Padthaway WINE REGION

Australian Government
Grape and Wine Research and Development Corporation

Water and Salt Balances in Padthaway Wine Region



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GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Principal Investigator: **Dr Helen Cleugh, CSIRO**

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Water and Salt Balances

in Padthaway Wine Region

Padthaway Grape Growers Association

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1. Abstract

The Padthaway area of South East South Australia sources irrigation water from a shallow local aquifer in which salinity has increased by up to 75% in the last 25 years, threatening wine quality and quantity.

This 3-year project quantified evaporation, and salt and water fluxes below the irrigated root zone, to allow more accurate predictions of recharge and inform irrigation management.

The project derived a simple model for vineyard water use which is valid at the monthly–seasonal time scale, but may not be valid for shorter time periods when excessive dryness may induce transpiration shutdown.

2. Executive summary

The long established Padthaway area in the South East of South Australia irrigates about 3900 ha of vineyards. Irrigation water is sourced from a high yielding unconfined aquifer which underlies the main irrigation area at shallow depth. Salinity in parts of that groundwater has increased from around 800 mg/L to 1400 mg/L the last 25 years.

This increase in groundwater salinity threatens the longer term viability of irrigation in parts of Padthaway. Some serious adverse impacts are already evident, and losses in wine quality and production are expected if the salinity increases further.

Physical characteristics of the soil and aquifer, loss of high water use vegetation and irrigation methods have all contributed to the salinity increase.

This 3-year project aimed to quantify the salt and water fluxes below the irrigated root zone in vineyards in the region and thereby allow more accurate predictions of recharge and informed management decisions on the use of irrigation in vineyards. The ultimate aim is a sustainable underground water supply for future grape production the Padthaway wine region.

Outputs designated for the project were:

1. point measurements of water and salt fluxes beneath the root zone
2. measurements of vineyard scale evapotranspiration using a mobile flux station
3. models of vineyard evapotranspiration across the Padthaway wine region
4. quantified estimates of the water use efficiency of the irrigated vineyards

Vineyard water use was measured in 3 different vineyards (one each year). Also measured were drainage, evaporation, soil moisture, irrigation volumes, temperature, relative humidity, rainfall and solar radiation. Long-term and current climate data were also sourced from the nearby Bureau of Meteorology station.

Temperatures trended warmer over the 3 years of the project. The general climate could be characterised as humid and cool in 2003–04, dry in 2004–05, and warmer with a higher frequency of very dry days and average growing season rainfall in 2005–06. Autumn rainfall in all years was below average.

Vineyard water use was the largest output flux in all years, averaging over 500 mm year^{-1}, or about 1/3 of the annual pan evaporation. Most water use was in the growing season.

Total water inputs (rainfall and irrigation), but not rainfall alone, exceeded vineyard water use in all years, suggesting that drainage would be possible and that the magnitude would be slightly less than the total irrigation amount.

Vineyard water use varied between years and sites: growing season evapotranspiration was about 75% the potential evaporation in the first two measurement years (2003–05) and increased to 80% for the last year (2005–06) when there was above average rainfall and a large vapour pressure deficit. Also in the last year, irrigation volumes were higher and the vine canopy was greater because of closer rows in the vineyard being sampled.

Nonetheless, the overall differences in growing season vineyard water use between the grape varieties were quite small at the seasonal time scale.

A simple analysis suggested that inter-row water use was 20–30% of the annual total vineyard water use, or 100–170 mm year^{-1}. That this is a similar magnitude to the irrigation points to the potential to better utilise the rainfall intercepted by the inter-row.

The drainage meter measurements suggested that drainage did occur in the autumn of 2006, while the stored soil–water data indicated that the magnitude of this drainage flux was about 60 mm.

The water balance analyses suggest drainage events of similar magnitudes in the winter–spring periods of 2003 and 2004, but there is large uncertainty in these estimates due to errors in all the measured terms (rainfall, irrigation, evapotranspiration and changes in stored soil–water). Drainage meters had not been installed in 2003, and they did not show evidence of drainage in 2004 (although they were not in the same vine block as the evapotranspiration measurements).

The project derived a simple model for vineyard potential evaporation that uses the measured pan evaporation from the Bureau of Meteorology's climate station and a pan coefficient (c_p) of 0.46. This factor was fairly consistent over the 3 years and vineyards, demonstrating that this coefficient is robust across a range of vine and soil types for the Padthaway region.

A simple model for vineyard water use is proposed:

$$\begin{aligned} ET &= f_c \, E_p \\ &= f_c \, c_p \, E_{pan} \end{aligned}$$

where the coefficient c_p is 0.46, and f_c varies from about 1.2 in the winter months when the vines are bare to 0.7 in the main growing season when they are in full leaf (monthly values are given in the report).

This simple modelling approach is valid at the monthly–seasonal time scale, but may fail for shorter time periods because of the limiting effect of elevated vapour pressure deficit on vine transpiration.

3. Background

The Padthaway area is a long established and important irrigation district in the South East of South Australia with vines, vegetables, various seed and pasture crops being the main irrigated produce. The total area irrigated is about 8700 ha, about 3900 ha of which are currently planted to vines.

Groundwater for irrigation is sourced from a high yielding unconfined aquifer which underlies the main irrigation area at shallow depth. Monitoring has shown an increase in groundwater salinity in parts of Padthaway of about 600 mg/L in the last 25 years, from around 800 mg/L to 1400 mg/L.

This increase in groundwater salinity threatens the longer term viability of irrigation in parts of Padthaway. Some vignerons already report serious adverse impacts, and losses in wine quality and/or production are expected if the increase in groundwater salinity is not arrested.

Salt accession to the aquifer, and thus increased groundwater salinity, has resulted from:

- groundwater extractions exceeding the vertical recharge
- cycling of irrigation water
- the shallow depths to groundwater
- highly permeable soil profiles in the main irrigation areas
- mobilisation of the historic salt store in the soil profile above the watertable by increased vertical recharge following native vegetation clearance
- loss of high water use perennial pastures in the more elevated Naracoorte Ranges area east of Padthaway.

4. Project aims and performance targets

Objectives

The project aimed to quantify the salt and water fluxes below the irrigated root zone in vineyards in the Padthaway wine region and thereby provide constrained and better predictions of recharge and groundwater salinity. A better understanding of these salt and water fluxes would inform management decisions on the use of irrigation in vineyards and lead to a sustainable underground water supply for future grape production the Padthaway wine region.

This project complemented the broader Department of Water, Land and Biodiversity Conservation (DWLBC) Padthaway Salt Accession Project.

Outputs and Performance Targets

Outputs	**Performance targets**
1. point measurements of water and salt fluxes beneath the root zone	Install drainage meters Determine stored water and increased frequency of soil solute sampling by measurements with neutron moisture meters Deliver final measurements
2. measurements of vineyard scale evapotranspiration using a mobile flux station	Take measurements with the flux station at different sites in each season of the project Deliver final measurements
3. models of vineyard evapotranspiration across the Padthaway wine region	Test equilibrium evaporation model against actual data measured at the flux station Further refine and test the coefficients used in the model by continuing measurement of actual water use Develop a physiologically based model based on the Penman Monteith equation Produce final models
4. quantified estimates of the water use efficiency of the irrigated vineyards	Collect data to quantify estimates of water use efficiency in irrigated vineyards Deliver estimate of water use efficiency of vineyards

5. Method

The space/time variations in canopy cover, and spatial variability in soil type and depth, meant that new methodologies were needed to quantify the dynamics of the water and salt balances in the project area. Specifically these were:

a. *Micrometeorological methods* continuously and directly measured vineyard water use (evapotranspiration (ET)) on an hourly basis using "flux tower" technology. Over the 3-year duration of the project, the flux tower was moved to a different vine block each season to sample a range in grape variety, vine architecture and soil type.

b. *Drainage meters* were deployed in two vineyards to provide point measurements of the volume of water draining below the root zone – in both the vine row and inter-row.

These measurements of vineyard water use and drainage were combined using the expressions for the water balance (5.1) and salt balance (5.2) for a volume of soil defined by the plant rooting depth. Figure 5.1 illustrates this volume and the water flux terms:

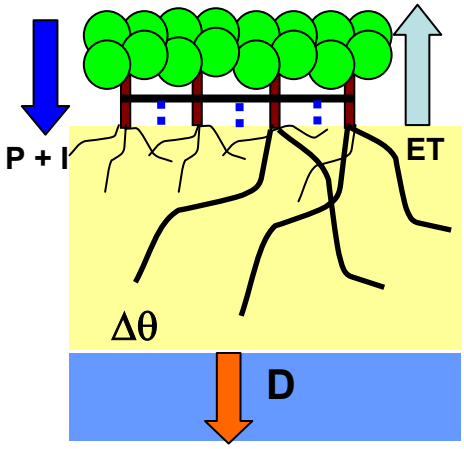


Figure 5.1: Conceptual representation of soil–plant volume for 1-dimensional water and salt balance analysis

5.1 Water balance

Water balance is expressed by the equation:

Inputs Outputs

$$P + I = ET + \Delta\theta + D \quad (5.1)$$

where:

runoff is assumed to be negligible
P and I are the inputs from rainfall and irrigation
ET is evapotranspiration comprising evaporation from the soil, transpiration from inter-row plants and vines, and evaporation of any water intercepted by the plant leaf and stem surfaces
$\Delta\theta$ is the change in stored soil–water in the soil volume
D is drainage below the root zone.

The largest terms in Equation 5.1 are inputs through rainfall and irrigation, and vineyard water use: in the Padthaway vineyards, these were in the range of 450, 150 and 550 mm per year, respectively. Compared to total inputs through rainfall and irrigation, and vineyard water use, the drainage term is quite small but has large consequences for the quality of the groundwater resource because of the potential for leaching of salts into the groundwater.

The flux tower provided continuous measurements of vineyard water use, spatially averaged over an entire vine block (as opposed to an individual vine or soil plot). Given the dominance of this term in the water balance, these data provided an effective constraint on estimates of the drainage term that were derived from water balance models.

