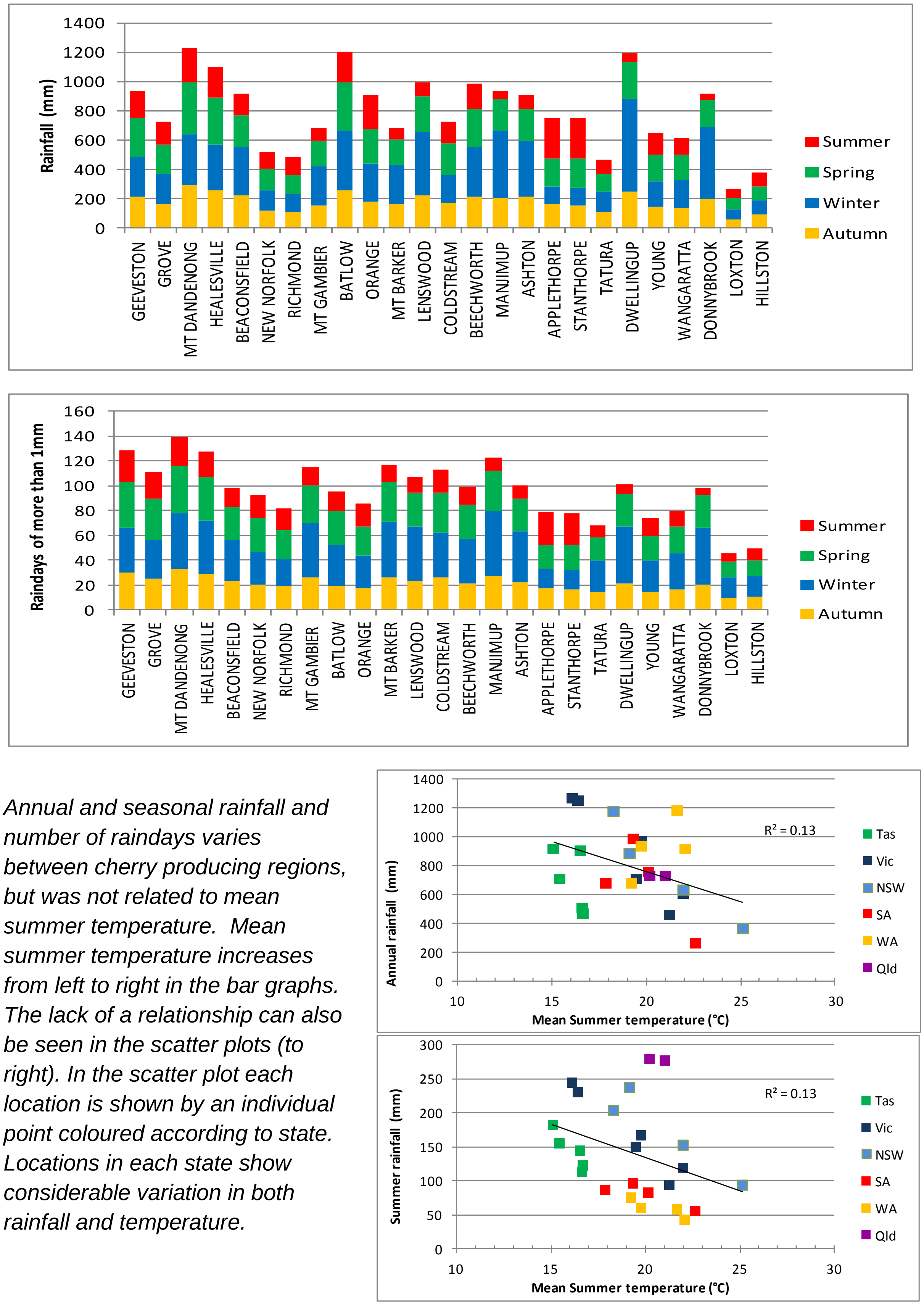
Analysing and evaluating the risk of insufficient rain or irrigation water for growth.

