DWLBC Report

Frost Protection in Vineyards and Volumetric Allocations in the South East

2007/07

Government of South Australia
Department of Water, Land and Biodiversity Conservation

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

The Volumetric Conversion Project was a four-year project initiated in 2002 to facilitate the process of converting the existing area based water licences in the South East of South Australia to licences with a volumetric basis for allocation. The conversion approach was developed following a comprehensive community consultation process, using the best available science and extensive field data.

The conversion approach will be implemented through the review of Water Allocation Plans for the Padthaway, Tatiara and Lower Limestone Coast Prescribed Wells Areas that is being conducted by the South East Natural Resource Management Board. The reviewed Water Allocation Plans will define the arrangements for the issue of new volumetric allocations, taking into account the recommendations of this report, the sustainability of the resource and input from the stakeholder community.

Rob Freeman
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ASSOCIATED REPORTS

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Frost can cause serious damage and or total crop loss in vines. Spring frosts in the South East (SE) of South Australia pose a significant economic risk to the viticultural industry, as vines are sensitive to frost damage at this stage of their annual growth cycle. Vineyards may be protected against frost damage by various means (frost pots, wind machines, helicopters etc.); however applying water to the canopy via overhead sprinklers is recognised as the most effective form of protection. This method is commonly practised in the SE.

In the SE of South Australia water license holders are currently licensed to maintain a given area of crop with no restriction on the amount of water used. Upon finalisation of the review of the Water Allocation Plans the licensing arrangements will change and irrigators will be limited to a defined volume of water. As significant volumes of water are used for frost protection in vineyards it is important to understand the practice of frost protection when formulating the volumetric conversion approach. It is proposed that water allocated for frost protection will be made available through the 'Specialised Production Requirements' component of the volumetric conversion model.

With the help of the Limestone Coast Wine Industry Council Water Resources Committee it was possible to benchmark frost protection practices in the South East of South Australia. The Coonawarra wine region has been the focus of this research as the majority of vines protected by overhead frost control systems are located in this region (and it was the area from which the most information was received). In Coonawarra frost protection systems are typically activated when the ambient temperature in the vineyard falls to 2.0 °C; ~25 mm of water is applied per frost event. Twenty years of historical weather data and real 'start-up' information were combined to determine that Coonawarra on average experiences 6.2 frost events per season (during September to November).

In order to develop the conversion approach it was necessary to consider the impacts of frost protection practices on the groundwater resource. Modelling was undertaken to determine the likelihood of water used for frost protection returning to the source aquifer. The results indicate that a significant amount of the water used for frost protection is lost through evapotranspiration and thus does not return to the source aquifer.

It is recommended that eligible licensees should be allocated enough water to protect against frost damage in an 'average' year (6.2 frost events). The amount of water required to achieve this will be equal to 6.2 x 25 mm (average application depth) minus crop water use (as a volume of water has already been allocated for crop water use). This equates to an allocation of 155 mm or 1.55 ML of water per annum for each hectare of vines protected by overhead sprinkler systems.

Further research is required to determine whether the amount of water used for frost protection can be reduced. Two avenues worthy of further investigation are; the temperature at which frost systems are activated (the critical temperature) and the sprinkler output rate required to provide adequate protection in SE wine regions.

1. BACKGROUND

In response to The State Water Plan – South Australia (Department for Water Resources, 2000) and in order to facilitate better resource management, current area based water allocations in the Prescribed Wells Areas of Tatiara, Padthaway and Lower Limestone Coast (formerly Naracoorte Ranges, Comaum Caroline and Lacepede Kongorong) are being converted to volumetric allocations.

Water license holders are currently permitted to maintain a given area of crop with no restriction on the amount of water used, however upon finalisation of the revised Water Allocation Plan irrigators will be licensed to pump a given volume of water. Some vignerons currently use water to prevent their vines from being damaged by frost. Understanding the amount of water used for frost protection, and what happens to this water are two significant issues that need to be understood by the resource manager for a seamless transition to volumetric allocations. It is proposed that water allocated for frost protection will be made available through the 'Specialised Production Requirements' component of the volumetric conversion model (see Pudney et al. 2006 for more information).

This report investigates the occurrence of frost events in the South East (SE) of South Australia, the use of sprinklers to prevent frost damage (in the SE), and the potential impacts of frost water applications on the groundwater resource. A recommended policy direction is presented. The report concludes by identifying areas for further research.

2. WHY FROST IS A PROBLEM IN VINEYARDS

Frost can cause serious damage and or total crop loss in vines. Frost damage occurs when the water within the plant cell freezes and expands, the cell wall is ruptured and the tissue dies. The degree of damage is related to the minimum temperature reached, the rate at which the temperature falls, the amount of time below a critical temperature and the previous season's growing conditions and crop load (Trought et al, 1999). Most frosts experienced in the South East are radiation frosts that occur on clear nights.

Grapevines are particularly vulnerable to frost damage when shoots and the subtending flowers are developing in spring. The potential damage in any season depends on the time of frost events in relation to the growth cycle of the vine.

Some vine cultivars produce only minimal crops from secondary (replacement) shoots, while others can produce 30–40% of the crop from undamaged primary shoots.

Dormant buds and shoots will tolerate temperatures as low as -15 °C. New leaves, shoots and flowers are vulnerable to temperatures just below 0 °C (Trought et al, 1999). Table 1 shows the temperatures at which damage occurs at various vine growth stages. Note wind can cause freezing at higher temperatures. In general, young, developing tissues are more susceptible to frost damage than older tissues as they contain more water per gram of tissue.

Table 1. Temperatures at which frost damage occurs at various vine growth stages

Growth stage	°C
Woolly bud stage	-3.5
Early Bud stage	-1.1
Shoots up to 150 mm	-0.5
Shoots over 150 mm	0.0

(Source: Pocock and Lipman, 2002)

The perennial nature of grapevines means that frost events not only impact upon the current season's crop, but also future crops; productivity may be reduced for several seasons after a severe frost event (Trought et al, 1999).

3. METHODS FOR PREVENTING FROST DAMAGE

There are several options for protecting against frost damage these include:

1. Frost Pots and Heating. Heating provides protection by increasing the temperature within the vineyard.
2. Wind machines and helicopters, can be used to protect vineyards when there is a strong inversion layer. They work by mixing the warm upper air (inversion layer), with the cool air at vineyard level.
3. Sprinklers. Heat is gained as water freezes through the release of latent heat. By applying water to the vineyard when temperatures are below 0 °C the plant tissues are protected against frost damage.
4. Various cultural practices (trellis height, pruning technique, inter-row management, soil wetness) can help reduce the susceptibility of the vineyard to frost damage.