5.2 Salt balance

Salt accession into the groundwater can be similarly considered using a salt and water balance framework, where the inputs are simply the salt concentration of the rainwater and irrigation water multiplied by the volumes of each. The output is the salt flux to the groundwater and can be estimated[1] from the drainage flux (5.1) and the solute concentration in this drainage water:

Inputs Outputs

$$P.c_{sp} + I.c_{si} \quad D.c_s + \theta_{cs} \tag{5.2}$$

where

c_{sp}, c_{si} and c_s are the salt concentrations in rainfall, irrigation water and soil–water, respectively
θ_{cs} is the salt concentration in root zone soil–water.

The flux tower and drainage meter measurements of *ET* and *D* are essentially point measurements – the former has a sample area (footprint) that extends upwind about 50–400 m while the latter has a footprint equivalent to 50–100 cm. The sampling configuration adopted to ensure that the water use and drainage measurements reflect some of the spatial variation expected across the Padthaway Flats area is described in Section 5.3 together with the timing of these measurements.

5.3 Water and climate measurements

All terms in the water balance (5.1) were measured (see summary in Table 5.1) as follows:

ET CSIRO flux tower measures vineyard water use directly and continuously

- Installed July 2003 at CS-5 (Stonehaven vineyard, NAP-1)
- Moved to CS-4 (NAP-6) in August 2004
- Moved to CS-6 (NAP-7) in August 2005

Drainage meters installed at CS-5 and CS-6 in October 2004

Soil–water $\Delta\theta$ monitored to a depth of 4 m using a neutron moisture meter (NMM) and a network of 24 access tubes installed at the vineyard sites (6 access tubes per vineyard: 3 in the vine row and 3 in the mid inter-row)

Sentek EnviroSMART® soil–water sensors installed at each vine block to continuously monitor soil moisture; logged using the automatic weather stations (AWS) data acquisition system

P Rainfall measured by a network of raingauges across the Padthaway Flat region, operated by CSIRO, Bureau of Meteorology (BoM) and DWLBC

I 2 AWS loggers modified to record time-on and time-off of irrigation valves that control drippers in each vine block

Irrigation duration combined with measured dripper rate quantifies total irrigation volumes for each growing season

Climate 4 CSIRO-designed AWSs installed and operated at 4 locations to capture expected north–south gradient in rainfall across the Padthaway Flats region

[1] Note this is an approximation as the diffusion of salt is ignored in this simple equation

AWSs continuously monitored rainfall, temperature and solar radiation along with the EnviroSMART soil moisture levels

The BoM Padthaway Climate Station (Site ID: 26100) is located immediately northeast of site CS-4 and provided daily temperature, rainfall and pan evaporation for the duration of the project. The data for long-term climate record was from the previous Site ID:26089.

Details of the technologies and methods used can be found in the reports in Appendix 5.

Table 5.1: CSIRO measurements, sensor technologies and installation details

Measurement	Technology Sampling frequency	Installed	Site description
Vineyard water use (*ET*)	CSIRO flux tower Sampling: 20 Hz 1 Hz Averaged to: 15 min and 60 min	Jul 2003 Jul 2004 Jul 2005	CS-5 (Stonehaven) Chardonnay (NE sector) Riesling (all other sectors) CS-4 (Stonehaven) Shiraz CS-6 (Orlando, Richmond Grove) Chardonnay (SW sector) Cabernet sauvignon (SE sector) Merlot (N sector)
Drainage (*D*)	CSIRO drainage meters 60 min	Oct 2004	CS-5 (Chardonnay block) CS-6 (Chardonnay block) Vine row and mid inter-row
Soil moisture ($\Delta\theta$) 0–4 m	NMM Fortnightly	Jul 2003	CS-1 (Riesling block) CS-4 (Shiraz block) CS-5 (Chardonnay block) CS-6 (Chardonnay block) 6 access tubes per block: 3 each in the vine row and mid inter-row
Soil moisture	EnviroSMART sensors 60 min	Jul 2003	CS-5 (Chardonnay block) CS-6 (Chardonnay block) Vine row and mid inter-row
Irrigation (*I*)	Time-on, time-off[1]	Apr 2004	CS-5 (Chardonnay block) CS-6 (Chardonnay block)
Climate: . air temperature . relative humidity . rainfall . solar radiation	CSIRO automatic weather stations 15 min	Jul 2003	CS-1 (Riesling block) CS-4 (Shiraz block) CS-5 (Chardonnay block) CS-6 (Chardonnay block)

1. Combined with dripper flow rate and the number of drippers ha^{-1}, enables irrigation volume to be calculated

6. Results and discussion

6.1 Climate

All three measurement years (2003–04; 2004–05 and 2005–06) differed in total rainfall received and its distribution throughout the year, and in temperature and humidity.

Tables 6.1 (rainfall), 6.2 (maximum and minimum air temperature) and 6.3 (vapour pressure deficit (VPD)) provide a brief overview of the climate as background to water flux results presented (Section 6.2). Figures 6.1 and 6.2 illustrate these data in graphical form.

In 2003–04 rainfall was slightly higher and temperatures were cooler than average; it was the most humid of the three measurement years. The second year, 2004–05, was the driest in annual and growing season rainfall and in humidity deficit (as indicated by VPD). Reflecting the pattern across much of Australia, air temperatures (mean, maxima and minima) trended warmer from 2003 to 2006 (Figure 6.1). There were more than 10 extremely dry days (maximum VPD > 50 hPa) in the 2004–05 and 2005–06 growing seasons. The latter occurred in conjunction with an above-average growing season (spring and summer) rainfall, so evaporative water losses were expected to be large because of this large atmospheric demand.

Table 6.1: Rainfall

Rainfall (mm)	Long-term average	BoM Padthaway climate station	Flux tower[1]	AWS[2]
(a) Annual				
Aug 2003–Jul 2004	506.9	519.9	476.6[3]	513.2
Aug 2004–Jul 2005	506.9	389.1	377.6	384.7
Aug 2005–May 2006	439.4	421.7	367.4	411.7
(b) Growing season				
Sep 2003–Feb 2004	193.1	184.5	165.6	191.7
Sep 2004–Feb 2005	193.1	155.2	147.0	163.1
Sep 2005–Feb 2006	193.1	249.5	216.6	229.7

1. Totals for different locations as flux tower moved each year
2. Average across all 4 AWS raingauges
3. An underestimate due to sheltering from the vine rows

Table 6.2: Air temperature

Temperature (°C)	Long-term average		BoM Padthaway climate station		Flux tower	
	Daily max	Daily min	Av daily max	Av daily min	Av daily max	Av daily min
(a) Annual						
Aug 2003–Jul 2004	21.1	8.4	20.6	8.1	19.4	8.1
Aug 2004–Jul 2005			21.7	8.6	21.1	9.2
Aug 2005–May 2006	22.4	9.0	22.5	8.4	21.6	9.3
(b) Growing season						
Sep 2003–Feb 2004	24.0	9.7	23.4	9.3	21.9	8.6
Sep 2004–Feb 2005			24.1	9.9	23.1	10.3
Sep 2005–Feb 2006			24.4	10.4	23.4	10.6

Table 6.3: Vapour pressure deficit for three growing seasons, using flux tower measurements only

Vapour pressure deficit (hPa)	Average	No. of days when VPD_x[1] exceeded:	
		20 hPa	40 hPa
Sep 2003–Feb 2004	8.89	86	7
Sep 2004–Feb 2005	9.70	110	12
Sep 2005–Feb 2006	9.53	94	11

1. VPD_x is the maximum daily VPD

The distribution of rainfall varied across the measurement years, with large spring and summer rainfalls making the 2005–06 growing season the wettest (Figure 6.2). The rainfall deficit recorded in the spring and autumn of the 2004–05 overwhelmed the slight above-average rainfall recorded in the preceding winter to yield a very dry growing season and year. The 2003–04 total rainfall was about average, mainly due to above average falls in the winter months; growing season rainfall was below average. Autumn rainfalls were below average in all measurement years (Figure 6.2).

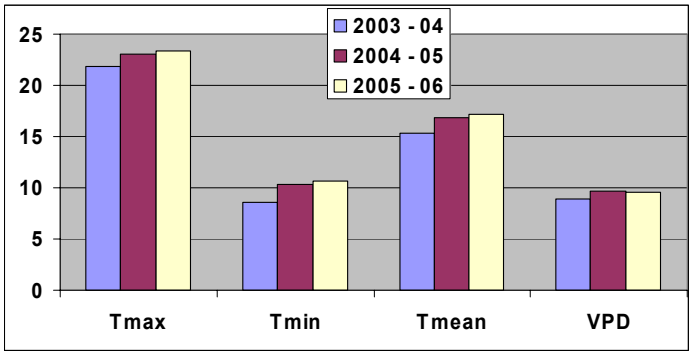


Figure 6.1: Growing season temperature and vapour pressure deficits for each year of measurements

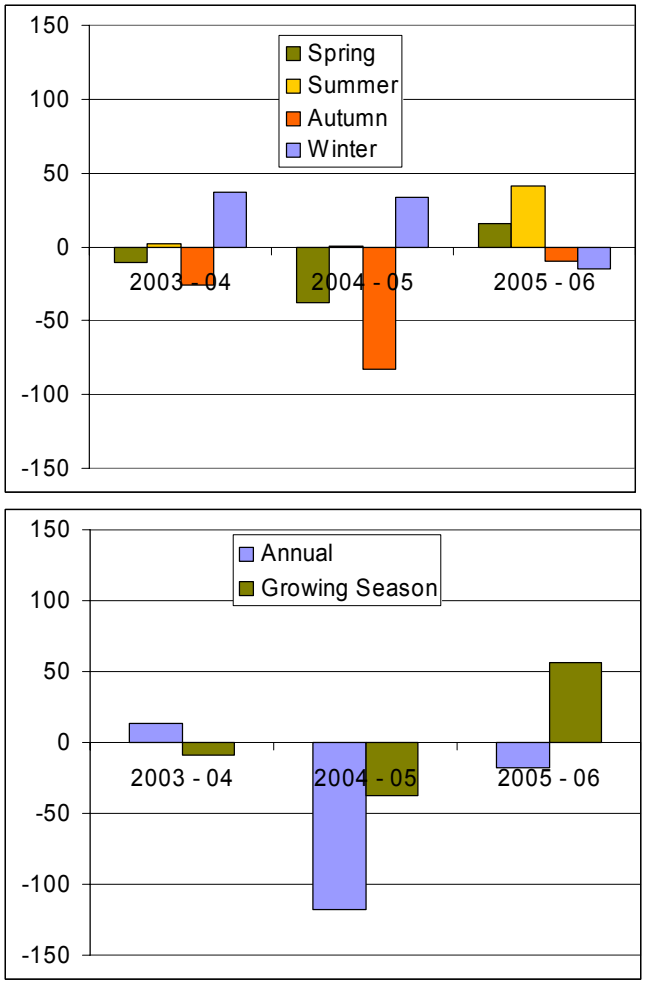


Figure 6.2: BoM climate station rainfall (annual, growing season and seasonal) totals plotted as departure from the long-term average (mm)
A negative quantity indicates below average rainfall for the period

6.2 Water fluxes

The most significant measurements for the project are continuous vineyard *ET* fluxes, and then water use and drainage.