Annual rainfall in Hillston, NSW was 261 mm and 1206 mm at Mt Dandenong in Victorias' Yarra valley. Similarly the number of raindays (Figure 15 shows raindays of more than 1 mm) varied with location. Table 10 show these data and a seasonal breakdown of rainfall and raindays. Figure 15 also shows these data in the bar graphs with locations listed from those with coolest mean summer temperature to warmest mean summer temperature. There is no relationship between rainfall and summer temperature. The scatter plot in Figure 15 also shows this. Cherry producing locations in all states show variation between mean summer temperature and annual rainfall.

Table 10. Risks associated with insufficient rainfall.

These risks were calculated as an annual period and for each season. The table shows the rainfall for each period and the number of days having more than 1mm rainfall or more than 5mm rainfall. Locations are listed from the coolest mean summer temperature to the warmest mean summer temperature.

		Rainfall (mm)					Raindays >1mm					Raindays >5mm				
Location	**State**	Annual	Autumn	Winter	Spring	Summer	Annual	Autumn	Winter	Spring	Summer	Annual	Autumn	Winter	Spring	Summer
GEEVESTON	Tas	916	210	274	268	182	128	30	37	37	25	59	13	18	17	11
GROVE	Tas	709	164	202	205	155	111	25	31	33	22	44	10	12	13	9
MT DANDENONG	Vic	1267	297	379	368	245	139	33	45	38	23	74	17	24	22	13
HEALESVILLE	Vic	1252	278	403	360	231	128	29	43	35	21	72	16	24	21	12
BEACONSFIELD	Tas	905	225	326	221	144	99	23	34	26	16	56	13	20	14	9
NEW NORFOLK	Tas	501	118	135	145	113	92	21	26	27	18	32	7	9	9	7
RICHMOND	Tas	468	111	117	130	123	81	19	22	24	17	28	6	7	8	7
MT GAMBIER	SA	676	151	270	175	87	115	26	45	30	15	45	9	20	11	5
BATLOW	NSW	1181	252	415	328	204	96	19	34	27	16	61	12	22	17	10
ORANGE	NSW	889	181	257	233	238	86	17	27	23	19	49	10	15	13	12
MT BARKER	WA	677	163	263	180	75	117	26	44	32	14	43	10	18	11	4
LENSWOOD	SA	987	224	434	241	96	107	24	43	28	13	56	12	25	14	5
COLDSTREAM	Vic	710	173	189	212	149	113	26	37	32	18	46	11	13	14	9
BEECHWORTH	Vic	968	213	337	264	167	100	21	37	27	15	56	12	21	15	9
MANJIMUP	WA	933	206	455	216	60	122	27	52	32	11	58	12	29	14	3
ASHTON	SA	757	179	309	193	83	100	22	41	26	11	47	11	21	11	4
APPLETHORPE	Qld	727	158	121	190	280	79	18	15	20	26	40	8	7	11	14
STANTHORPE	Qld	727	153	121	197	277	78	17	15	20	25	41	8	7	12	14
TATURA	Vic	458	108	136	126	94	68	15	25	19	10	28	7	9	7	5
DWELLINGUP	WA	1183	245	639	247	58	101	21	46	26	7	62	12	32	14	3
YOUNG	NSW	635	141	178	176	153	74	15	25	20	14	37	8	12	10	8
WANGARATTA	Vic	606	138	191	166	119	80	17	29	22	13	37	8	13	10	6
DONNYBROOK	WA	916	196	496	184	43	98	21	46	26	6	51	11	27	11	2
LOXTON	SA	261	54	76	79	56	46	10	16	13	7	15	4	4	5	3
HILLSTON	NSW	367	94	91	96	94	50	11	16	13	10	22	5	6	6	5



Annual and seasonal rainfall and number of raindays varies between cherry producing regions, but was not related to mean summer temperature. Mean summer temperature increases from left to right in the bar graphs. The lack of a relationship can also be seen in the scatter plots (to right). In the scatter plot each location is shown by an individual point coloured according to state. Locations in each state show considerable variation in both rainfall and temperature.

Figure 15. Rainfall and raindays show considerable seasonal and geographic variation.

Date from current climate

Treating the risk of insufficient rainfall

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology provide forecast of daily rainfall either for the next few days, next week or seasonal outlooks for many locations.
- Water availability from non-farm irrigation sources are typically managed by state or federal government departments. The supply of the irrigation water is subject to water availability and government policy.