Applying water to the vine canopy via overhead sprinklers is currently recognised as the most effective form of protection against frost damage. This method is commonly practised in the SE. The sprinkler rate required to protect against frost is dependent on minimum temperature reached and windspeed (Table 2). For frost protection to be effective water application needs to be commenced before the air or tissue temperature reaches a critical value. Water application should only be ceased when temperatures are well above freezing.

Table 2. Sprinkler rate (mm/h) necessary for cold protection at different tissue temperatures and windspeeds*

Tissue temperature (°C)	**Wind speed** (km/h)				
	0–1.5	*3–6.5*	*8–13*	*15–22*	*29–32*
-2	–	–	–	–	–
-3	0.25	0.25	0.36	0.50	1.00
-4	0.25	0.40	0.75	1.00	2.00
-5	0.30	0.60	1.25	1.50	3.00
-6	0.35	0.70	1.40	1.80	3.65
-7	0.40	0.75	1.50	2.00	4.00

* Grapevine buds (scale crack, first swell and full swell) are either at or very near ambient temperature, the relationship between ambient temperature and tissue temperature is not known for later stages of shoot growth (Trought et al, 1999).

4. BENCHMARKING FROST CONTROL PRACTICES IN THE SOUTH EAST

The viticultural industry was approached to supply information on frost protection practices throughout the SE. In response to the Departments request for information the Limestone Coast Wine Industry Council Water Resources Committee distributed a survey to its members. The survey requested information on the volume of water used for frost protection and the volume of water used for general irrigation. A summary of the survey results is presented in (App. A). Nearly all of the survey responses were from vineyards located in the Coonawarra wine region; this is not surprising as the vast majority of frost protection systems are installed in this region. It is estimated that there are ~2000 ha of vines with frost protection systems installed in the Coonawarra compared to ~300 ha in Padthaway, ~150 ha in Bordertown, ~50 ha in Mt Benson, ~50 ha in Wrattonbully, and ~300 ha in all other lower limestone coast areas. As a result the following information represents practices in the Coonawarra region.

As expected the survey results indicate that the amount of water applied per frost event is highly variable. It seems the size of the vineyard holdings is one factor that influences the amount of water used for frost protection; larger vineyards (corporate) typically apply more water for frost protection than smaller vineyards (App. A).

To determine how many millimetres of water are applied per frost event, all records were weighted by area and then averaged. The average amount of water applied per frost event is 25 mm. As overhead sprinklers with an output of 3.7 mm/hr are commonly used for frost protection (in Coonawarra) this equates to 6.8 hour of operation per frost event. In the last 15 years the amount of water used for frost protection (p.a.) has ranged from 0.4–6.5 ML/ha (App. A), in general somewhere between 1–2 ML/ha is used for irrigation.

Several meetings were also held with industry representatives to ascertain how and when frost protection systems are activated. It is common practice in the SE to have a staff member monitoring the ambient temperature in the vineyard on nights where a frost is expected. Frost protection systems are activated when the ambient temperature falls to 2.0 °C. The overhead sprinkler systems are operated until ambient temperature has risen to above 0 °C. Historical weather records (Coonawarra weather station) were analysed to determine if the frequency of vineyard 'start-ups' matches the occurrence of minimum temperatures of 2.0 °C (or less) at the Coonawarra weather station.

In Coonawarra most frost events occur between March and November. The occurrence of frost events varies greatly between years (Fig. 1 and App. B) and with location (Table 3). On average 6.2 frosts (critical temperature of 2.0 °C – Coonawarra weather station) occur during the months of September to November (when Coonawarra vines are most susceptible to damage). As can been seen from Table 4 a trigger temperature of 2.0 °C at the Coonawarra Weather Station matches the actual number of start ups quite well.

In summary the benchmarking process established that Coonawarra vignerons activate their frost protection systems when the ambient temperature reaches 2.0 °C and on average they apply 25 mm per event (deduced from metered records).

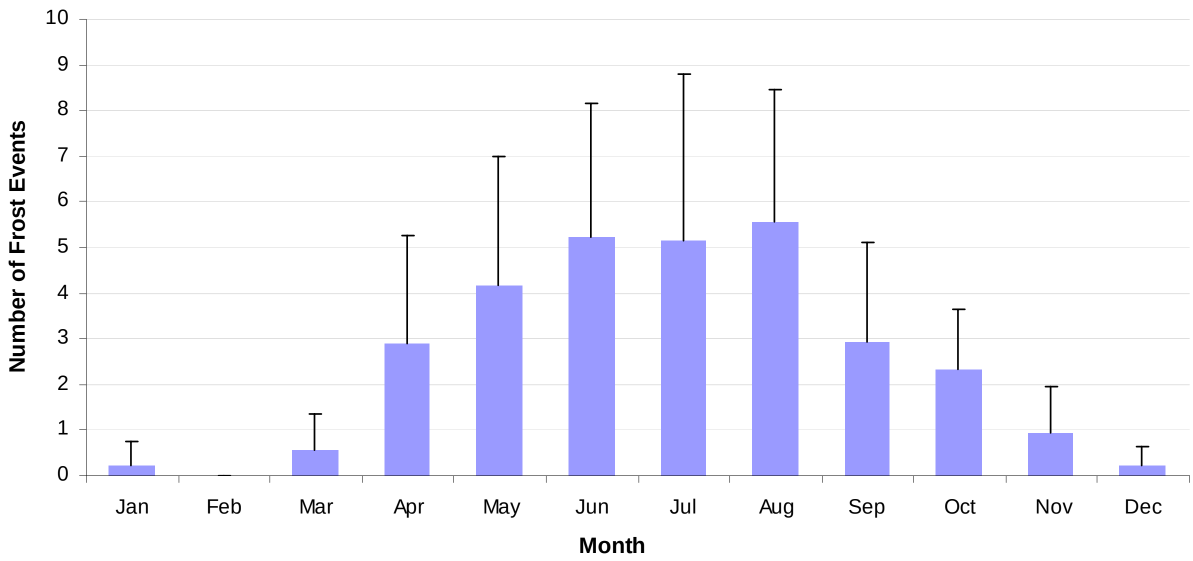

Figure 1. Average number of frost events per month in Coonawarra (Critical Temperature 2.0 °C, ± StDev)

Table 3. Average number of frost events experienced in South East wine regions during the frost risk period (SILO DataDrill).

