CONTROLLED WATER TABLE MANAGEMENT AS A STRATEGY FOR REDUCING SALT LOADS FROM SUBSURFACE DRAINAGE UNDER PERENNIAL AGRICULTURE IN SEMI-ARID AUSTRALIA[1]

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ABSTRACT

Recent community based actions to ensure the sustainability of irrigation areas and associated ecosystems in the Murrumbidgee Irrigation Area (MIA) of Australia has seen the implementation of Land and Water Management plans. These aim to improve land and water management within the irrigation area and minimise downstream impacts associated with irrigation. Part of the plan has seen objectives set to decrease current salt loads generated from subsurface drainage in perennial horticulture within the area from 20 000 tonnes/year to 17 000 tonnes/year. In order to meet such objectives Controlled Watertable Management (CWM) is being investigated as a possible 'Best Management Practice', which can be used to reduce drainage volumes and salt loads.

During 2000 – 2002 a trial was conducted on a typical 15 ha subsurface drained vineyard. This compared a traditional unmanaged subsurface drainage system with a controlled drainage system utilizing weirs to maintain watertables and changes in irrigation scheduling to maximize the potential crop use of a shallow watertable. Drainage volumes, salt loads and watertable elevations throughout the field were monitored to investigated the effects of controlled drainage on drain flow rates and salt loads.

Results from the experiment showed that controlled drainage significantly reduced drainage volumes and salt loads compared to unmanaged systems. However, there were marked increases in soil salinity which will need to be carefully monitored and managed.

Keywords: Controlled drainage, Water table management, drain salinity, EM38, Grapevines

1 INTRODUCTION

In the Murrumbidgee Irrigation Area (MIA) the development of high water table areas has been a major concern. Within the horticultural areas large losses in agricultural production have been experienced through waterlogging and salinisation throughout their history. Extensive subsurface drainage schemes have been implemented and currently 70% (12000 ha) of all horticultural areas are protected with subsurface drainage, (Polkinghorne, 1992). The success in preventing waterlogging and salinisation was clearly evident and benefits from an agronomic perspective have been reported in a number of studies (Talsma and Haskew 1959; van der Lely 1978). However, a major effect, which was not envisaged at the time of design and development of the subsurface drainage systems, was the environmental consequences associated with disposal of saline drainage water.

Major environmental problems are now emerging with the secondary effects associated with land drainage. These include contamination due to sediment, nutrients and pesticides found in drainage waters (Bowmer et al. 1998) and problems associated with saline drainage water (Blackwell et al. 2000; van der Lely and Ellis 1974; van der Lely 1984; van der Lely and Tiwari 1995). These impacts affect both instream users such as fish and other aquatic biota as well as downstream consumptive users. Within the MIA the issues and restrictions on drainage water disposal have come from problems faced by downstream consumptive water users in the Wah Wah Irrigation Area, whose irrigation water contains drainage water from the Murrumbidgee Irrigation Area. Due to these pressures, options for reducing the salt load from subsurface drainage systems in the MIA are being investigated.

In reviewing options for reducing subsurface drainage salt loads it is interesting to look at how in the past subsurface drainage systems have been implemented and the associated outcomes. Figure 1 compares the traditional implementation of a subsurface drainage system and the outcomes with that of drainage implementation that also considers water quality. With traditional implementation no management occurs after installation with systems simply left to operate continuously. This has led to extensive problems with large volumes of drainage water being generated and hence disposal problems and also reduced irrigation water use efficiency (Christen, Ayars and Hornbuckle 2001).