Can the undesired climate be avoided or the impact reduced?

There are several methods available to producers to make the best use of water. For example:

- Improve the efficiency of irrigation method (drip vs spray) and irrigation scheduling including the use of forecasts of rain.
- Direct rain to trees rather than to inter-rows (use above tree covers or on ground covers. This redirection of rain (fresh water) could also be used to flush soil of salt build-up as a consequence of saline irrigation water. (See npsi.gov.au)
- Improve run-off into on-farm dams.
- Artificial covers for dams are available that reduce evaporation losses.
- New water supplies could be sourced. These could include additional dams, pipelines, use of reclaimed/treated water.
- Netting can reduce evapotranspiration, leaf temperature and increase humidity. These conditions are commonly associated with reduced irrigation requirements.

Further reading

Chiew FHS. (2006). An overview of methods for estimating climate change impact on runoff. In 3rd Hydrology and Water Resources Symposium, 4-7 December 2006 Launceston, Tasmania, Australia.

Risk 7. Rain near harvest

Identifying the risk of rain near harvest and placing it in context.

Causes of ‘cracking’ have been studied extensively but there is still a level of uncertainty about the physiology and climatic conditions that cause ‘cracking’ remains. Rain is implicated but so is tree water status, humidity, length of time fruit is wet, and fruit development stage. It is important to note that while initial development of cracks frequently coincides with rainfall, the threshold of rain that causes cracking is no known (Measham et al., 2009).

Recent research from Tasmania shows that a key factor in understanding the causes of ‘cracking’ is to be aware of the differences between two types of cracks – side cracks and cuticular – and adapting existing growing techniques to prevent them (see Measham et al. 2009 and http://www.tia.tas.edu.au/__data/assets/pdf_file/0020/149402/cherry-cracking-fact-sheet.pdf). These techniques include spraying, irrigation, crop-load and pruning. High crop loads and pruning can reduce ‘cracking’.

Cracking occurs when the skin is put under pressure. Skin integrity can be improved by even irrigation throughout the season and ensuring that fruit do not experience dry conditions during early development. The risks associated with irrigation supply are addressed in Risk 6. The research from Tasmania indicates that the association between rain and ‘cracking’ can occur because when the trees experience dry conditions the fruit shrinks in the day and swells at night, affecting the skin. It then cannot tolerate the rush of water during high rainfall and cracks as a result. This highlights the importance of adapting management to ensure adequate irrigation.

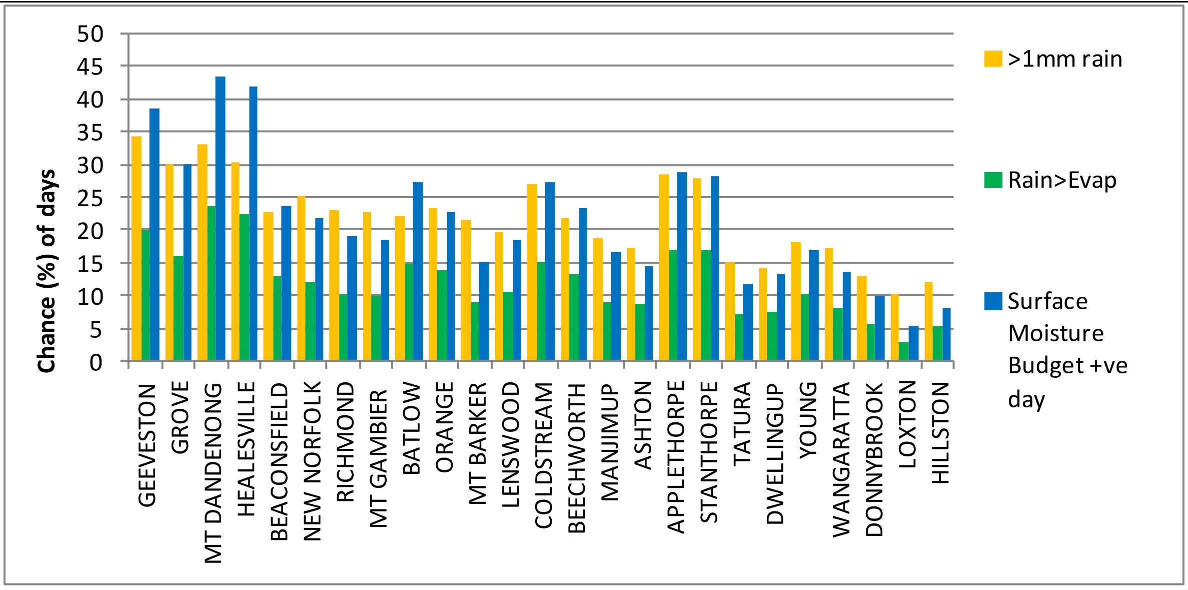
It should also be recognized that high temperatures can reduce skin integrity. Research has yet to determine critical temperatures for reductions in skin integrity. The risks associated with high temperature are addressed in Risks 2 and 4.