Region	Latitude	Longitude	Av No. of frost events
Coonawarra	-37.30	140.85	3.92*
Padthaway	-36.60	140.50	4.24
Robe	-37.15	139.75	0.04
Mt Benson	-37.00	139.80	0.16
Bordertown	-36.30	140.75	4.56
Wrattonbully	-37.15	140.95	6.00

* Please note the average number of frosts experienced in Coonawarra differs from the value used in the rest of this report as it was necessary to use a different data source (SILO DrillData, Queensland Department of Natural Resources and Mines) to complete the regional comparison. This discrepancy highlights the influence of topography on frost occurrence.

Table 4. **'Start Ups' (number of times frost protection system activated) vs the occurence of temperatures of 2.0 °C or less at the Coonawarra weather station during September to November.**

Year	**Coonawarra Weather Station***	**Number of times Frost Protection Systems activated**																									
		Viticulture Survey Sites																								*Corporate Sites*	
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*1*	*2*	*3*
1999	4					2	4	4	4	1	6	9				7	7	8	8	8		3	3	3	3			9 (7–9)
2000	5	4	4	2	1	3	2			3	4	5		2		4	3	4		4	5	6	6	6	6			5 (0–5)
2001	4	2	3				4				3	7	1	4	1	5	3					6	6	6	6			4 (3–7)
2002	6												2													3 (1–5)		3 (0–4)
2003	10																									6 (4–10)	10–13	7 (1–9)

*Number of times a minimum temperature of 2.0 °C or less was recorded at the Coonawarra weather station (September to November).

Note: individual 'block' records from corporate vineyards have been grouped, the number presented in Table 4 represents the number of times the frost protection system was most commonly activated, the range of actual start-ups is given in brackets.

5. ESTIMATING RECHARGE

5.1 INTRODUCTION AND METHODS

A 'bucket' model was used to estimate recharge under different scenarios (Bekeski and McConichie, 1999). Recharge (drainage) occurs when the soil moisture store (bucket) is full and the irrigation and/ or rainfall rate exceeds evapotranspiration. The model assumes run-off is insignificant. The model is defined by the following equation:

$$Recharge = P + I_F - ET +/- \Delta S$$

Where: P = Rainfall

I_F = Frost water (irrigation),

ET = Evapotranspiration,

ΔS = Change in soil moisture store

Two of the key model inputs are Rainfall and Evaporation data. This information has been sourced from the Bureau of Meteorology Coonawarra weather station 26091 (June 1986–September 2004); where data gaps exist Mount Gambier weather station data has been used. As Class A Pan Evaporation data was sourced from the Bureau it was necessary to define pan and crop coefficients to estimate crop evapotranspiration. A Pan Factor of 0.75 was selected to relate pan evaporation data to reference crop evapotranspiration (ET_o). According to FAO Irrigation and Drainage Paper No. 24 this pan coefficient is appropriate where: the pan is placed in a short green cropped area, relative humidity is low to moderate (0–70%) and average windspeed is between 5–8 ms^{-1}. ET_o is multiplied by a crop coefficient to determine crop evapotranspiration. In this modelling exercise the crop coefficient was assumed to be 1.0 as during the frost risk period two thirds of the vineyard area (inter-row cover crop) is behaving as per reference crop, the crop coefficient for the remaining area (occupied by vines) is most likely to be around 0.7 (the vine canopy is being developed during the frost risk period). A crop coefficient of 1.0 is likely to slightly overestimate crop water use and thus produce conservative 'recharge' estimates.

The model also requires information on Readily Available Water, Available Water and Wilting Point; these values determine the size of the soil moisture store. Once again Coonawarra vignerons were approached to provide this information. Based on the information provided the following ranges were specified:

- Readily Available Water: 20–50 mm.
- Available Water: 60–100 mm.
- Wilting Point: 80–270 mm.

This range of soil parameters covers both the terra rossa and black cracking clay soils typically found in the Coonawarra.

The amount of water that drains through the profile was modelled under several scenarios:

- Scenario 1: Water application = rainfall only.
- Scenario 2*: Water application = rainfall + 25 mm of water applied when minimum temperature reaches 2.0 °C.
- Scenario 3: Water application = rainfall + 25 mm of water applied when minimum temperature reaches 1.5 °C.

* Scenario 2 matches the general practice in Coonawarra.

Annual recharge estimates were obtained by running the model 100 times using random combinations of soil parameters (within the ranges specified above) for each of the three scenarios (for the entire weather record).

Estimates of daily recharge were obtained by modelling the behaviour of five randomly selected soil profiles for each of the three scenarios above (for the entire weather record). The soil parameters randomly selected for the each of the five soil profiles are given in Appendix C.

The daily recharge estimates for 1994 and 1995 were investigated in detail to examine what happens to recharge in a year where there are numerous frost events. In 1994 there were seven frost events during spring (the average number of frosts is 6.2 – see App. B); in 1995 there were 14.

5.2 RESULTS

Annual recharge for each of the scenarios was estimated to be:

- Scenario 1 (Rainfall only): 135 ± 7 mm.
- Scenario 2 (Rainfall + 25 mm when min temp 2.0^{0}C): 235 ±8 mm.
- Scenario 3: (Rainfall + 25 mm when min temp 1.5^{0}C): 189 ± 8 mm.

These values reflect the amount of water that percolates beyond the crop rootzone; the ‘recharge’ water may or may not return to the source aquifer. It should also be noted that model assumes no run-off and that the annual recharge estimates are based on a constant pan factor, there is no adjustment for the growth stage of the vine or cover crop. As a result of these model limitations it is likely that the recharge estimates are to be more accurate for the frost risk period than the whole year. Recharge during the frost risk period (September to November) was estimated to be:

- Scenario 1 (Rainfall only): 25.5 mm.
- Scenario 2 (Rainfall + 25 mm when min temp 2.0 °C): 123.2 mm.
- Scenario 3: (Rainfall + 25 mm when min temp 1.5 °C): 78.8 mm.

When the daily recharge estimates for each of the five soil profiles are averaged and graphed it is apparent that as evaporation rates increase and rainfall frequency decreases, from September through to November, less water drains through the profile (Fig. 2). The model results indicate that ~25% of rainfall percolates beyond the rootzone in the five weeks following September 1st. When frost protection is practiced, between 40–60% of water applied during this period drains through the profile. However post week six (mid October) recharge rates decrease markedly.