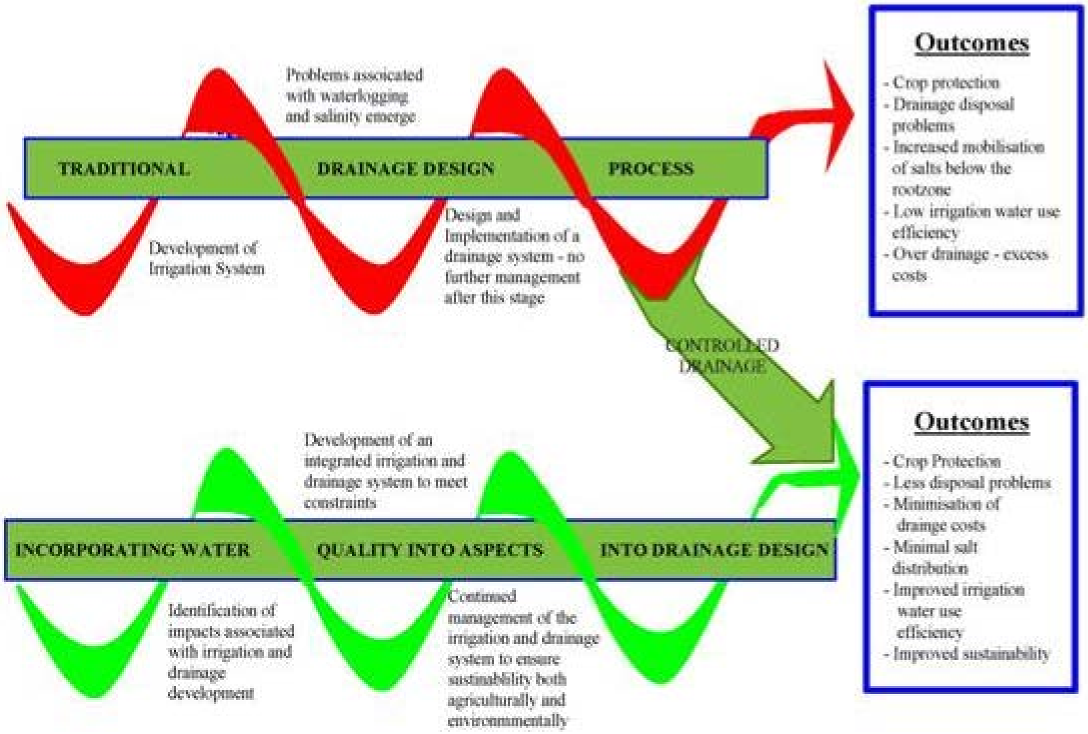


Figure 1 Subsurface drainage design processes from a past and future perspective

Figure 1 also shows the alternative process of subsurface drainage design when drainage water quality and volume are considered, with a view to creating a sustainable, both agriculturally and environmentally, irrigation and drainage system. This process involves considering at early stages the off-site consequences of subsurface drainage and incorporating these factors into the design process. While alternative designs can produce more environmentally acceptable drainage systems its application is limited to new drainage installations. In areas with existing subsurface drainage then other options need to be considered which modify the management of the drainage system to minimise off-site environmental impacts. Modifying existing systems to incorporate water quality targets is commonly referred to as controlled drainage, (Ayars, Grismer and Guitjens 1997; Christen, Ayars and Hornbuckle 2001; Thomas, Hunt and Gilliam 1992).

Considering the large majority of horticultural areas in the MIA are already drained through subsurface drainage and currently no management of the drainage systems is undertaken then the application of controlled drainage practices may have significant potential to reduce salt loads generated with these existing systems.

While previous field studies on controlled drainage have shown potential for drainage volume and hence salt load reduction in semi-arid areas (Ayars 1996, Ayars et al. 1999), these trials have been undertaken on annual crops. In the MIA subsurface drained lands coincide with the growing of perennial horticultural crops (grapevines, citrus, prunes, peaches) for which the application of controlled drainage practices need to be investigated. This work was undertaken to assess the possible benefits associated with the application of controlled drainage management in the MIA.

The specific aim of this research was to investigate the effects of controlled drainage on subsurface drainage volumes, salt loads, watertables and root zone soil salinities in an irrigated winegrape vineyard.