6.2.1 Actual, potential and pan evaporation

Evaporation can be described in several ways.

Actual evaporation: the actual water lost through transpiration, soil evaporation and evaporation of surface water. It is the quantity measured by the CSIRO flux tower.

Potential evaporation: the theoretical upper limit to evaporation. There are many ways of defining potential evaporation but the general definition of the *maximum evaporation rate that can be sustained from a moist surface* is appropriate. If the moist surface is sufficiently extensive (tens to hundreds of kilometres), then this upper limit equates to the energy supply and is given by the following expression for equilibrium evaporation (λE_{eq} in energy units):

$$\lambda E_p \approx \lambda E_{eq} = \frac{s(R_n - G)}{s + \gamma} \quad (6.1)$$

where R_n and G are the net all-wave radiation and soil heat fluxes; s and γ are thermodynamic variables (s is the slope of the saturation vapour pressure – air temperature curve and γ is the psychrometric constant ~ 0.66 hPa $^oC^{-1}$). λE_p is the energy equivalent (units – W m^{-2}) of the potential evaporation mass flux, E_p (m s^{-1}):

$$E_p = \frac{\lambda E_p}{L_v \rho_w} \quad (6.2)$$

where L_v and ρ_w are the latent heat of vaporisation and density of water, respectively. If the moist surface is localised, more like 10^3 m in spatial extent rather than 10^4 m or 10^5 m, then potential evaporation equations such as Penman's are a reasonable description of potential evaporation (Meyer 1999; milestone reports in Appendix 5.

In this report, we prefer to use the equilibrium evaporation definition of potential evaporation, noting that the Penman equation converges towards the energy limited equilibrium rate at the limit of an extensive, moist surface.

Pan evaporation: This is the daily evaporation rate as measured by a US Class A evaporation pan. The pan evaporation rate (E_{pan}) is related to potential evaporation (E_p) by a pan coefficient, c_p:

$$E_p = c_p \, E_{pan} \quad (6.3)$$

which in turn can be related to actual evaporation by a vine or crop coefficient:

$$\begin{aligned} ET &= f_c \, E_p \\ &= f_c \, c_p \, E_{pan} \end{aligned} \quad (6.4)$$

where c_p is typically around 0.5 and f_c for vines varies from 0 before the growing season starts to 0.6 to 0.7 at maximum canopy cover and leaf area index. However, these coefficients vary with climate and type of crop and so published values cannot be assumed to apply to the Padthaway vineyards. Appropriate coefficients for these vineyards and climate were thus determined in this study.

Figure 6.3 plots measured potential evaporation from July 2003 to June 2006 with measured weekly actual evaporation (Figure 6.3a) and with the time series of potential evaporation modelled using pan measurements and a pan coeffcient (c_p) of 0.46 (Figure 6.3b). Agreement between measured and modelled potential evaporation is good (R^2 = 0.95, slope of line of best fit fitted through a plot of measured vs modelled = 1.0007 for monthly data and very similar statistics for weekly totals), except for a tendency for modelled E_p to exceed measured in the autumn to winter period of February–July 2005.

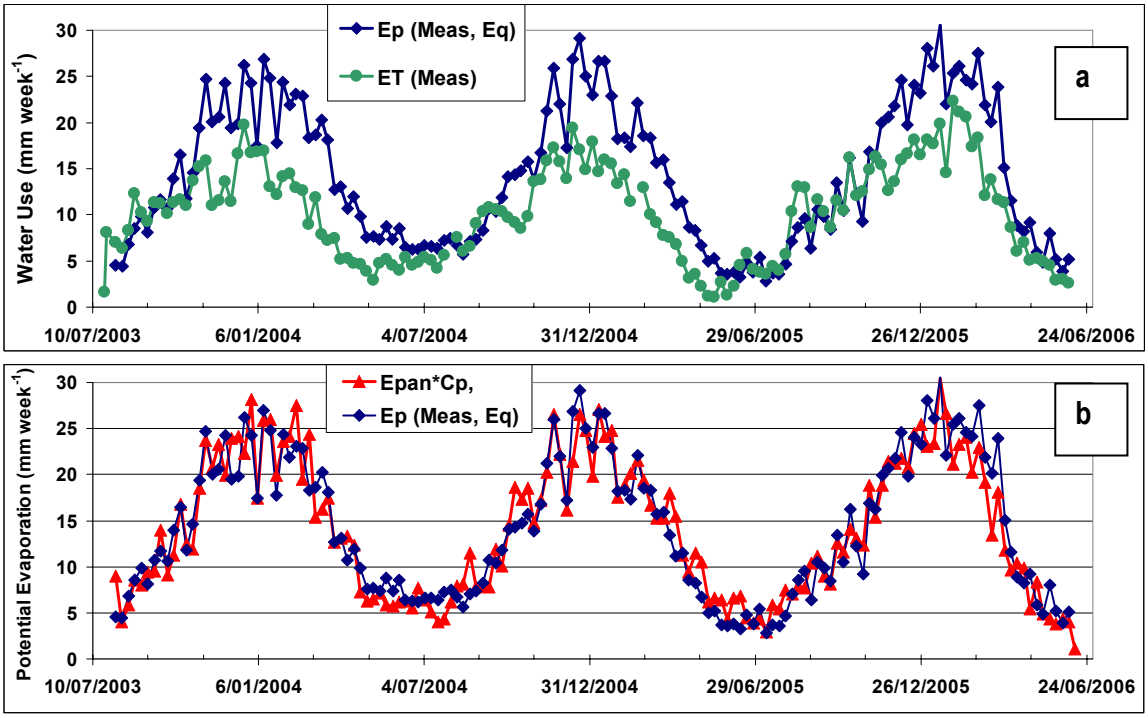


Figure 6.3: Measured potential (Ep) evaporation plotted with (a) measured weekly actual (ET) and (b) modelled (Epan*cp) weekly potential evaporation

Optimising c_p for each vineyard yielded the values and model parameters shown in Table 6.4. A pan coefficient of 0.46 appears to be a robust coefficient across a range of vine and soil types.

Table 6.4: Evaporation values and model parameters

Time period	c_p	R^2	intercept
All years	0.46	0.90	0.31
2003–04	0.40	0.90	1.85
2004–05	0.48	0.92	-1.18
2005–06	0.47	0.90	0.41

The relationship between pan, potential and actual evaporation (i.e. vineyard water use) is more complex (see milestone reports in Appendix 5). A model for the relationship at Padthaway is presented in Section 6.3.

6.2.2 Rainfall, irrigation and vineyard water use

Annual and growing season rainfall, irrigation, vineyard water use, potential and pan evaporation for all three measurement years are presented in Table 6.5 and Figure 6.4 (for monthly data see Appendix 5). Actual and potential evaporation rates come from different vineyards in each year; thus inter-annual variability reflects both climate drivers and the effects of vine architecture and soil type.

Table 6.5: Annual and growing season water fluxes for each year of measurements

Water flux	mm	mm	mm
Annual	Aug 03–Jul 04	Aug 04– Jul 05	Aug 05–May 06
Rain plus Irrigation	509.6 + 140 =	377.6 + 163 =	367.4 + 288 =
Total	649.6 (±33)	540.6 (±27)	655.4 (±33)
Actual evaporation	532.1 (±53)	495.3 (±49)	568.1 (±57)
[*P*+*I*] – *ET*	117.5	45.3	87.3
Potential evaporation	722.9	646.7	689.5
Pan evaporation	1586.4	1562.6	1428.2
Growing season	Sep 03–Feb 04	Sep 04– Feb 05	Sep 05–Feb 06
Rain plus Irrigation	171.8 + 102.2 =	147 + 122.2 =	216.6 + 195 =
Total	276.8	269.2	411.6
Actual evaporation	362.2	352	412.8
[*P*+*I*] – *ET*	-85.4	-82.8	-1.2
Potential evaporation	484.4	474.2	504.4
Pan evaporation	1068.0	1042.6	1044.6

Note: Rainfall data are from flux tower not BoM climate station. Irrigation figures are for the vine block in which the flux tower was located in each year. Values in brackets are estimates of errors on *P*+*I* (5%) and *ET* (10%) measurements.

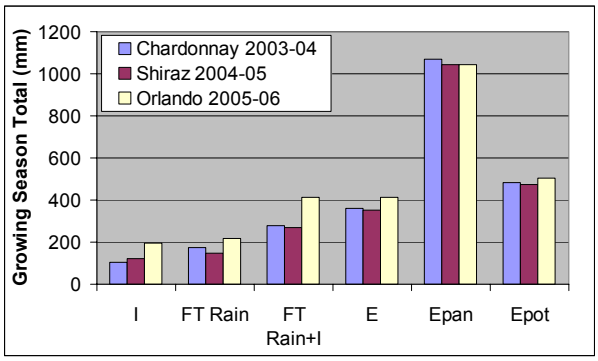


Figure 6.4: Growing season irrigation, rainfall and evaporation for each year of measurement at the flux tower (FT)

Annually, water inputs exceeded the vineyard water use term, suggesting that drainage is possible in most years. The vineyard water use in the growing season matched the input from rainfall and irrigation in 2005–06 but exceeded these input fluxes in the earlier 2 years. Only one-third of the total rain fell in the growing seasons of 2003–04 and 2004–05; in 2005–06 it was almost two-thirds (60%). The ratio of growing season to annual water use was quite consistent across the 3 sites and years at 68%, 71% and 73%.

All growing season water fluxes (*P*, *I* and *ET*) were higher in the last measurement year. In the first 2 years, growing season *ET* was about 75% and 33%, respectively, of potential and pan evaporation. This rose to 80% and 40%, respectively, for 2005–06, reflecting the combined weather (above average rainfall and large VPD), increased irrigation and greater vine canopy with closer vine rows at CS-6.