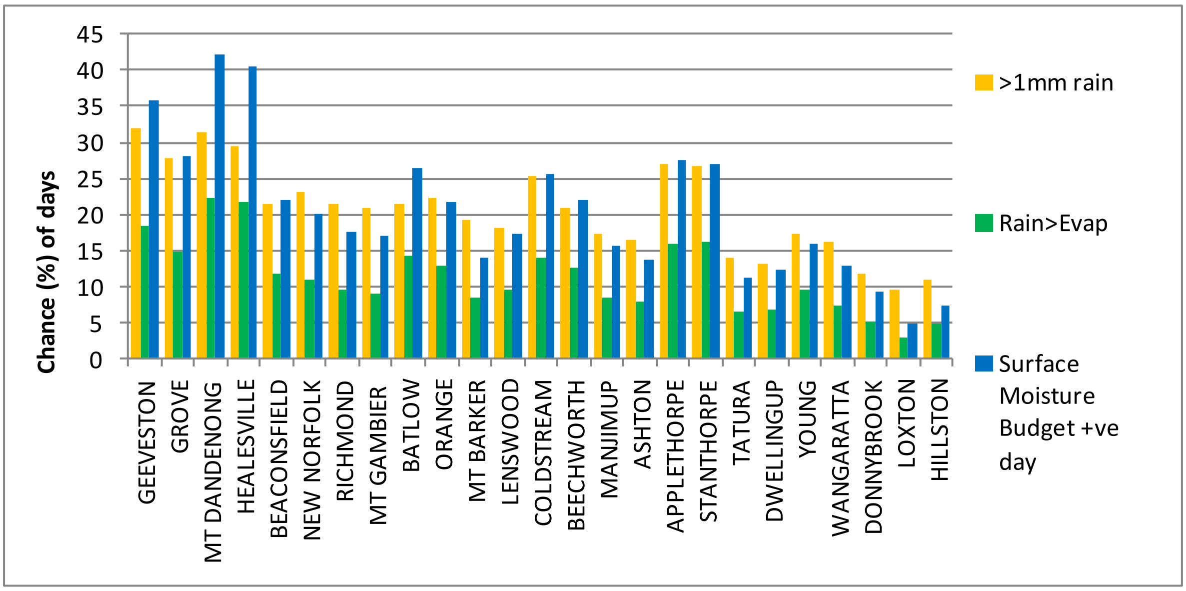
The uncertainty of the climatic causes of ‘cracking’ makes it difficult to predict the effect of changes in climate on ‘cracking’. While rain is implicated, it should be recognised that the effects of rain may interact with the effects of irrigation or plant water status. From another point of view, if ‘cracking’ is related to length of time fruit is wet then perhaps better associations with climate could be obtained by examining relationships between ‘cracking’ and evaporation, potential evapotranspiration, or days that have a positive surface water balance (MB +ve), not just rainfall. The surface moisture budget for a day was calculated by subtracting the evaporation from the rainfall for a given day and adding this to the any water that is carried forward from the previous day. In this analysis we set the maximum amount of water that could be carried forward from the previous day to 10 mm.

Analysing and evaluating the risk of rain near harvest.