2 MATERIALS AND METHODS

This site was located in the Murrumbidgee Irrigation Area in south eastern Australia (34^0, 146^0). The vineyard was previously used for rice production before conversion to wine grapes 7 years prior to the installation of a subsurface drainage system in November 2000. The grapevines (*Vitis vinifera*) consisted of a mixture of cultivars Cabernet Sauvignon and Semillon. Surrounding areas are planted to a mixture of horticulture, rice and pastures all of which are irrigated.

2.1 Site

The soil was identified as an Alfisol, in the Red – Brown Earth's of the Great Soil Groups of Australia outlined by Stace (1968). The surface soil is a shallow loam (0.1 – 0.3m) and passes into a clay loam at a depth of 0.6m. The deeper subsoil varies from a dark brown to red-brown in color and is associated with alternating sandy and clayey layers. Both soft and hard carbonates are present.

Soil salinity at the site was highly varied from the supply end to runoff end due to shallower water tables of higher salinity at the runoff end. Results from 16 cores taken at the site are shown in Figure 2.

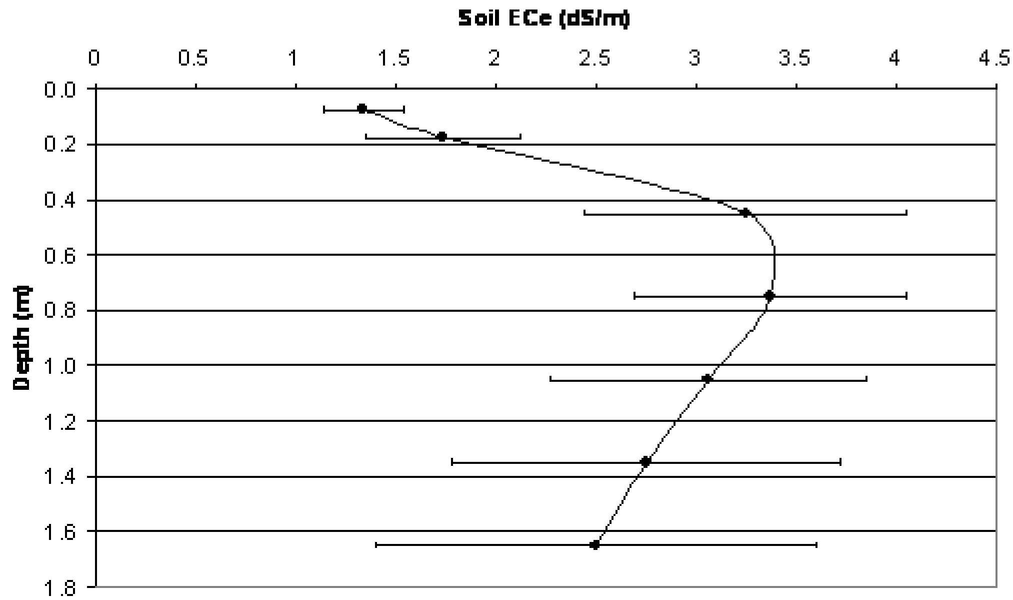


Figure 2 Soil salinity at the site determined from 16 cores. Error bars show standard deviation

The water table at the experimental site before drainage ranged from 0.9 to 1.3m below the soil surface. Groundwater salinity was rather varied and ranged from 0.5 to 15 dS/m