Cumulative water inputs (rainfall only) and vineyard water use for each measurement year, together with the 40-year average rainfall and pan evaporation (Figure 6.5), showed some key features of the water balance:

a. Rainfall measured at the flux tower was below the 40-year average for all years (July 2003–July 2004; August 2004–July 2005; August 2005–June 2006).

b. Pan evaporation, which was very close to the long term average in 2003–04 but slightly lower than the long-term average in 2004–06, was about 3 times larger than vineyard water use on an annual basis, but only twice vineyard water use in winter.

c. Vineyard water use was the largest term in the water balance – second only to rainfall in magnitude.

d. In the first two years (Figure 6.5a and b), when winter rainfall was above average, vineyard water use was less than the rainfall due to the low atmospheric demand in the cooler, more moist winter months (July–November). Some drainage and 'flushing' of the vine root zone could be expected in that period, depending on the antecedent rainfall. In the late spring to late autumn period (i.e. the main part of the growing season from November to April) vineyard water use equalled or exceeded rainfall. Thus growing season water-use can only be sustained by drawing on soil moisture reserves, irrigation and (possibly) some access to the groundwater.

   In the final year (Figure 6.5c, 2005–06), winter rainfall was below average; vineyard water use matched rainfall throughout winter and then exceeded rainfall throughout the growing season.

Total water balance figures for the 3 years of measurements, are given in Table 6.6.

Table 6.6: Water balance figures for 3 years

Time period	Rainfall (mm)	Irrigation (mm)	Total inputs (mm)	Water use (mm)
Total: 3 years	1255	591	1846	1595
Total: 3 growing seasons	535	422	957	1127

This simple analysis suggests potential for annual drainage at the sites, of a magnitude similar to the irrigation volume. However, sites must be assessed dynamically (i.e. on a weekly or monthly basis) because of rainfall distribution across the year. A more complete analysis is presented in Section 6.3.

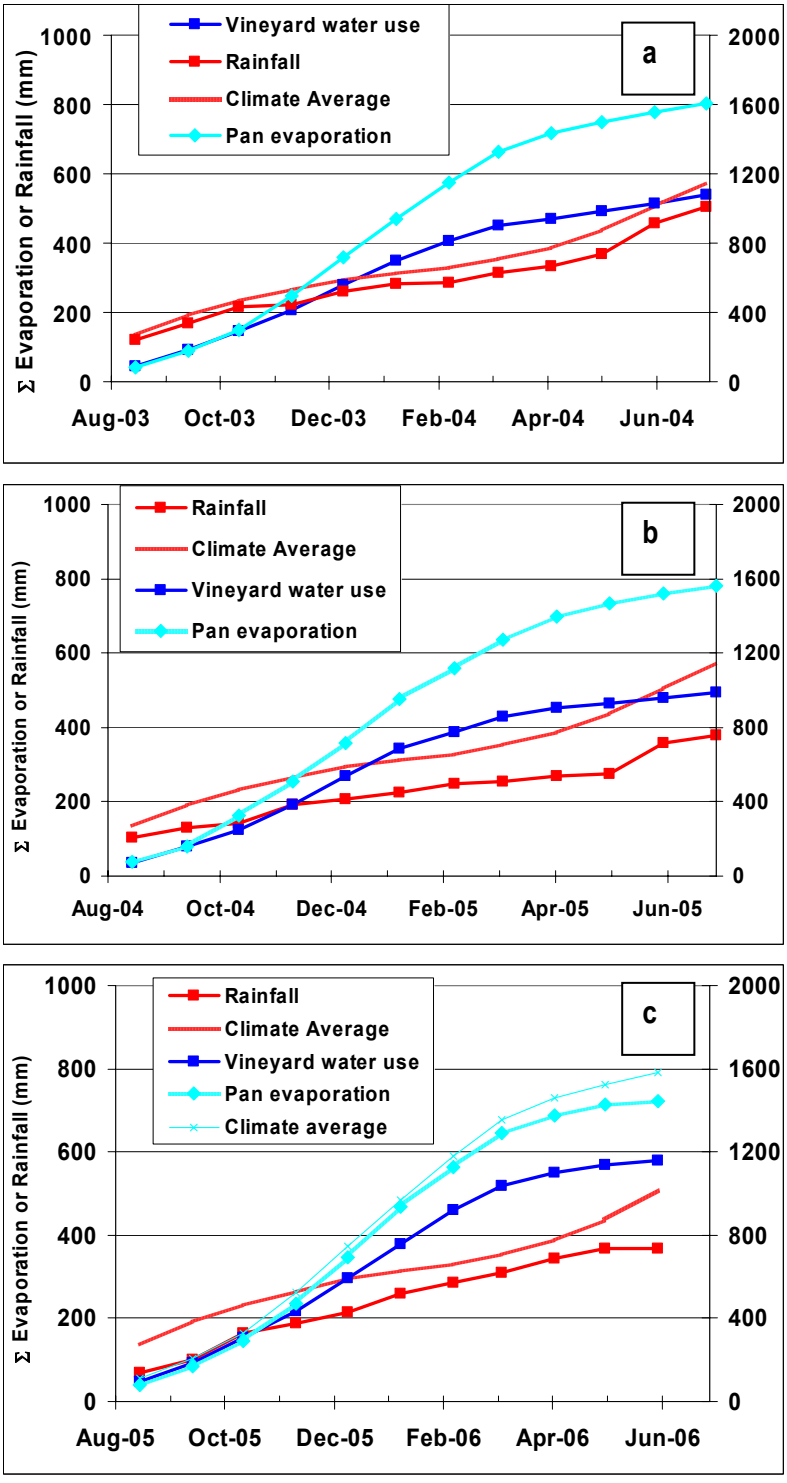


Figure 6.5: Cumulative rainfall and vineyard water use (evaporation) on left-hand axis, and pan evaporation (right hand axis, mm y^{-1}) for (a) chardonnay block, CS-5; (b) shiraz block, CS-4; and (c) mixed chardonnay–cabernet sauvignon–merlot, CS-6

6.2.3 Water balance: Storage and drainage

The drainage meters installed in the vine-line (VL) and inter-row (IR) at the Orlando (Figure 6.6) and Stonehaven (Figure 6.7) vineyards measure:

a. soil–water potential (ψ > -100 cm) at depths of 190 cm and 210 cm using a pair of tube tensiometers (Hutchinson and Bond 2001)

b. soil temperature at 340 cm depth (inside the instrument casing)

c. electrical capacitance of the diatomaceous earth inside the tube tensiometers.

These outputs can be used to estimate the vertical component of the drainage flux (D) from the following equation:

$$D = K(\psi)\left[1-\frac{d\psi}{dz}\right] \quad (6.5)$$

$$\approx K(\overline{\psi})\left[1-\left(\frac{\psi_1-\psi_2}{z_1-z_2}\right)\right]$$

where:

$K(\overline{\psi})$ is the unsaturated hydraulic conductivity of the soil at 200 cm depth at a soil–water potential of $\overline{\psi}$,

$$\overline{\psi} = \frac{\psi_1+\psi_2}{2}$$

and z_1 and z_2 are the depths of the tube tensiometers, in this case 190 and 210 cm.

When soil–water potential is drier than -100 cm, or -120 cm in the case of the upper tube tensiometer, the output from the tube tensiometers cannot be used to estimate drainage, but at these dry potentials drainage flux is expected to be small. For most of the measurement periods at the Orlando and Stonehaven vineyards the soil–water potentials were drier than -100 cm for the lower tube tensiometer (P2) and -120 cm for the upper tensiometer (P1). The exceptions to this (see Figures 6.6 and 6.7) were:

a. Orlando IR: a gradual decrease in recorded soil–water potential at P2 from the time of installation (December 2004) to August 2005

b. Stonehaven IR: high frequency variations in soil–water potential at P2 for the first 6 months of the deployment (December 2004–May 2005)

c. Stonehaven VL (P1, P2) and Orlando VL (P1): a gradual increase in soil–water potential in the last 6 months of the deployment (November 2005–May 2006).

The last two exceptions (c) were due to real changes in soil–water potential and drainage, but the first two (a, b) were speculated to be owing to air entrapment in the vent tubes of the tube tensiometers and not related to real changes in soil–water potential.

The electrical capacitance of the diatomaceous earth inside the tube tensiometers is a secondary source of information about the soil–water content status surrounding the drainage meters: as soil–water content decreases, the relative capacitance also decreases. However as Figures 6.6 and 6.7 show, capacitance is also a strong function of temperature and to date no work has been done to separate these two effects.

During the last 6 months of measurements the relative capacitance underwent high frequency changes caused by changes in soil–water content inside the tube tensiometer. These rapid changes cannot have been caused by the slow change in temperature at this depth.

Observations of soil–water potential have not been converted into drainage flux using equation 6.5 because further developmental work on the drainage meter in another project to enable measurements of $K(\psi)$ was not completed before the project's end. Nonetheless, the gradient of -1 and an average soil–water potential of -107 cm, measured in the VL at Stonehaven, indicates a small downward drainage flux over the last 6 months (November 2005–May 2006).