The Table 11 shows the risk of rainfall near harvest. We decided to analyse the risk of more than 1 mm rain while acknowledging that this may not be the best metric as reported by Measham et al. (2009) who did not observe an absolute threshold of rain that caused cracking. Nevertheless the risk of 1mm rain will provide a very conservative calculation of risk of rain near harvest. In addition to the chance of more than 1 mm rain on a day near harvest, two methods relating to wetness were assessed. These were the chance that the daily rainfall is greater than the daily evaporation, and the chance that a day will have a positive surface water balance (MB+ve). The chances were calculated for the period from three weeks before harvest until the end of harvest using common harvest dates for all cherry producing locations. The chances were also calculated for a drier future. A drier future was determined by reducing historic daily rainfall by 5%, 10% or 20%. This approach is simple but reasonable considering the low to medium confidence in rainfall projections from Global Climate Models and difficulty in getting daily rainfall from Global Climate Models.

Generally there are only minor reductions in the risks when rainfall is reduced, with the largest differences in risk remaining as differences in location. This can be seen by comparing the data in Table 11 or the two bar charts in Figure 16. The top chart shows the risks using the historic climate, the lower graph shows the risk when rainfall was reduced by 10%.





The risk of rain or wetness near harvest was assessed as the chance of a day having more than 1 mm rain; of the chance that on any day the rainfall is greater than evaporation; and the chance that a day has a positive surface moisture balance (MB+ve). These methods of assessing the risks were highly related. A location either had high chance for any of these events or low chance for any of these events. The top chart shows the risks using the historic climate, the lower graph shows the risk in a 10% drier climate.

Figure 16. Risk of rain near harvest and two methods to assess wetness in the current climate and in a 10% drier climate.

The risk associated with rain or wetness near harvest were higher in locations having cooler mean summer temperature. This can be seen by generally higher chances of undesired events at locations to the left had side in the bar graphs and also the scatter plots (to right). In the scatter plot each location is shown by an individual point coloured according to state. All three methods used to assess rain or wetness near harvest showed similar relationships with location and mean summer temperature.

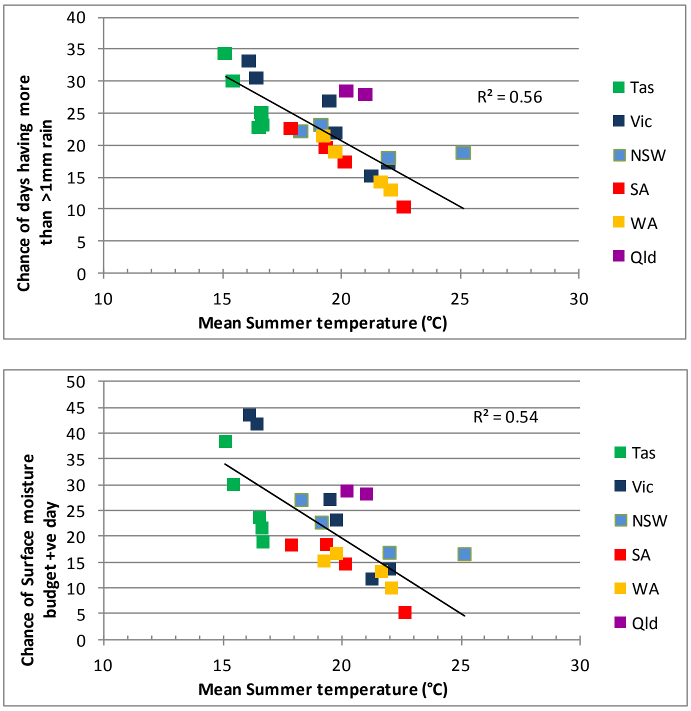


Figure 17. The risk of rain or wetness near harvest was related to mean summer temperature in the current climate.

Table 11. Risks associated with rainfall near harvest.

The risks were calculated for the period from three weeks before harvest until the end of harvest. The risks are calculated as the chance (of percentage of days) that has more than 1mm rainfall (1mm), or that on any day the rainfall exceeds evaporation (R:E >1), or that the day has a positive Surface Moisture Budget (MB+ve). Calculations have been done for the climate using the historic record, and also for several warming scenarios. These are a 5% less, 10% less or 20% less rainfall. Locations are listed from the coolest mean summer temperature to the warmest mean summer temperature.