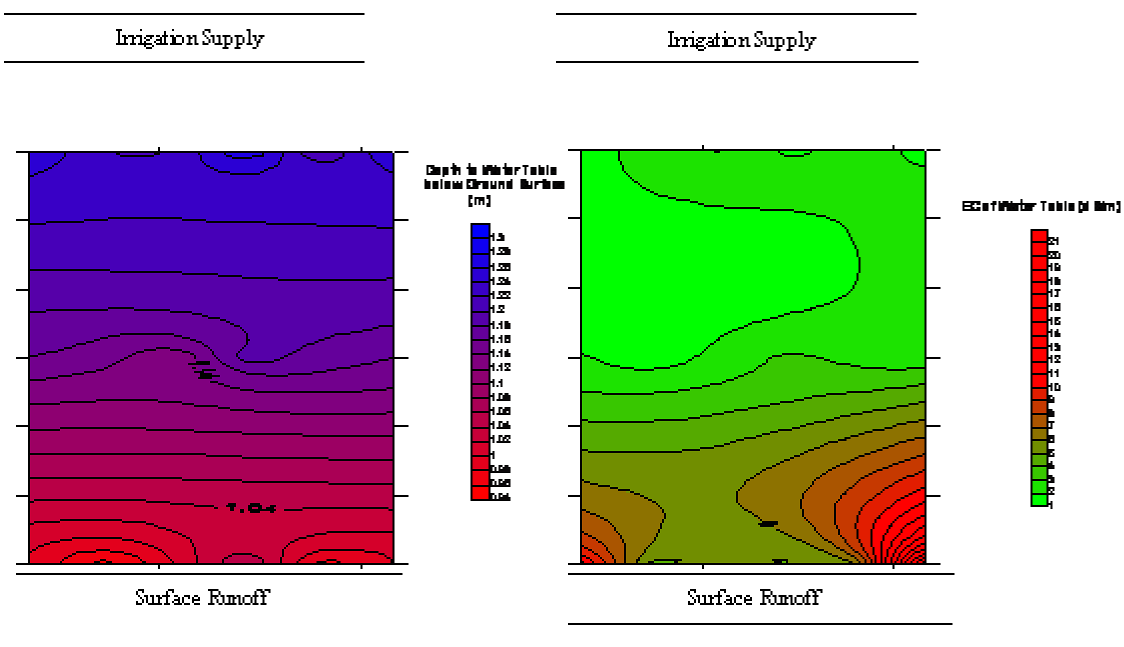


Figure 3 Water table and salinity contours measured at the experimental site before drainage installation

2.2 Drainage System Layout

Subsurface drainage was installed at the site in November 2000. Drain spacings were calculated using the design procedures outlined by Talsma and Haskew (1959), which led to a design spacing of 36m at a depth ranging from1.8 to 2.2m. Perforated HDPE pipe (0.1m dia.) was used for laterals and the main was sealed (0.15m dia.) HDPE pipe. A gravel envelope was used on all laterals. Inspection sumps were installed at the junction of each lateral to the main.

2.3 Experimental Layout

A controlled and uncontrolled drainage area was implemented at the site. The Uncontrolled area was situated over drainage laterals 1-3 (Figure 4) where the Cabernet Sauvignon variety was grown. The controlled areas were situated over drainage laterals 4-7 where the Semillon variety was grown (Figure 4). The selection of these areas was based on the vine variety. Red grape varieties such as Cabernet Sauvignon typically require periods of water stress to improve grape quality hence a high watertable would not be beneficial. White varieties such as Semillon do not require any periods of water stress and hence this area was chosen for the controlled drainage.

This design allowed for two drainage treatments, an uncontrolled free drainage treatment (F) and a controlled drainage treatment which had two plots C1 and C2. Monitoring of drain flow volumes and salinity was undertaken at sumps 2, 5 and 6 and testwells were installed at three drainage cross-sections in each treatment, Figure 4.

Implementation of controlled drainage was undertaken using PVC risers on the laterals entering sumps 4 to 7 as shown in Figure 5.