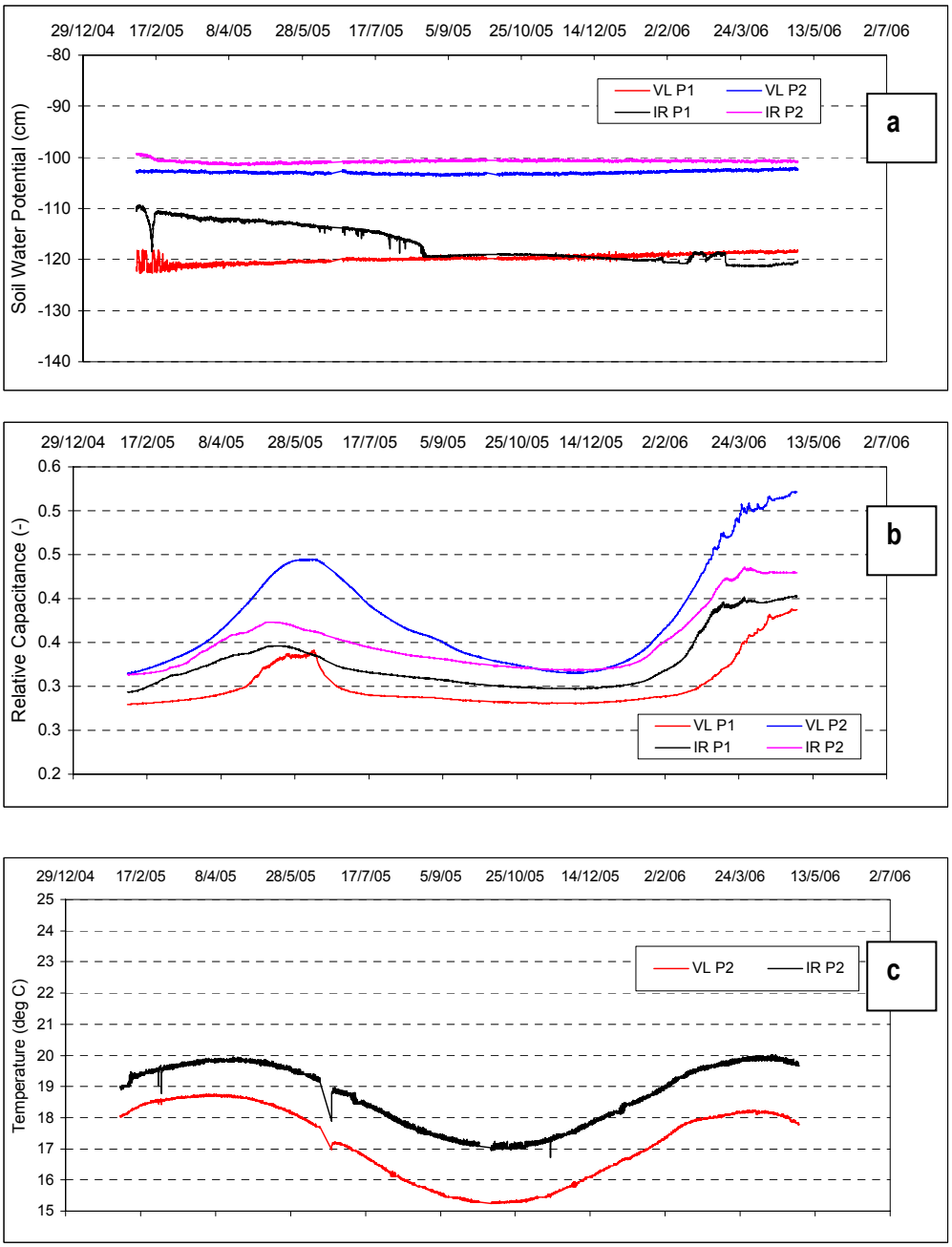


Figure 6.6: (a) Soil–water potential, (b) relative capacitance and(c) temperature from the drainage meter in the vine-line (VL) and inter-row (IR) at Orlando vineyard
Note: drainage cannot be estimated for soil–water potentials drier than -100 cm for P2 and -120 cm for P1, but drainage is unlikely.

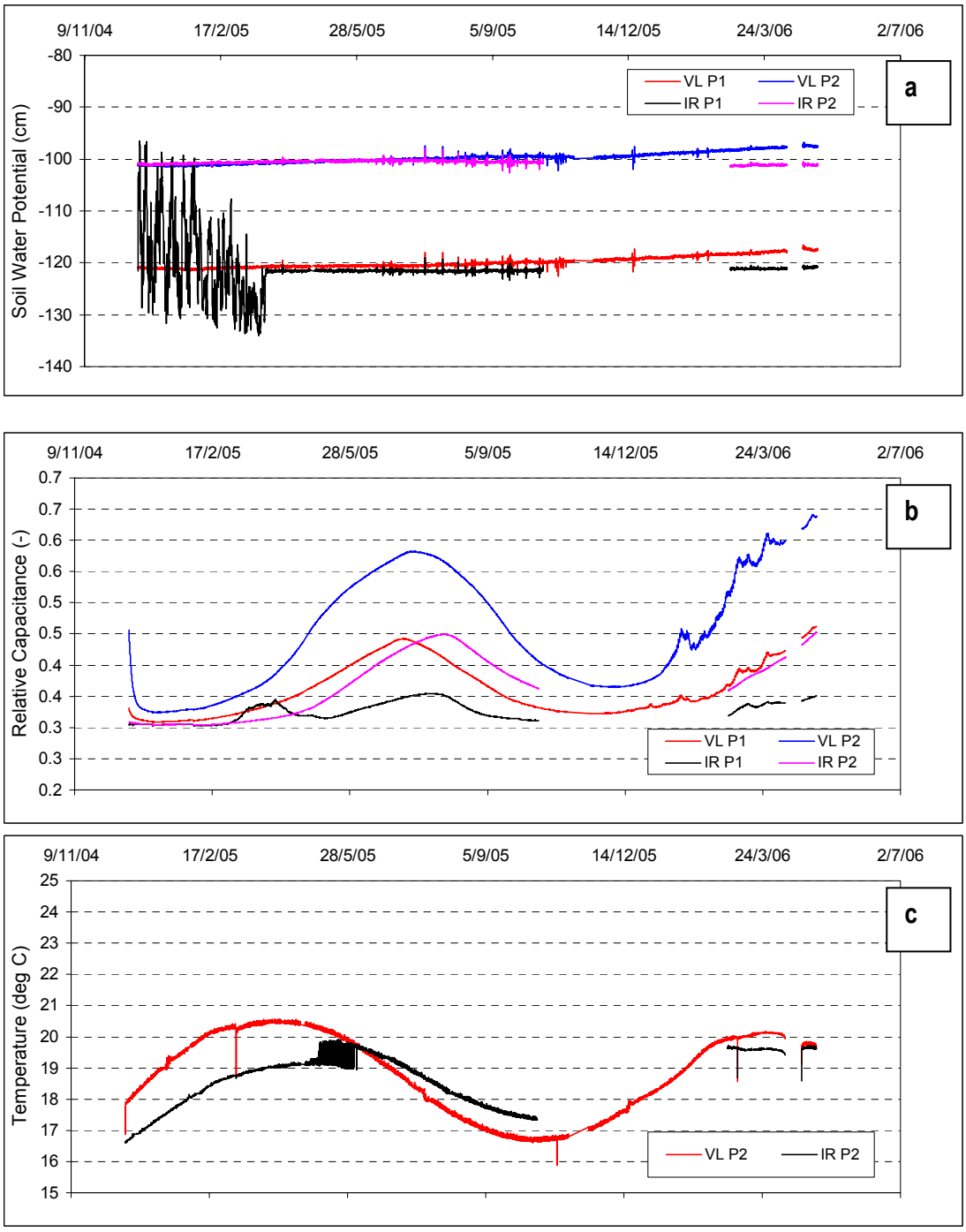


Figure 6.7: (a) Soil–water potential, (b) relative capacitance and(c) temperature from the drainage meter in the VL and IR at Stonehaven

The change in stored soil–water measured at each vineyard was obtained from neutron moisture meter (NMM) measurements that are used to calculate the water stored within the root-zone (above 195 cm) at each of the 6 measurement sites in each vineyard. The long-term mean stored soil–water is subtracted from each measurement, and then averaged to yield a change in stored soil–water for each vineyard (Figure 6.8). The deviation between sites at each vineyard is shown by the error bar. The calibration between NMM counts and soil–water content used here is for clay soils from McKenzie et al (1990)[2].

[2] VSW % = 0.707 x CNT/WD – 0.160

In all vineyards the storage changed during the season, increasing towards a local maximum in spring of each year as the soil profile was filled by winter rainfall, and decreasing towards a local minimum in autumn as stored soil–water was depleted by evaporation. The amplitude of the change in storage was 40–80 mm. At the Orlando and Southcorp vineyards the amplitude was the same in the VL and IR, but at the Stonehaven vineyard the amplitude was larger in the IR than the VL. The deviation between sites was ~ 10 mm.

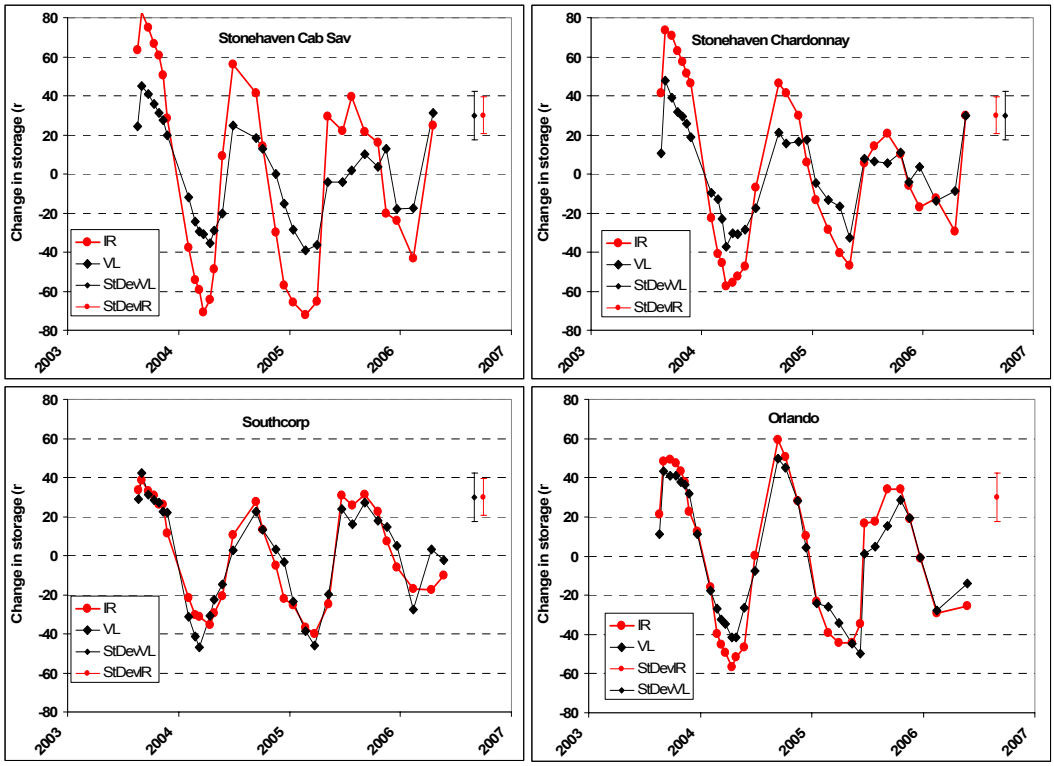


Figure 6.8: Change in stored soil-water derived from NMM measurements
Error bars show the range in storage measured for each site

Figures 6.9 and 6.10 compare the stored soil–water determined from the NMM measurements (described above) and stored soil–water estimated from the Sentek EnviroSMART® soil–water sensors installed at depths of 25, 45, 95 and 145 cm. The EnviroSMART sensor measures the electrical capacitance of soil close to the PVC access tubes installed at each vineyard. The values in Figures 6.9 and 6.10 were determined by summing stored soil–water above 145 cm, and applying the factory default calibration for the relationship between counts and soil–water content multiplied by the factor 0.55 (chosen to generate a similar stored soil–water result to that obtained using NMM).