Risk of Rainfall near harvest from one week prior to harvest to one week after harvest

				Historic record				5% drier				10% drier				20% drier		
Location	**State**	**Start**	**End**	1mm	R:E>1	MB+ve		1mm	R:E>1	MB+ve		1mm	R:E>1	MB+ve		1mm	R:E>1	MB+ve
GEEVESTON	Tas	24 Oct	15 Jan	34	20	38		32	19	37		32	18	36		31	17	33
GROVE	Tas	24 Oct	15 Jan	30	16	30		28	15	29		28	15	28		26	14	26
MT DANDENONG	Vic	24 Oct	15 Jan	33	24	44		32	23	43		31	22	42		31	21	40
HEALESVILLE	Vic	24 Oct	15 Jan	30	22	42		30	22	41		29	22	41		29	21	39
BEACONSFIELD	Tas	24 Oct	15 Jan	23	13	24		22	12	23		22	12	22		21	11	20
NEW NORFOLK	Tas	24 Oct	15 Jan	25	12	22		24	11	21		23	11	20		22	10	18
RICHMOND	Tas	24 Oct	15 Jan	23	10	19		21	10	18		21	9	18		20	9	16
MT GAMBIER	SA	24 Oct	15 Jan	23	10	18		21	9	18		21	9	17		20	8	15
BATLOW	NSW	24 Oct	15 Jan	22	15	27		21	14	27		21	14	26		21	13	25
ORANGE	NSW	24 Oct	15 Jan	23	14	23		22	13	22		22	13	22		22	12	20
MT BARKER	WA	24 Oct	15 Jan	21	9	15		19	9	15		19	8	14		18	8	12
LENSWOOD	SA	24 Oct	15 Jan	20	10	18		18	10	18		18	10	17		17	9	16
COLDSTREAM	Vic	24 Oct	15 Jan	27	15	27		26	15	26		25	14	25		25	13	23
BEECHWORTH	Vic	24 Oct	15 Jan	22	13	23		21	13	23		21	12	22		21	12	21
MANJIMUP	WA	24 Oct	15 Jan	19	9	17		17	9	16		17	8	16		16	8	15
ASHTON	SA	24 Oct	15 Jan	17	9	15		17	8	14		16	8	14		16	7	12
APPLETHORPE	Qld	24 Oct	15 Jan	28	17	29		27	16	28		27	16	28		27	15	26
STANTHORPE	Qld	24 Oct	15 Jan	28	17	28		27	17	28		27	16	27		26	15	25
TATURA	Vic	24 Oct	15 Jan	15	7	12		14	7	12		14	7	11		13	6	10
DWELLINGUP	WA	24 Oct	15 Jan	14	8	13		13	7	13		13	7	12		13	7	11
YOUNG	NSW	24 Oct	15 Jan	18	10	17		17	10	16		17	9	16		17	9	15
WANGARATTA	Vic	24 Oct	15 Jan	17	8	14		16	8	13		16	7	13		16	7	12
DONNYBROOK	WA	24 Oct	15 Jan	13	6	10		12	5	10		12	5	9		11	5	8
LOXTON	SA	24 Oct	15 Jan	10	3	5		10	3	5		10	3	5		9	3	4
HILLSTON	NSW	24 Oct	15 Jan	12	5	8		11	5	8		11	5	7		11	5	7

Treating the risk of rain near harvest

Are there systems in place that inform producers of the risks?

- The Bureau of Meteorology provides forecast of daily rainfall either for the next few days, or the next seven days for many locations. This information can be used by producers to assess the risks for their orchard and to make management decisions accordingly.

Can the undesired climate be avoided or the impact reduced?