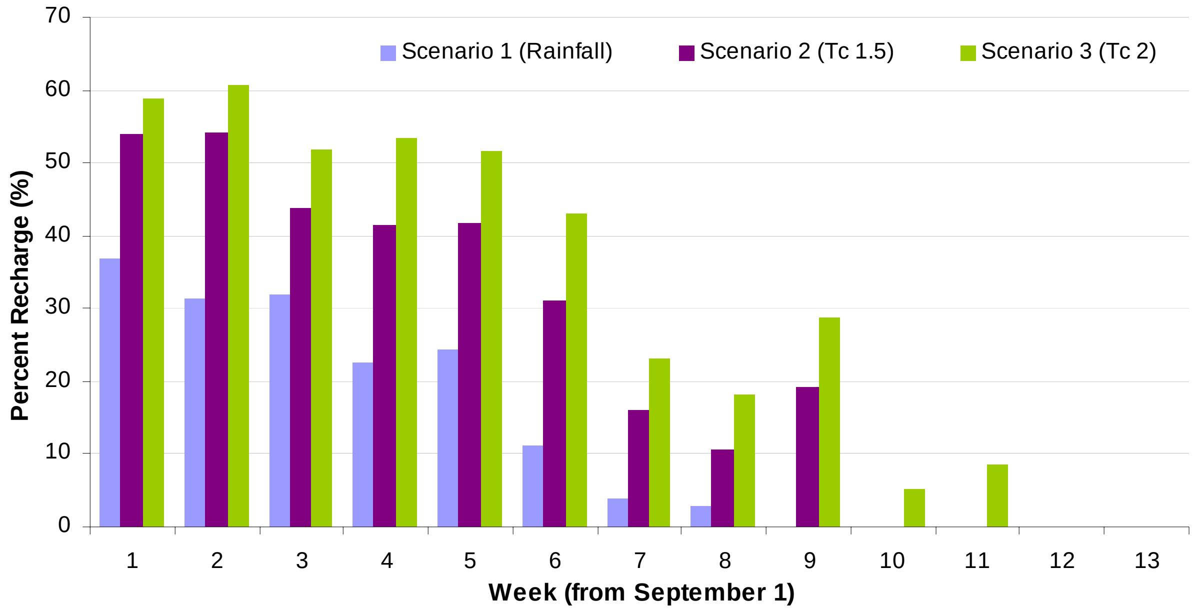

Figure 2. Recharge as a percent of water applied (rainfall and frost water).

The data can also be analysed to determine the percentage of 'Frost' water that passes beyond the crop rootzone (Fig. 3). According to the model, if 25 mm frost irrigations are applied when the minimum temperature reaches 2.0 °C, on average 61% of this water passes beyond the crop rootzone. The number of frosts that occur in any one season does not seem to substantially influence the percent of frost water that passes beyond the rootzone. In 1994 (an 'average' frost year) the proportion of water that passed beyond the rootzone was calculated to be 68%; in 1995 (a 'high' incidence frost year) recharge was calculated to be 59%.

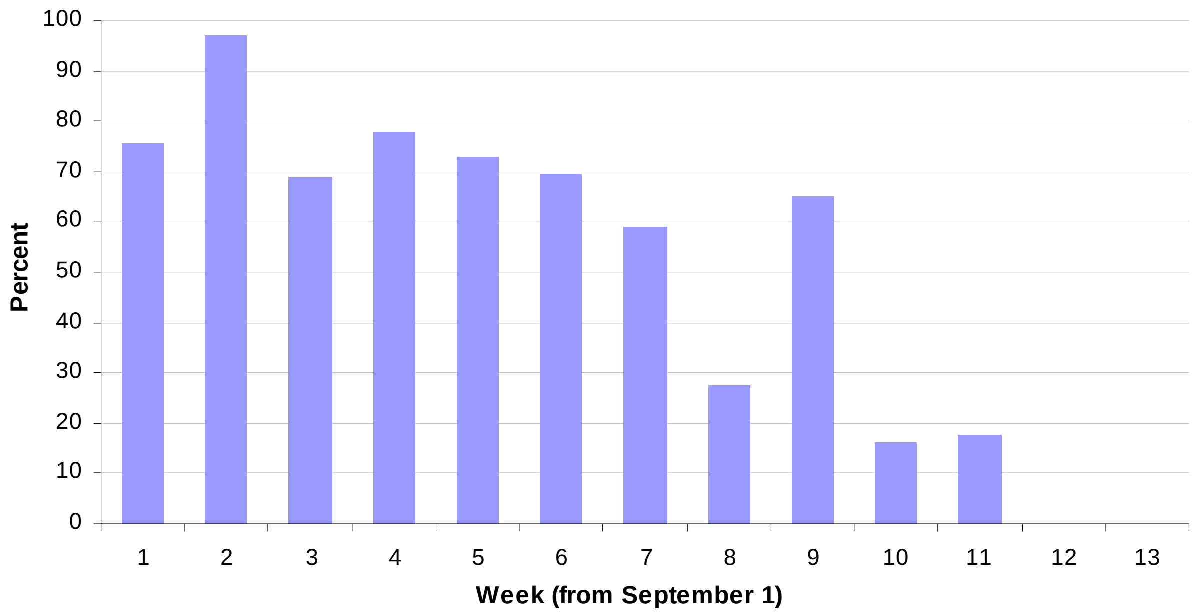

Figure 3. The percent of 'Frost' water that percolates below the crop rootzone (when 25 mm of Frost water applied when minimum temperature ≤2.0 °C)

5.3 MODEL VERIFICATION

With the cooperation of Coonawarra vignerons it was possible verify the model predictions. Daily recharge estimates (from the model) were compared against real soil moisture records from five vineyards with frost control systems installed; soil moisture records were only available for the more recent frost seasons (November 2002–November 2004). A sample soil moisture trace depicting two frost control events is given in Figure 4. The first frost event occurred on September 4th and second on October 16th. The rise in the soil moisture at depth following the first frost event indicates that water passed beyond the deepest soil moisture sensor. In terms of the verification process recharge would have been deemed to have occurred on this day, ideally piezometer records would be used to validate this assumption. There was no drainage (recharge) following the second frost event. The results of the verification process are given in Table 5.