The stored soil–water in the top 145 cm calculated from the NMM and the EnviroSMART sensors showed a very rough agreement, but EnviroSMART is clearly contaminated by temperature effects. The seasonal amplitude in storage, obvious in the NMM data, is not reproduced by EnviroSMART because its data were masked by changes in seasonal temperature. EnviroSMART data from the VL at the Stonehaven vineyard showed the opposite seasonal changes in storage to the NMM data and correlated with seasonal temperature.

Therefore, EnviroSMART data were not used in this study, other than to identify periods of rapid change in soil moisture which indicated root activity, irrigation and rainfall events that could not be seen in the NMM data because of the two-week sampling interval and large sampling volume.

EnviroSMART data showed that the stored soil–water increased rapidly in the IR of both vineyards in June 2005 and fluctuated rapidly in February 2006. These events were caused by rainfall.

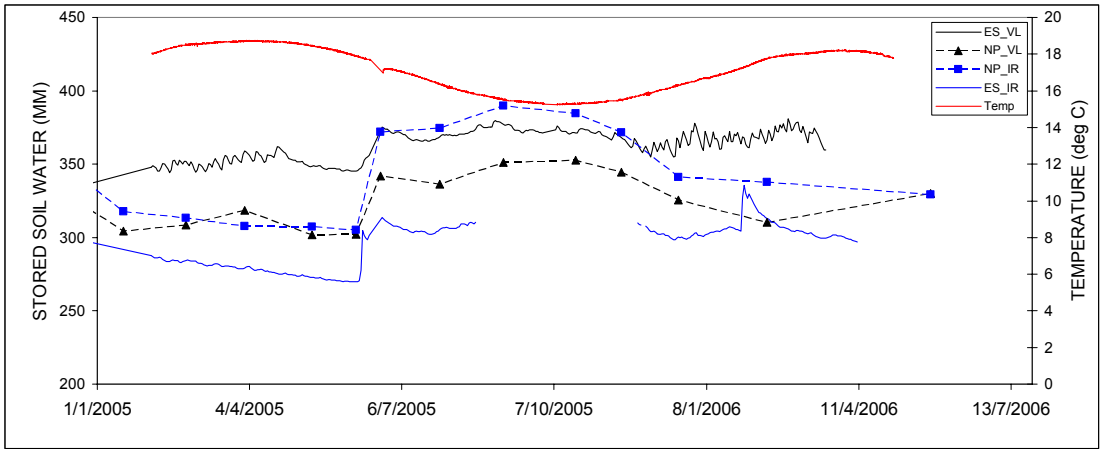


Figure 6.9: Soil–water stored in top 1.5 m measured with EnviroSMART (ES) and NMM (NP) at Orlando

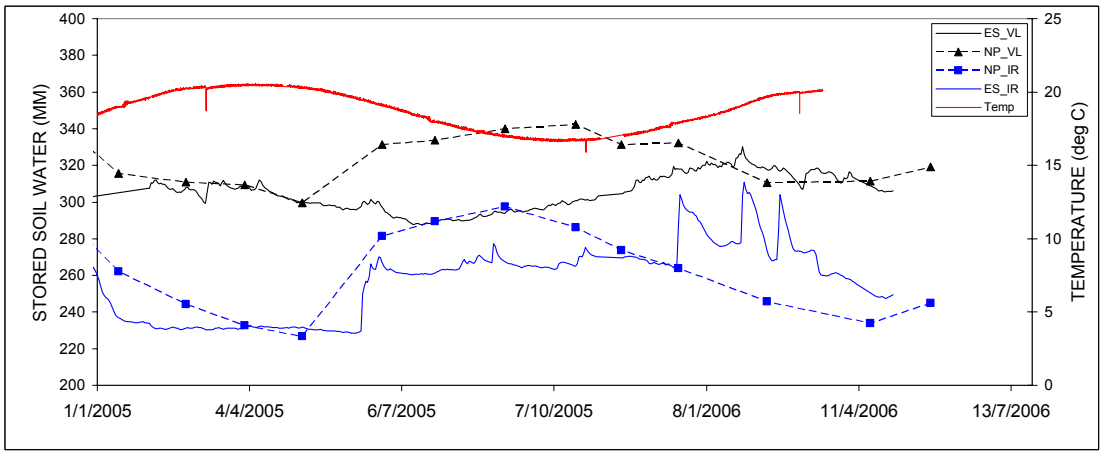


Figure 6.10: Soil–water stored in top 1.5 m measured with EnviroSMART (ES) and NMM (NP) at Stonehaven

Lastly, we quantified the complete water balance using both the water balance and the drainage meter data (Table 6.7A). Drainage was expected to be larger in the winter–spring period, when the seasonal change in storage is at a maximum. Conversely, we would expect drainage to be at a minimum in the summer–autumn period when change in stored soil–water is at a minimum. The estimates shown in Table 6.7A illustrate this for the first 2 years of measurements, while the last year shows reverse behaviour as a result of the much wetter spring and summer period. This large, and somewhat surprising, drainage event (i.e. 72 mm between December 2005 and May 2006) inferred from the water balance approach is in qualitative agreement with the data from the Stonehaven drainage meter, and the relative trends soil–water variations measured by the EnviroSMART sensors that suggest drainage events (Figure 6.10 from Dec 2005 to Mar 2006).

Calculating the drainage for those periods when successive occasions when $\Delta\theta \sim 0$ reduces the uncertainty introduced by likely errors in the NMM data (due to the coarse spatial and temporal sampling). This analysis shows similar magnitude drainage estimates to those computed for the season (Table 6.7A and B). Our assessment of those periods when drainage should be zero reveals that drainage fluxes less than ±16 mm are not detectable with this water balance approach. The errors in the calculated drainage term are also large due to the fact that the rainfall and ET errors are ±5% at best for each.

Table 6.7: Estimated drainage term using water balance estimates integrated (A) over seasons and (B) over periods when change in storage is around 0

	$P + I$	ET	$\Delta\theta$	D	D

				(difference)	(drainage meters)
A. Seasonal estimates					
Year 1					
Winter–Spring: Aug 2003–Nov 2003	297	200	32	65	Not installed
Autumn[a]: Feb 2004–May 2004	241	302	-71	9[b]	Not installed
Year 2					
Winter–Spring: Aug 2004–Nov 2004	268	252	-77	93	No evidence at other vine blocks
Summer–Autumn: Dec 2004–June 2005	320	315	24	-19[b]	No evidence at other vine blocks
Year 3					
Winter–Spring: Jul 2005–Nov 2005	229	205	10	14[b]	No evidence
Summer–Autumn: Dec 2005–May 2006	535	515	-52	72[c]	Possible drainage at Stonehaven
B. Estimates when successive measurements of $\Delta\theta \sim 0$					
Feb 2004–Sep 2004	221	160		61	
Sep 2004–Jan 2005	326	332		16[b]	
Jan 2005–Jun 2005	299	250		5[b]	
Jun 2005–Dec 2005	392	309		67[c]	

Note: (a) No NMM data available for Nov–Feb, hence autumn estimate only
(b) Not significantly different from zero
(c) Rainfall for this period very high

6.3 A water use model for Padthaway

The weekly, monthly and seasonal ET measurements taken in this project provide indicate how a simple model for vineyard water use, appropriate at these timescales and for these sites, can be constructed. The annual course of vineyard water use (Figure 6.3) is characterised by 4 phases explained by obvious climate and phenology factors:

Phase I: Actual evaporation ~ 20% larger than the potential evaporation rate in the winter period between late June and September

Phase I represents the time when soil moisture levels are enhanced by winter rainfall and low evaporative demand (when $ET < P$ in Figure 6.5). The Padthaway Flats are well-watered and there is an extensive cover crop across the vineyards and the surrounding agricultural area but the vines are not active. Evaporation therefore proceeds at slightly higher than the equilibrium rate, as expected from theoretical considerations of the feedbacks between the atmospheric boundary layer and surface evaporation.

Phase II: Actual evaporation falls to 70–80% of potential in the main growing season (November–March)

During the main growing season the bulk of vineyard water use is from vine transpiration and perhaps a small contribution from soil evaporation and cover crop transpiration that is likely to be negligible by late spring or early summer (i.e. early November). The variation in vineyard ET represents the net effect of the developing vine canopy (vine transpiration increasing) and reducing cover crop transpiration and soil evaporation.

Phase III: A transition period in late autumn–early winter and a relatively shorter spring transition period

Phase IV: Periods (days rather than weeks) during the growing season when *ET* falls to less than 50% of the potential rate.

6.3.1 Model development

Evaporation results (Section 6.2.1) and Equation 6.4 indicate a simple model for vineyard water use with the following form:

$$ET = f_c E_p$$
$$= f_c c_p E_{pan}$$

The phases described above also suggest that f_c will vary from about 1.2 in the winter months, to 0.7 in the main growing season. Figure 6.11 illustrates the monthly variation in f_c where the measured values are calculated from Equation 6.4, using measured potential and actual vineyard evaporation.

Figure 6.11 illustrates Stages I–III clearly and also demonstrates subtle differences in the growing season values of f_c that reflect differences in vine architecture and grape variety. In particular it shows that, for most of the growing season, the Orlando vineyard had a higher water use. This is consistent with the higher rainfall and irrigation volumes applied over the season, the elevated VPDs recorded, and vines more closely spaced than in the other two vineyards.