- Avoid the risk eg. Use Bureau of Meteorology forecasts of near future chance of rainfall to inform decision to harvest more quickly if fruit is of marketable quality.
- Rain shelters / redirectors to reduce rain on fruit.
- Ensure adequate irrigation throughout growing season.
- Adjust crop load.
- Netting (useful for other purposes) could impact on 'cracking' as humidity increases under nets; and rain (if it gets through the netting - this will depend on design and net construction) can take longer to evaporate due to reduction in wind and reduction in solar radiation. Thus fruit may remain wet for longer.
- Netting can reduce temperature which may be advantageous.
- Particle film technology sprayed onto fruit can reduce temperature.
- Varietal selection to ripening in less vulnerable time.
- Change markets.

Further reading

The following publication provides comprehensive concise information and practical advice

- Measham PF, Bound SA, Gracie AJ, Wilson SJ. (2009). Incidence and type of cracking in sweet cherry (*Prunus avium* L.) are affected by genotype and season. *Crop and Pasture Science*. **60**:1002-1008.

The TIAR publication summarises the information in Measham et al. (2009) [above] and other locally relevant findings.

- Cherry cracking in Tasmania
  http://www.tia.tas.edu.au/__data/assets/pdf_file/0020/149402/cherry-cracking-fact-sheet.pdf

The book chapter provides a succinct history of research into 'cracking'

- Christensen JV. (1996). Rain induced cracking of sweet cherries: its causes and prevention. in AD Webster, NE Looney (eds). Cherries: crop physiology, production and uses CAB International. 513 pages.

Risk 8. Wind damage to trees and flowers

Identifying the risk of wind damage to trees and fruit and placing it in context.

It is very hard to make any predictions or calculations of potential wind damage as these events are often linked to micro climate events. In those areas where wind is a regular issue grower cultural practices are already used to reduce the severity and impact of wind damage.

Analysing and evaluating the risk of wind damage.

As wind is notoriously difficult to predict using climate models we are unable to analyse and evaluate the risks of wind.

Treating the risk

Can the undesired climate be avoided or the impact reduced?

- Wind breaks and/or use of netting may reduce the chance of wind damage but the impact of wind breaks on air drainage could alter risk of frosts, or restrict air circulation that is important for cooling and drying. However prevailing wind direction changes during the year so it may be possible to place wind breaks to reduce damaging winds without adversely contributing to an increase in other risks.
- Netting issues: determine the primary purpose of the netting. Insect, bird/fruitbat, hail, wind, temperature.

Further reading

Further information on the effectiveness of netting can be found in

- Rigden, P. (2008). To net or not to net. 3rd edition. Queensland Government Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/documents/BusinessAndTrade_BusinessDevelopment/Orchard-Netting-Report.pdf

Risk 9. Hail damage to trees, flowers and fruit.

Identifying the risk of hail damage to trees, flowers and fruit and placing it in context.

Like wind damage, it is very hard to make any predictions or calculations of potential hail damage as these events are often linked to micro climate events.

Analysing and evaluating the risk of hail damage.

As hail is notoriously difficult to predict using climate models we are unable to analyse and evaluate the risks of hail.

Treating the risk

Can the undesired climate be avoided or the impact reduced?

- Hail netting is widely used in horticultural crops. There are many benefits. Hail netting usually has larger holes thus some of the impacts (positive and negative) of netting with smaller holes (eg fruit fly exclusion netting, shade netting) are avoided.

Further reading

Further information on the effectiveness of netting can be found in

- Rigden, P. (2008). To net or not to net. 3rd edition. Queensland Government Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/documents/BusinessAndTrade_BusinessDevelopment/Orchard-Netting-Report.pdf

Main points

Some major climate related risks to cherry production are placed into context using available knowledge.

The risks are analysed using historic weather and climate information for 25 cherry producing locations in Australia.

How these risks may change if global temperature increased by up to 2°C, or if rainfall decreased by 10% are examined.

Management options that may reduce the impact of the risks are provided. This list is not exhaustive and other options may be available.

The major climate related risks examined included:

- insufficient chill accumulation – page 19
- excessive heat accumulation – page 28
- temperatures undesirable for effective pollination – page 36
- heatwaves – page 42
- frosts – page 49
- insufficient rainfall for irrigation – page 58
- rain near harvest contributing to ‘cracking’ – page 62
- hail and wind damage – page 68 and 69.

Understanding and managing the risks and opportunities from climate change on Cherry production

Dane Thomas, Peter Hayman, Paul James

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