Table 5. Model Verification

Date	Evap (mm Class A)	Rain (mm)	Min Temp	Model Recharge	Vineyard 1	Vineyard 2	Vineyard 3	Vineyard 4	Vineyard 5
21-Nov-02	6.6	0.0	2.2	0.0	No Recharge	No Recharge	No Irrigation		No Irrigation
04-Sep-03	1.8	0.0	0.5	21.2	No Irrigation		No Irrigation		No Irrigation
07-Sep-03	1.2	1.0	0.4	20.3	No Irrigation		No Irrigation		No Irrigation
11-Sep-03	2.5	1.0	1.5	17.3	No Irrigation		No Irrigation		No Irrigation
28-Sep-03	3.0	0.0	0.4	9.9	Recharge		Recharge		No Irrigation
29-Sep-03	4.6	1.8	1.1	23.4	Recharge		No Irrigation		No Irrigation
30-Sep-03	2.4	0.0	-0.5	23.2	Recharge	Recharge	No Irrigation		No Irrigation
04-Oct-03	1.8	0.3	0.5	21.7	Recharge	Recharge	No Irrigation		No Irrigation
09-Oct-03	3.9	0.5	1.0	17.9	Recharge	Recharge	Recharge		No Irrigation
11-Oct-03	3.0	0.6	1.2	22.2	Recharge	Recharge	No Irrigation		No Irrigation
12-Oct-03	2.8	0.0	1.9	22.9	No Irrigation	No Irrigation	No Irrigation		No Irrigation
04-Nov-03	2.3	0.0	2.4	0.0	Recharge	No Recharge	No Irrigation	No Irrigation	No Irrigation
04-Sep-04	1.6	1.0	0.5	22.1	No Irrigation	No Irrigation		Recharge	Recharge
05-Sep-04	1.2	1.0	2.3	0.1	No Irrigation	No Irrigation		No Irrigation	Recharge
12-Sep-04	1.8	3.0	1.9	26.7	No Irrigation	No Irrigation	Recharge	No Irrigation	No Irrigation
16-Oct-04	6.7	1.6	0.7	0.0	No Recharge	No Recharge		No Irrigation	No Recharge
24-Oct-04	3.2	0.0	1.6	0.0	No Irrigation	No Irrigation		No Irrigation	No Recharge
25-Oct-04	5.2	0.0	1.5	0.0	No Recharge	No Recharge		No Recharge	No Recharge
29-Oct-04	5.2	0.0	1.9	13.3	No Recharge	No Recharge			No Recharge
08-Nov-04	3.6	0.0	1.9	15.0	Recharge	Recharge	Recharge		No Recharge

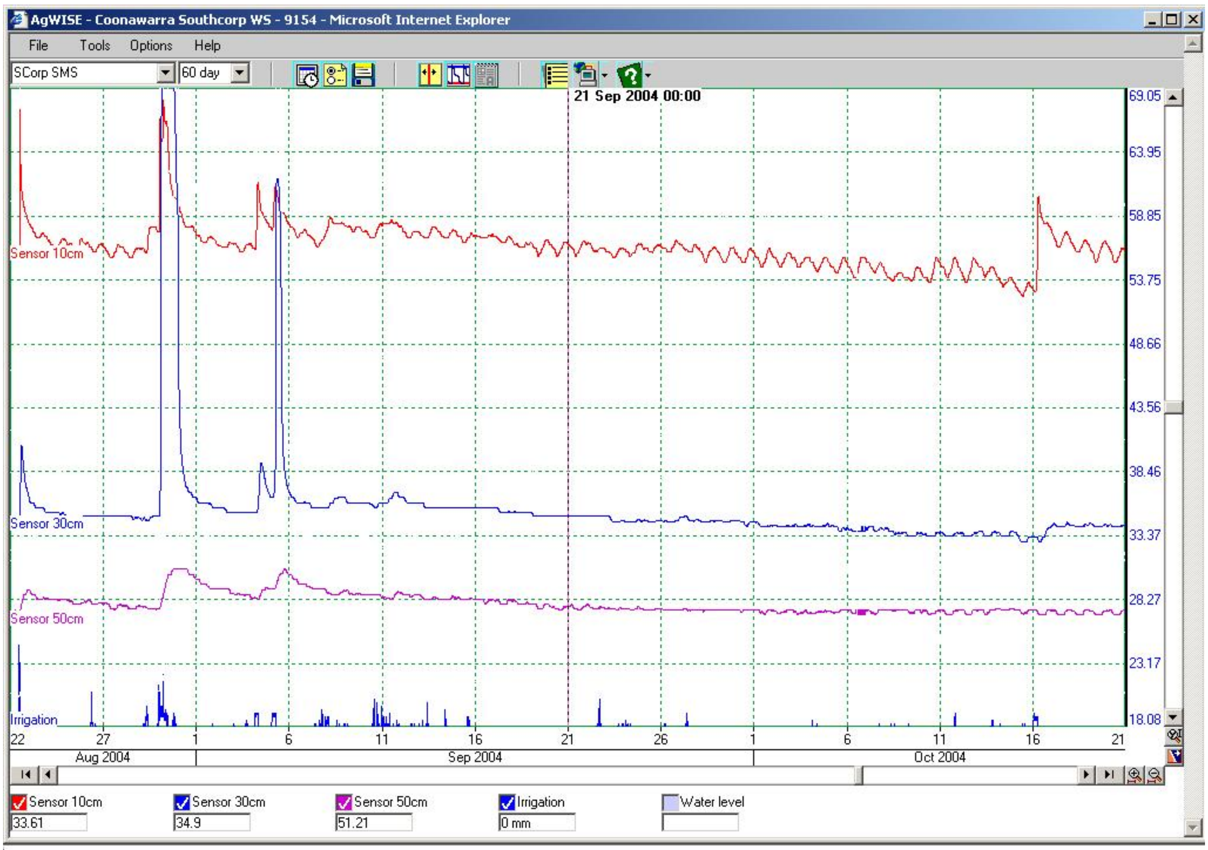

Figure 4. Sample soil moisture trace

Table 5 lists every day on which a frost irrigation was applied (reflected by an increase in soil moisture readings) by any one of the five vineyards for which soil moisture traces were available. For each 'frost' day, Class A Pan Evaporation, Rainfall and the minimum temperature reached (as measured by the Coonawarra weather station) are given. The model prediction is given in the column 'Model Recharge'; the next five columns describe what happened in each vineyard on that day. 'No irrigation' means the frost system was not activated. 'Recharge' means that wetting front was registered by the deepest soil moisture sensor. 'No recharge' indicates the frost system was activated however the wetting front did not reach the deepest soil moisture sensor.

It is evident from Table 5 that frost control practices vary greatly between vineyards, not all vineyards activated their frost control systems when a minimum temperature of 2.0 °C or less was reached, some operated their systems when the temperature was greater than 2.0 °C. Assuming the results of the benchmarking exercise are correct, this would suggest that there is significant temperature variation across the Coonawarra wine region. It is also possible that not all frost irrigations were detected by the soil moisture sensors (which may explain high number of 'non-irrigations' in vineyards three and five.