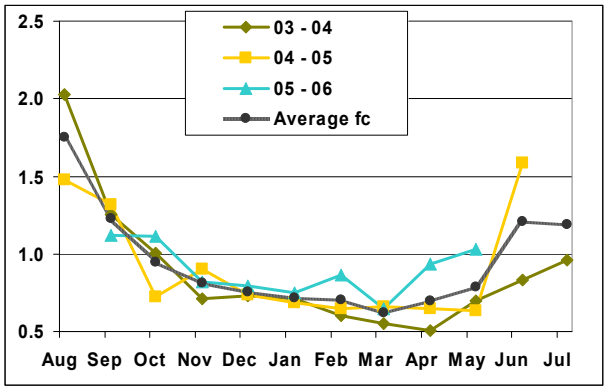


Figure 6.11: Variation in vineyard coefficient, f_c, for each month of measurements. In this figure, f_c is the same as the ratio of E/E_P, and the non-gapfilled (Appendix 5) *ET* measurements are used only for those months with more than 70% data record

Table 6.8 tabulates the f_c values calculated for each vineyard and month, and then averaged. These average *vineyard* coefficients can be compared to the UN Food and Agriculture Organization (FAO) values for *vines* (f_{cv}) taken from the literature (Goodwin 2002), and assuming bud-burst in September. It shows that from November to March, the FAO values agree closely with the measured vineyard coefficients. This suggests that in these months, vineyard water use is dominated by the vines and that inter-row water use is negligible. This observation is used below to separate vine and inter-row water use.

Table 6.8: Values of the literature-based vine (f_{cv}) and measured vineyard coefficients (f_c). The mean and standard deviations (sd) are calculated for each month, across all 3 years of measurements

Month	FAO	Measured values:		Year:		
	Vine f_{cv}	Mean f_c	sd	2003–04	2004–05	2005–06
Aug		1.75	0.52	2.03	1.48	0.99**
Sep	0.32	1.23	0.10	1.25	1.32	1.12
Oct	0.60	0.95	0.20	1.01	0.72	1.11
Nov	0.72	0.81	0.09	0.71	0.90	0.82
Dec	0.75	0.75	0.03	0.73	0.74	0.79
Jan	0.74	0.72	0.03	0.71	0.69	0.75
Feb	0.71	0.70	0.14	0.60	0.65	0.87
Mar	0.60	0.62	0.06	0.55	0.66	0.64
Apr	0.47	0.70	0.22	0.51	0.65	0.93
May		0.79	0.21	0.70	0.64	1.03
Jun		1.21	0.53	0.83	1.58	
Jul		1.19	0.32	0.96	1.42**	

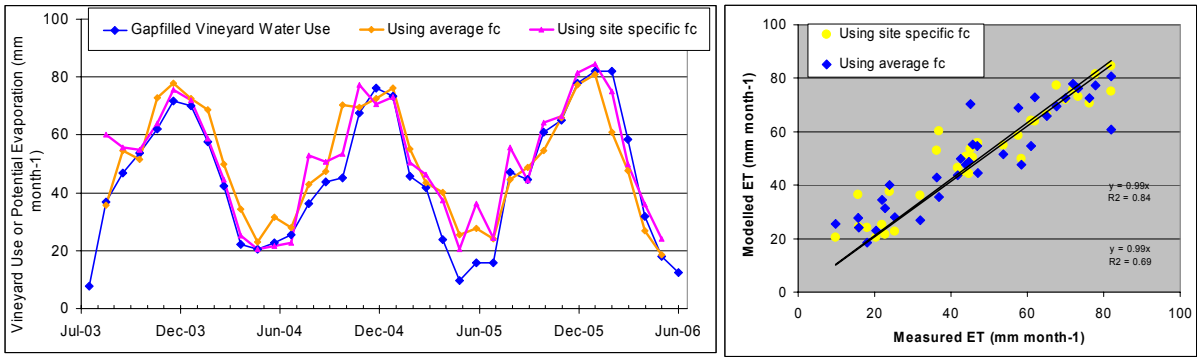
** Unreliable values because < 50% of possible measurement hours were recorded this month

Monthly vineyard water use *for the Padthaway vineyards* can thus be computed as follows:

1. Take the pan evaporation data from the BoM climate station
2. Compute potential evaporation (actually equilibrium evaporation) by: $E_P = 0.46 \, . \, E_{pan}$
3. Compute vineyard water use by: $ET = f_c \, . \, E_P$ where the values for f_c could either be the averages, or site specific values, listed in Table 6.8 (the former would yield an underestimate for more closely spaced vines such as those at Orlando).

Figure 6.12 illustrates the agreement between modelled and measured *ET* using these steps with both *average* and *site specific* vineyard coefficients (Table 6.8). It shows that the simple model captures the main seasonal variation, but overestimates water use from February to July 2005, a period when the measured and modelled potential evaporation diverged (recall Figure 6.3).

Figure 6.12: Time series and scatterplot showing model agreement for simple vineyard water use model



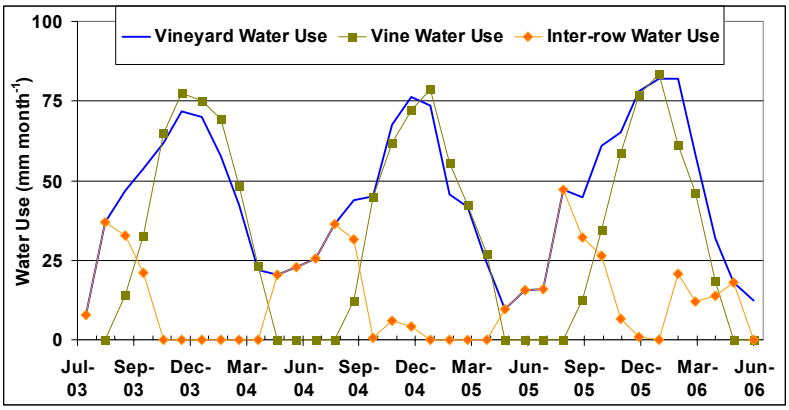
This analysis uses monthly data only. Applying the model at a weekly rather than monthly timescale revealed adequate performance in terms of the bias (slope of the line of best fit between measured and modelled = 1), but with much greater scatter ($R^2 = 0.6$). A major contributor to this scatter comes from periods of elevated VPD, when actual vineyard water use falls significantly below the modelled values as a result of increased physiological control over transpiration. This is particularly evident on

extreme dry days when the vines are still developing (late October–November). This phenomenon has been observed and described by vine physiologists (Stevens, pers. comm.).

These events cause the simple model to *overestimate* actual vineyard water use in these periods. At Padthaway the frequency of such events is low and has little impact on the model performance at monthly timescales.

FAO vine coefficients (Table 6.8) and the measured vineyard water use can be used to infer inter-row and vine water use for each vine block. Figure 6.13 illustrates the monthly variation in each of these components. Integrating under this curve for each year shows that inter-row water was between 20% and 30% of total vineyard water use, i.e. 100–170 mm per year. This is of the same magnitude as the irrigation and points to the potential to use this water to augment the stored soil–water.

Figure 6.13: Measured water use and inferred vine and inter-row components using the FAO coefficients



7. Conclusions

All outputs and performance targets set for this project have been met.

Outputs	Performance targets
1. point measurements of water and salt fluxes beneath the root zone	Drainage meters installed Stored water determined and increased frequency of soil solute sampled by measurements with neutron moisture meters Final measurements delivered
2. measurements of vineyard scale evapotranspiration using a mobile flux station	Measurements taken with the flux station at different sites in each season of the project Final measurements delivered
3. models of vineyard evapotranspiration across the Padthaway wine region	Equilibrium evaporation model tested against actual data measured at the flux station Coefficients used in the model further refined and tested by continuing measurement of actual water use Physiologically based model derived from the Penman Monteith equation Final models produced
4. quantified estimates of the water use efficiency of the irrigated vineyards	Data collected to quantify estimates of water use efficiency in irrigated vineyards Water use efficiency of vineyards estimated

Electronic data sets have been transferred to DWLBC to contribute to the wider Padthaway Salt Accession Study (see Appendix 1 for a list of DWLBC reports on the wider Padthaway Salt Accession Study).

The improved understanding of the salt and water fluxes in irrigated root zones of vineyards in the Padthaway wine region will enable vignerons to make informed irrigation management decisions. These decisions will enable vineyards to use irrigation water at a rate that allows sustainable use of the groundwater resources and stops the decline in water quality from increased salinity levels. Padthaway wine will thus not suffer from a drop in quality nor in quantity.

8. Recommendations

This project found a significant proportion of total vineyard water, suggested to be as much as 25–30%, was used by the inter-row cover crop. It is the first time a figure has been given to the contribution of the inter-row crop to vineyard ET.

Based on these numbers, further investigations into possible management strategies for the inter-row area are warranted.

The project also found occasions when actual vineyard water use fell significantly below the modelled values. This was particularly evident on extreme dry days when vines were still developing (late October–November). The water use fell as a result of increased physiological control over transpiration, a phenomenon observed and described by vine physiologists.

These events cause a simple model to overestimate actual vineyard water use in these periods. A fruitful avenue for further work could be to use a more physiologically sound ET model to correctly account for this physiological control.

In the context of broader industry practice, results from this project have already been applied to studies in the wider Padthaway Salt Accession Study.

Appendix 1: Communication

A public meeting organised by the South East Catchment Water Management Board was held to present an update on the Padthaway Salt Accession Project in May 2005. Presentations were made by both chief investigator Helen Cleugh and Jason van den Akker from DWLBC.

The final results of the project were also presented at the Padthaway Grape Growers Association AGM in the week of 11 September 2006.

As a consequence of the combined CSIRO and DWLBC Salt Accession studies a root zone salinity workshop was organised through the Limestone Coast Wine Industry Council with GWRDC RITA funding. This workshop brought together leading researchers to discuss the work being done in Padthaway and to formulate ideas for future research.