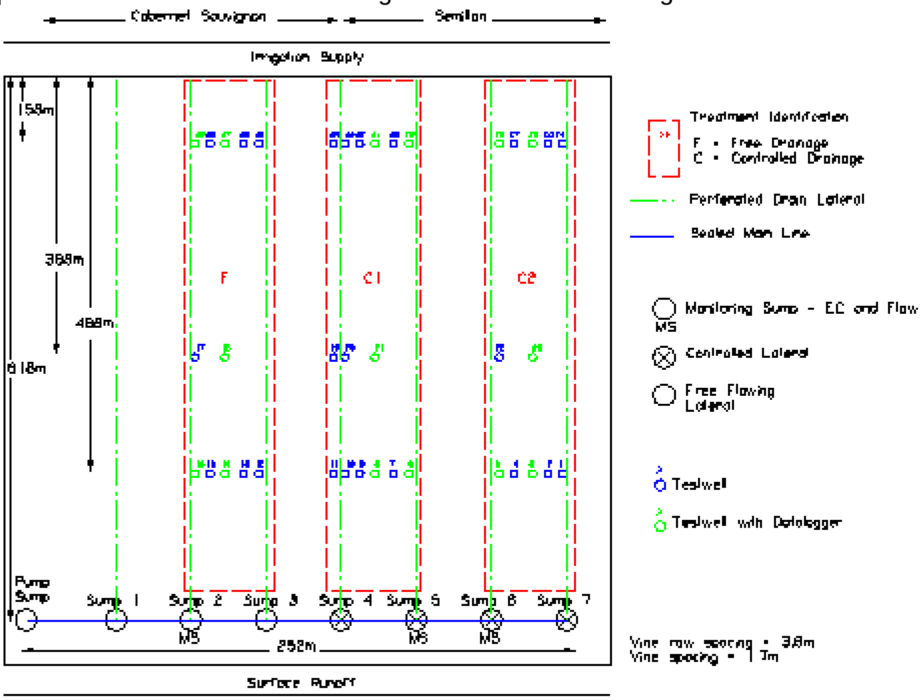


Figure 4 Experimental layout of field site showing drainage system and drainage treatments

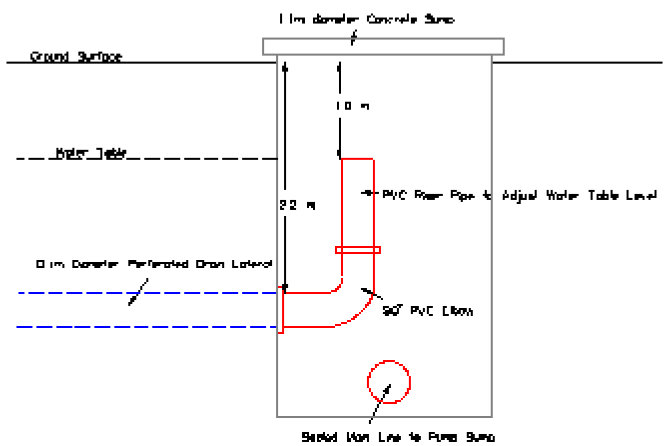


Figure 5 Cross-section of PVC pipe riser used as a weir for controlling flow and water tables

3 RESULTS

3.1 Water Tables

Irrigation events which produce higher recharge emphasize the major differences between controlled and uncontrolled drainage systems and their effect on the water table regime. During the course of the experimental monitoring period the first irrigation of the 2000/2001 irrigation season produced the greatest recharge. This event has been used to demonstrate the differences in watertables created by having controlled drainage, Figure 6 and Figure 7.