Another interesting observation to emerge from Table 5 is that vignerons do not appear to practice frost protection in early September; there is no evidence of water application in the soil moisture records in early September despite the minimum temperature being less than 2.0 °C.

The results of model verification are not entirely clear, on some occasions the soil moisture data supports the model predictions, on others it does not. It is likely that the match would be improved if ‘on site’ temperature data and soil information were available for each of the individual vineyards. Interestingly if a frost irrigation is applied, the model prediction is nearly always correct; if the soil moisture sensors show that water reached the deepest soil moisture sensor, the model estimates that recharge will have occurred and vice versa. As the frequency of frosts has been matched to real ‘start-up’ information and a good match was achieved, the model can be said to be a reliable indicator of recharge for the Coonawarra wine region during the frost risk period.

The most important result to come out of the modelling exercise is that not all water applied for frost protection returns to the aquifer, a large proportion of the water represents a net loss from the resource and thus must be accounted for in the volumetric allocation system.

6. POLICY FORMULATION

The benchmarking process established that Coonawarra vignerons activate their frost protection systems when the ambient temperature reaches 2.0 °C, on average 25 mm of water is applied to the vineyard per frost event. The modelling exercise demonstrated that not all water applied for frost protection returns to the source aquifer; if water is to be used for frost protection it must be represented in the water accounting system. Given the above, it is recommended that frost allocations be calculated as follows:

Average number of times a frost event is experienced in September to November (min. temp. ≤2.0 °C at Coonawarra weather station).	x	Average Amount of water applied for frost protection (mm)	-	Vine irrigation Requirement during September–November

This paper recommends that ‘Coonawarra averages’ (the data presented in this paper) be used to assign a value to each of the model components; Coonawarra has by far the largest area of vines with frost protection (see page 9) and is the only region for which there is sufficient information to generate recommendations. This proposal has received support from industry representatives from all of the major wine growing areas in the South East.

If it is accepted that the data presented in this paper represents current frost control practices in the South East of South Australia, then the frost allocation will be as follows:

Frost Allocation = 6.2 x 25 mm – 0*

= 155 mm or 1.55 ML/ ha of water per annum for each hectare of vines protected by overhead sprinkler systems.

*Vine water requirement (September to November, Coonawarra) calculated using FAO methodology – see Skewes 2006.

The ‘frost allocation’ is to be made available through the ‘Specialised Production Requirements’ component of the volumetric conversion model (see Pudney et al. 2006).

It is proposed that frost water should be managed as a separate component of the allocation (to prevent ‘frost’ water being used to increase the area of vines irrigated). This will be straightforward where the ‘frost’ bore is fitted with a meter and is separate from the irrigation bore. Where frost and irrigation water are extracted from the same bore viticulture representatives have suggested that it is reasonable to assume any water extracted prior to November 30 represents frost water (a meter reading on November 30th could thus be used to determine the amount of water used for frost protection).

Due to the variable nature of frost events (see Fig. 2 and App. B) the accounting system used to track frost water will need to allow for seasonal variability. The viticulture industry believes a three year rolling average would provide sufficient flexibility to prevent frost damage in most years. Detailed rules defining the use of water allocated for frost protection will be developed through the Water Allocation Planning process.

In conclusion it is recommended that vignerons should be allocated enough water to protect against frost in an 'average' year (6.2 frost events). The amount of water required to achieve this will be equal to 6.2 x 25 mm (average application depth) minus crop water use (as a volume of water has already been allocated for crop water use). This equates to an allocation of 155 mm or 1.55 ML of water per annum for each hectare of vines protected by overhead sprinkler systems.

7. FUTURE WORK

As large volumes of water are used for frost protection it is recommended that research is conducted to determine if the amount of water used per frost event can be reduced without compromising the effectiveness of the protection. Two avenues worthy of further investigation are; the temperature at which frost systems are activated (the critical temperature) and the sprinkler output rate required to provide adequate protection in SE wine regions.

If the critical temperature were reduced from 2.0 °C to 1.5 °C then the number of start-ups during the frost risk period would be reduced from 6.2–3.7. This represents a water saving of 63 mm, which is equivalent to 42% of the general irrigation water budget (assuming irrigation budget is 1.5 ML). The possibility of using a variable critical temperature should also be considered. Vines are more resistant to frost damage during the woolly and early bud stages than when shoots are present; thus a lower critical temperature may be used during early season growth and a higher value during more sensitive growth stages (shoot growth etc.).

A review of the sprinkler output rate required to provide adequate protection should also be conducted. The ‘required’ sprinkler rate is dependent of the minimum temperature reached and the windspeed. Eighteen years of Bureau of Meteorology weather station data shows that minimum temperatures of less than -3 °C are rarely experienced in the months of September to November in Coonawarra (Coonawarra weather station). Average windspeed during these months is 20 km/h; the windspeed during frost event is likely to be significantly less than this. If the minimum temperatures recorded at the Coonawarra weather station are representative of the minimum temperatures reached in frost prone vineyards, Table 2 indicates that a sprinkler rate much lower than 3.7 mm/hr will provide adequate protection for the majority of frost events in the Coonawarra. Many of the overhead sprinkler systems used for frost protection in the SE have a higher than necessary output rate as they were originally used to irrigate the vines. This may be an area where further water savings may be achieved.

As part of this investigation three piezometers were installed by vignerons in Coonawarra vineyards with frost protection systems. Future studies may benefit from these piezometer installations.

8. SUMMARY

The allocation system for irrigation entitlements in the SE of South Australia is about to change from area-based to volumetric. Some vignerons currently use water to prevent their vines from being damaged by frost. As this is a legitimate water use under the current licensing system it must be considered as part of the volumetric conversion process. Applying water to the vine canopy via overhead sprinklers is currently the most effective form of protection against frost damage; the results of a survey indicate that vignerons typically operate their sprinkler system when the minimum temperature is ≤2.0 °C. On average 25 mm of water is applied per frost event. Weather records and 'start-up' information indicate that the Coonawarra experiences on average 6.2 frosts per season. A modelling exercise revealed that not all of this water returns to the aquifer. It is recommended that vignerons be allocated 155 mm or 1.55 ML of water per annum (6.2 x 0.25 ML) for each hectare of vines protected by frost control systems. This should provide adequate water for 'current' frost protection practices, however as frost control practices are refined it may be possible to reduce the allocated volume. There is provision to amend the amount of water allocated for frost protection through the review of Water Allocation Plans, which must occur at least every five years.