A series of reports have been published by DWLBC on the wider Padthaway Salt Accession Study:

Harrington, N., van den Akker, J., Brown, K. and Mackenzie, G. 2004 Padthaway Salt Accession Study. Volume One: Methodology, site description and instrumentation. South Australia. Department of Water, Land and Biodiversity Conservation. DWLBC Report 2004/61

van den Akker, J. 2005. Padthaway Salt Accession Study. Volume Two: Results. South Australia. Department of Water, Land and Biodiversity Conservation. DWLBC Report 2005/15

van den Akker, J. Harrington, N, and Brown, K. 2005. Padthaway Salt Accession Study Volume Three: Conceptual Models. South Australia. Department of Water, Land and Biodiversity Conservation. DWLBC Report 2005

Harrington, N., van den Akker, J. and Brown, K. 2005. Padthaway Salt Accession Study Volume Four: Conclusions and Recommendations. South Australia. Department of Water, Land and Biodiversity Conservation. DWLBC Report 2005/35

Appendix 2: Intellectual property

No intellectual property.

Appendix 3: References

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Appendix 4: Staff

Project supervisor
Keith Brown, Senior Research Hydrogeologist, DWLBC
Replaced by
Glenn Harrington, Senior Research Hydrogeologist, DWLBC

Chief investigator
Dr Helen Cleugh, CSIRO Atmospheric Research

Investigators
Dr Paul Hutchinson, Soil Physicist, CSIRO Land and Water
Jason van den Akker, Hydrogeologist DWLBC
Nikki Harrington, Research Hydrogeologist, DWLBC

Administrative contact
Dr Carolyn Brown, Padthaway Grape Growers Association

Appendix 5: Data tables and reports

Table A1: Flux station temperatures and humidity deficit (*D*); and BoM climate averages for Padthaway Climate Station

Month	T_{max} °C	T_{min} °C	T_{mean} °C	Average *D* hPa	40-year average T_{max} (°C)	40-year average T_{min} (°C)
Jul-03	10.7	3.2	6.7	2.66	14.3	5.3
Aug-03	12.0	4.3	8.0	3.11	15.4	5.8
Sep-03	14.2	4.3	9.5	3.63	17.4	6.8
Oct-03	15.2	4.6	10.2	4.56	20.1	7.5
Nov-03	23.4	7.9	15.9	10.49	23.5	9.1
Dec-03	26.8	12.0	19.5	12.86	26.2	10.9
Jan-04	23.0	10.0	16.8	8.44	28.0	12.0
Feb-04	28.5	12.7	20.3	13.34	28.7	12.0
Mar-04	24.3	9.9	17.1	10.46	25.6	10.3
Apr-04	21.0	9.0	14.9	6.85	21.7	8.1
May-04	16.9	7.5	12.0	3.93	17.9	7.4
Jun-04	14.6	8.3	11.4	3.08	14.9	6.1
Jul-04	13.2	6.9	10.0	2.80	14.3	5.3
Aug-04	15.3	7.5	11.3	3.94	15.4	5.8
Sep-04	16.4	7.8	12.1	4.07	17.4	6.8
Oct-04	21.6	8.4	15.2	8.52	20.1	7.5
Nov-04	22.8	9.4	16.4	9.78	23.5	9.1
Dec-04	26.4	12.5	19.7	12.72	26.2	10.9
Jan-05	26.5	12.0	19.5	13.07	28.0	12.0
Feb-05	24.7	11.7	18.1	10.08	28.7	12.0
Mar-05	24.4	10.1	17.1	10.03	25.6	10.3
Apr-05	24.5	10.0	17.3	10.96	21.7	8.1
May-05	18.9	6.6	12.8	5.77	17.9	7.4
Jun-05	16.4	7.6	11.7	4.13	14.9	6.1
Jul-05	14.6	7.1	10.6	2.87	14.3	5.3
Aug-05	15.4	7.3	11.3	4.37	15.4	5.8
Sep-05	16.7	8.0	12.5	4.67	17.4	6.8
Oct-05	19.4	8.5	14.3	5.69	20.1	7.5
Nov-05	23.6	9.9	17.0	9.09	23.5	9.1
Dec-05	25.8	11.2	19.2	12.75	26.2	10.9
Jan-06	29.5	14.5	21.9	15.70	28.0	12.0
Feb-06	25.1	11.6	18.3	9.29	28.7	12.0
Mar-06	26.8	12.1	19.3	12.34	25.6	10.3
Apr-06	17.8	6.2	12.7	5.11	21.7	8.1
May-06	16.1	3.7	9.9	3.25	17.9	7.4

Table A2: Monthly rainfall totals (*M* means missing data)

Month	BoM rainfall (mm)	Flux tower rainfall (mm)	AWS-1 rainfall (mm)	AWS-2 rainfall (mm)	AWS-3 rainfall (mm)	AWS-4 rainfall (mm)	40-year rainfall (mm)
Jul-03	31.10	27.80	30.0	35.2	32.0	35.2	67.56
Aug-03	105.50	92.20	98.4	101.4	106.2	73.8	68.90
Sep-03	49.30	47.60	42.0	50.4	49.8	52.2	55.67
Oct-03	54.90	49.00	69.2	50.6	50.6	82.2	41.52
Nov-03	14.40	4.20	8.8	5.6	3.8	28.8	31.99
Dec-03	44.90	40.20	36.6	42.8	40.4	49.0	29.32
Jan-04	18.20	21.80	18.8	24.8	23.8	22.4	19.90
Feb-04	2.80	2.80	3.2	3.8	3.4	3.8	14.71
Mar-04	28.90	30.00	36.0	32.8	36.6	39.4	24.42
Apr-04	13.40	17.20	13.8	26.0	20.6	20.8	34.77
May-04	39.70	35.40	32.8	23.2	33.4	37.4	48.62
Jun-04	87.30	87.40	86.60	93.6	92	91.2	69.52
Jul-04	60.60	48.80	43.40	49.2	49	48.4	67.56
Aug-04	92.00	102.40	92.60	107.00	100.20	110.80	68.90
Sep-04	31.50	28.20	25.60	33.80	40.80	36.80	55.67
Oct-04	12.10	10.20	13.20	13.40	15.60	19.80	41.52
Nov-04	47.40	52.40	47.80	61.80	68.60	59.20	31.99
Dec-04	20.60	14.80	23.00	17.00	*M*	*M*	29.32
Jan-05	19.70	16.20	17.20	21.20	16.60	*M*	19.90
Feb-05	23.90	25.20	26.20	26.00	28.00	33.00	14.71
Mar-05	5.00	6.00	3.80	16.20	8.20	8.20	24.42
Apr-05	11.30	13.60	14.60	14.60	12.60	18.00	34.77
May-05	8.60	5.40	3.20	5.40	4.80	6.20	48.62
Jun-05	90.80	83.40	*M*	101.4	87.80	93.80	69.52
Jul-05	26.20	19.80	*M*	28.6	27.40	27.60	67.56
Aug-05	74.40	69.00	71.80	79.6	79.40	71.20	68.90
Sep-05	32.30	31.00	30.40	30.8	33.00	32.20	55.67
Oct-05	80.10	62.80	89.80	87.6	92.40	65.00	41.52
Nov-05	32.10	26.20	*M*	30.8	*M*	32.20	31.99
Dec-05	30.80	26.40	*M*	12.2	32.80	26.40	29.32
Jan-06	45.50	43.80	49.60	50.4	54.40	47.20	19.90
Feb-06	28.70	26.40	34.40	29.8	30.20	26.40	14.71
Mar-06	24.80	24.40	29.00	36	34.80	29.40	24.42
Apr-06	38.20	32.60	40.80	57.6	*M*	36.40	34.77
May-06	34.80	24.80	36.40	42.8	34.60	27.20	48.62

Table A3: Monthly measured pan, potential and actual evaporation

Month	BoM pan evaporation (mm)	Flux tower potential evaporation (mm)	Flux tower actual evaporation (mm)
Jul-03	17.20	3.3	7.8
Aug-03	64.60	19.2	36.9
Sep-03	96.60	40.3	46.9
Oct-03	118.60	57.4	53.8
Nov-03	195.40	90.4	61.9
Dec-03	224.60	98.6	71.9
Jan-04	220.40	100.4	70.0
Feb-04	212.40	97.4	57.6
Mar-04	175.00	81.4	42.5
Apr-04	107.40	47.9	22.1
May-04	63.60	32.9	20.4
Jun-04	56.60	28.5	22.7
Jul-04	51.20	28.5	25.4
Aug-04	77.60	25.8	36.2
Sep-04	84.00	36.3	43.9
Oct-04	161.60	65.1	45.1
Nov-04	186.60	80.2	67.7
Dec-04	208.80	109.8	76.2
Jan-05	231.40	111.2	73.4
Feb-05	170.20	71.7	45.6
Mar-05	153.20	67.3	41.7
Apr-05	125.20	38.9	23.9
May-05	70.20	18.2	9.7
Jun-05	49.80	10.5	15.8
Jul-05	44.00	11.7	15.9
Aug-05	80.60	31.6	47.0
Sep-05	86.20	40.5	44.7
Oct-05	125.40	57.9	61.0
Nov-05	176.60	84.2	65.1
Dec-05	223.00	102.8	77.9
Jan-06	245.40	119.8	82.0
Feb-06	188.00	99.1	82.0
Mar-06	167.80	95.4	58.4
Apr-06	84.20	37.1	31.9
May-06	51.00	21.0	18.0

Appendix 6: Budget reconciliation

GRAPE & WINE RESEARCH & DEVELOPMENT CORPORATION
Statement of Receipts and Expenditure - **FORM B**
Reconciliation Funding for 2005/06

Trust Fund :	RESEARCH TRUST FUND	FUNDING	
Project No :	RD 04/02-1	Salaries	$50000.00
Grantee :	Padthaway Grape Growers Association	Travel	
Title of Project :	Water and salt balances in Padthaway Wine Region	Operating	
		Capital	
		Total Funding	$50000.00

EXPENDITURE										
	Salaries		Travel		Operating		Capital		Total	
	$	¢	$	¢	$	¢	$	¢	$	¢
A Uncommitted (c/f 1 July)										
B Outstanding Commitments (c/f 1 July)										
C Refunds of funding										
D Cash Received From Trust Fund	42500									
E Approved transfers (from Form C)										
F Cash available (A+B-C+D±E)	42500									
G Expenditure	50000									
H Outstanding Commitments (30 June)										
I Total funds Committed (G-H)	50000									
J Uncommitted (30 June) (F-I)	-7500									
K Other income (Paid to Trust Funds)										

Note : *Row B should be the same as Row H from the previous year and Row A the same as Row J from the previous year.*

I hereby certify that this statement of expenditure is correct.		
…….	…….	…….
Signature	Printed Name	Date