APPENDICES

A. VITICULTURE SURVEY RESULTS

		1999					2000					2001				
Site Number	Area	ML/ ha Applied for frost protection	No. Frost Events	Average Application per frost event (mm)	% of vineyard area represented by site	Average Application by area (mm)	ML/ ha Applied for frost protection	No. Frost Events	Average Application per frost event (mm)	% of vineyard area represented by site	Average Application by area (mm)	ML/ ha Applied for frost protection	No. Frost Events	Average Application per frost event (mm)	% of vineyard area represented by site	Average Application by area (mm)
1	10.3						0.42	4	10.50	3.4%	0.36	0.37	3	12.33	2.9%	0.36
2	10.3						0.42	4	10.50	3.4%	0.36	0.37	3	12.33	2.9%	0.35
3	8						0.62	2	31.00	2.6%	0.81					
4	8						0.05	1	5.00	2.6%	0.13					
5	9	0.47	2	23.50	3.7%	0.88	0.28	3	9.33	3.0%	0.28					
6	8	0.97	4	24.25	3.3%	0.81	0.42	2	21.00	2.6%	0.55	0.66	4	16.50	2.2%	0.30
7	3.5	0.73	4	18.25	1.5%	0.27										
8	3.5	0.73	4	18.25	1.5%	0.27										
9	1.5					0.00	0.52	3	17.33	0.5%	0.09					
10	10.8	0.85	6	14.17	4.5%	0.63	0.66	4	16.50	3.5%	0.58	0.58	3	19.33	3.0%	0.40
11	9.31	1.20	9	13.33	3.9%	0.52	1.08	5	21.60	3.1%	0.66	1.09	7	15.57	2.6%	0.39
12	23.6					0.00						0.17	1	17.00	6.6%	1.05
13	7.93					0.00	0.30	2	15.00	2.6%	0.39	0.70	4	17.50	2.2%	0.52
14	3.4					0.00						0.13	1	13.00	1.0%	0.17
15	7.7	1.06	7	15.20	3.2%	0.49	0.67	4	16.63	2.5%	0.42	0.59	5	11.78	2.2%	0.34
16	11	1.09	7	15.57	4.6%	0.71	0.59	3	19.67	3.6%	0.71	0.25	3	8.33	3.1%	0.34
17	3.6	1.20	8	14.96	1.5%	0.22	0.67	4	16.63	1.2%	0.20					
18	3.6	0.59	8	7.36	1.5%	0.11										
19	5.7	1.20	8	14.96	2.4%	0.35	0.67	4	16.63	1.9%	0.31					
20	5.7					0.00	0.59	5	11.78	1.9%	0.22					
21	12.2	0.75	3	25.00	5.1%	1.27	1.71	6	28.50	4.0%	1.14	1.71	6	28.50	3.4%	1.30
22	90.5	0.75	3	25.00	37.6%	9.39	1.71	6	28.50	29.7%	8.47	1.71	6	28.50	25.4%	9.64
23	9.7	0.75	3	25.00	4.0%	1.01	1.50	6	25.00	3.2%	0.80	1.50	6	25.00	2.7%	0.91
24	4	0.75	3	25.00	1.7%	0.41	1.50	6	25.00	1.3%	0.33	1.50	6	25.00	1.1%	0.37
25*	48.87	5.44	34	16.00	20.3%	3.24	4.33	22	19.68	16.0%	3.16	4.51	26	17.35	13.7%	3.17
26*	22.53						1.14	5	22.80	7.4%	1.69					
27*	88.1											5.22	31	16.85	24.8%	5.55
28*	95.58															
29*	25.75															
30*	38.17															
31*	102.9															
32*	174.6															
33*	46.5															
34*	38.37															
35*	45.28															
36*	254.9															
37*	102.5															
38*	115.2															

	1999	2000	2001
Average Application (mm)	18.5	18.5	17.8
Average Application by Area (mm)	20.6	21.6	25.1

Site Number	Area	2002 ML/ ha Applied for frost protection	2002 No. Frost Events	2002 Average Application per frost event (mm)	2002 % of vineyard area represented by site	2002 Average Application by area (mm)	2003 ML/ ha Applied for frost protection	2003 No. Frost Events	2003 Average Application per frost event (mm)	2003 % of vineyard area represented by site	2003 Average Application by area (mm)
1	10.3										
2	10.3										
3	8										
4	8										
5	9										
6	8										
7	3.5										
8	3.5										
9	1.5										
10	10.8										
11	9.31										
12	23.6										
13	7.93										
14	3.4										
15	7.7										
16	11										
17	3.6										
18	3.6										
19	5.7										
20	5.7										
21	12.2										
22	90.5										
23	9.7										
24	4										
25*	48.87	7.21	39	18.49	15.1%	3.02					
26*	22.53										
27*	88.1										
28*	95.58	14.76	69	21.39	29.5%	7.16					
29*	25.75	9.49	41	23.15	8.0%	4.98					
30*	38.17	1.33	14	9.50	11.8%	0.29					
31*	102.9						17.68	85	20.80	11.7%	2.43
32*	174.6						62.33	268	23.26	19.8%	4.61
33*	46.5						27.77	135	20.57	5.3%	1.09
34*	38.37						24.27	71	34.18	4.4%	1.49
35*	45.28						8.31	46	18.07	5.1%	0.93
36*	254.9						40.76	95.5	42.68	29.0%	12.36
37*	102.5						23.04	50	46.08	11.6%	5.37
38*	115.2	11.30	40	28.25	35.6%	7.24	25.80	94	27.45	13.1%	3.59
				Average Application (mm)	20.2				Average Application (mm)	29.1	
				Average Application by Area (mm)	22.7				Average Application by Area (mm)	31.8	
									Grand Average (by area)		**24.38**
									STDEV		7.61

* Denotes a corporate vineyard.

Note: records from individual blocks in corporate vineyards have been grouped, hence ‘ML/ ha applied for frost protection’ and ‘No. of frost events’ is the total from several vineyard blocks.

B. OCCURRENCE OF FROST EVENTS IN COONAWARRA (1986–2004), CRITICAL TEMPERATURE 2.0 °C

Year	January	February	March	April	May	June	July	August	September	October	November	December	Yearly Total	Sept-Nov Total
1986	0	0	0	0	1	4	4	5	5	1	3	0	23	9.00
1987	2	0	2	5	2	6	9	6	4	2	1	0	39	7.00
1988	0	0	0	0	0	1	3	4	1	0	0	0	9	1.00
1989	0	0	1	0	1	10	6	6	1	1	0	0	26	2.00
1990	0	0	1	2	3	7	3	5	1	1	1	0	24	3.00
1991	0	0	1	0	5	2	4	3	1	1	1	1	19	3.00
1992	0	0	0	1	5	2	2	6	5	1	0	0	22	6.00
1993	0	0	0	6	9	5	3	4	1	3	3	0	34	7.00
1994	1	0	2	3	8	8	5	12	5	1	1	1	47	7.00
1995	0	0	2	4	2	4	2	4	8	4	2	1	33	14.00
1996	0	0	0	4	5	7	4	1	4	4	2	0	31	10.00
1997	0	0	1	6	6	6	17	8	3	3	0	0	50	6.00
1998	0	0	0	2	4	12	10	6	2	3	2	0	41	7.00
1999	0	0	1	6	2	5	3	8	1	2	1	1	30	4.00
2000	0	0	0	3	1	3	2	6	1	4	0	0	20	5.00
2001	0	0	0	7	3	6	7	1	1	3	0	0	28	4.00
2002	0	0	0	4	8	7	4	11	4	2	0	0	40	6.00
2003	0	0	0	1	9	2	6	7	6	4	0	0	35	10.00
2004	1	0	0	1	5	2	4	3	2	4	1	0	23	7.00
Average	0.2	0.0	0.6	2.9	4.2	5.2	5.2	5.6	2.9	2.3	0.9	0.2	*Average*	6.21
STDEV	0.54	0.00	0.77	2.35	2.85	2.94	3.64	2.87	2.15	1.34	1.03	0.42		

C. SOIL PARAMETERS RANDOMLY SELECTED FOR DAILY RECHARGE ESTIMATES

Soil Profile	RAW	AW	WP	Pan Factor
1	34.2	60.3	261.2	0.75
2	42.2	82.9	144.7	0.75
3	21.5	93.6	264.8	0.75
4	42.2	74.8	97.1	0.75
5	45.9	66.1	84.7	0.75

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
degrees celcius	°C	Base unit	temperature
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
Irrigation rate/requirement	ML/ha	Mm depth	rate
kilolitre	kL	1 m^3	volume
megalitre	ML	10^3 m^3	volume
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
percent	%	fractions, decimal	proportion
second	s	base unit	time interval
year	y	356 or 366 days	time interval

Hectare Irrigation Equivalent	haIE	Area based entitlement

GLOSSARY

Application Depth. The depth of water applied (mm) with each irrigation.

Area-Based Licensing System (haIE). Existing water access entitlements to irrigate a given area of crop per annum, with no restrictions on the volume of water applied to the crop. Measured in terms of hectares of irrigation equivalents (haIE).

Available Water (AW). Also known as plant available water, is the amount of water that may be taken up by plants from field capacity (wettest drained condition of the soil) to the permanent wilting point (driest soil condition that plants can tolerate).

Class A Evaporation Pan. Rate of water loss by evaporation from an open surface of a pan (Doorenbos and Pruitt, 1977). The Australian Bureau of Meteorology uses the Class A Pan as the standard for measuring evaporation.

Critical Temperature. The temperature at which frost protection systems are activated to prevent frost damage.

Crop Coefficient (Kc). Ratio between crop evapotranspiration (ETC) and the reference crop evapotranspiration (ET_0) when crop is grown in large fields under optimum growing conditions, or ETC = Kc x ET_0 (Doorenbos and Pruitt, 1977).

Crop Water Requirement. Depth of water required by a crop for evapotranspiration during a given period (Doorenbos and Pruitt, 1977).

Deep Drainage. Water that percolates past the crop root zone and is no longer available to the crop for transpiration.

Evaporation. The process where liquid water is converted to water vapour and lost from the evaporating surface.

Evapotranspiration (ET). Rate of water loss through transpiration from vegetation plus evaporation from the soil (Doorenbos and Pruitt, 1977).

FAO 56. Food and Agriculture Organization of the United Nations. FAO Irrigation and Drainage Paper, 56 (1998) - Crop Evapotranspiration; Guidelines for Computing Crop Water Requirements.

Frost Protection Water. Water applied to the crop canopy using fixed overhead sprinklers to prevent frost damage to the crop.

Full Point. Also known as field capacity, is the wettest drained condition of the soil

Groundwater (Underground water). Water occurring naturally below ground level.

Megalitre (ML). One ML equal one million litres or one thousand Kilolitres.

Piezometer. A well specifically installed for monitoring groundwater levels.

Prescribed Wells Area (PWA). A water resource declared by the Governor to be prescribed under the Water Resources Act 1997, and includes underground water to which access is obtained by prescribed wells.

Radiation Frost. Is a frost where freezing is caused by rapid heat loss from the ground surface (heat is radiated from the ground to the sky); radiation frosts typically occur on nights where there is very light (or no) wind, clear skies and the air is of low humidity.

Recharge. The infiltration of water (rainfall, streamflow, irrigation) into an aquifer from the surface

Readily Available Water (RAW). Amount of water in the soil that can be easily be obtained and used by plants.

Reference Crop Evapotranspiration (ET_0). Rate of evapotranspiration from an extended surface of 8–15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977).

SILO DataDrill. Continuous interpolated daily climatic data. Queensland Department of Natural Resources and Mines.

Specialised Production Requirements (SPR). (1) Water that is necessarily applied as a part of the crop production process that does not contribute to crop water use and is not included in the delivery component (e.g. to prevent soil drift or to protect against frost damage). (2) Water that is required in addition to base allocation due to significant changes in the crop production system (as recognised by FAO 56). For example Maximum Production Pasture.

Transpiration. Rate of water loss through the plant, which is regulated by physical and physiological processes (Doorenbos and Pruitt, 1977).

Volumetric Conversion Model. Describes the components and methodologies for the conversion of existing area-based allocations to volumetric allocations.

Volumetric Licensing System. Licensees are entitled to pump a certain volume of water per annum, but are not restricted by the area of crop/s grown.

Water Licence. A licence granted under the natural resource management act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area.

Water Allocation Plan (WAP). A plan prepared by a Natural Resource Management Board or water resource planning committee and adopted by the Minister in accordance with Division 3 Part 7 of the Water Resources Act 1997.

Wilting Point (WP). Driest soil condition that plants can tolerate (all available water has been extracted).

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