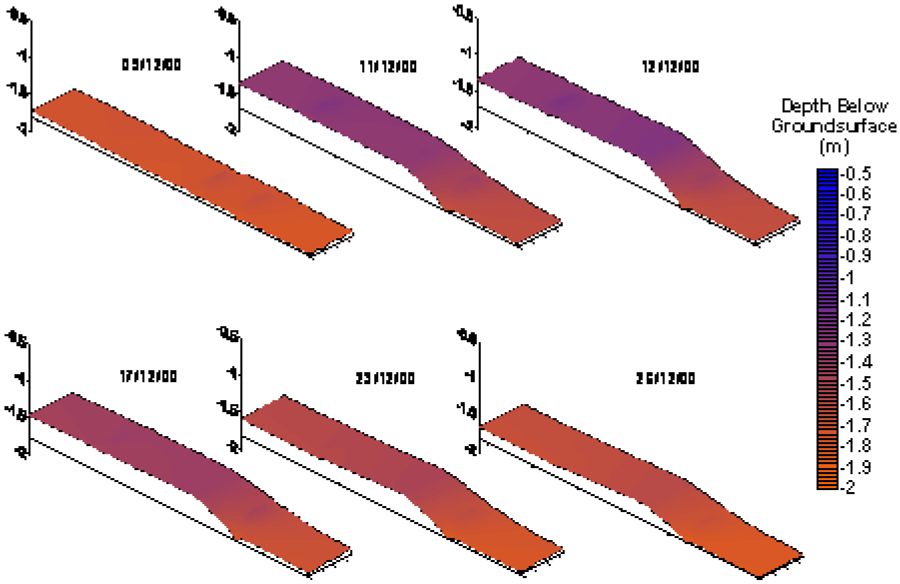


Figure 6 Water surface under the free drainage plot F

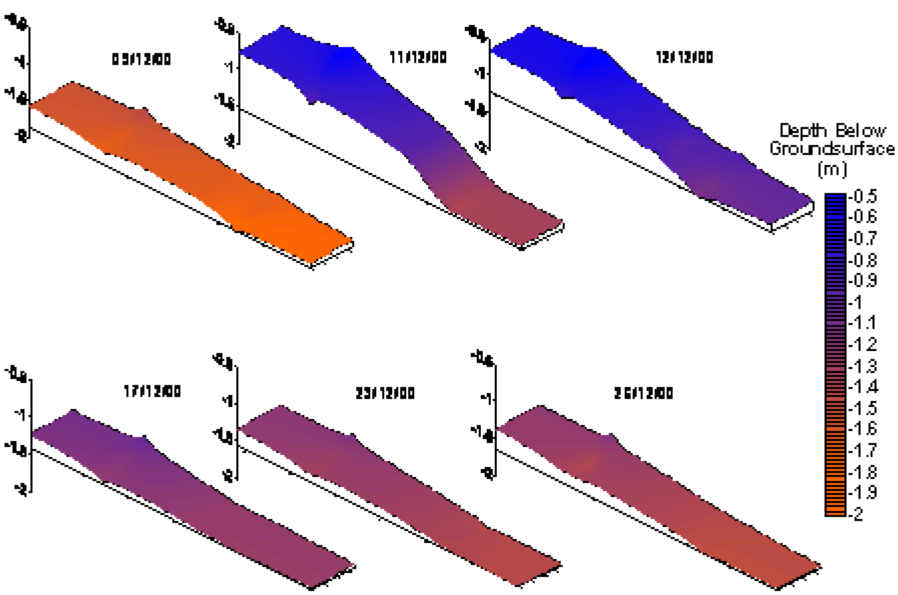


Figure 7 Water table surface under controlled drainage plot C1

The water table elevation within plots had a general trend of a higher water table at the supply end compared to the drainage end. In the controlled drainage plots the water table rose more rapidly and remained higher for longer than the free drainage plot. The time that the average water table depth was above specified depths for a 17 day period between the start of the 1st irrigation and the commencement of the 2nd irrigation is shown in Table 1. It can be seen that the controlled drainage plots (C1,C2) had a higher proportion of time that the water table depth was above 1.5m allowing potential beneficial use by the crop. The controlled drainage did not significantly increase the time the water table was above 1m, hence waterlogging protection was still provided.

Table 1 Water table depths between the first and second irrigation

Watertable depth	**Number of Days**		
	F	**C1**	**C2**
< 1m	0	1	0

1 to 1.5m	5	11	11
> 1.5m	12	5	6

The control structures placed on the drainage laterals were effective in maintaining a higher water table in the controlled drainage plots, which had a significant effect on the drainage volumes and salt loads as shown in the next section.

3.2 Drain flow and Salt loads

The drain discharge hydrographs during the first irrigation of the 2000/2001 irrigation season are shown in Figure 8. It can be seen the controlled drainage resulted in significantly less drainage than allowing free drainage. The controlled drains only flowed for between 38-41 hours, flows from the free drainage plot occurred for over 320 hours, flowing continuously until the next irrigation event. Peak discharges were lower and occurred about 12 hours later with controlled drainage. This was the extra time required to fill the profile to the pipe weir depth before drainage could occur.

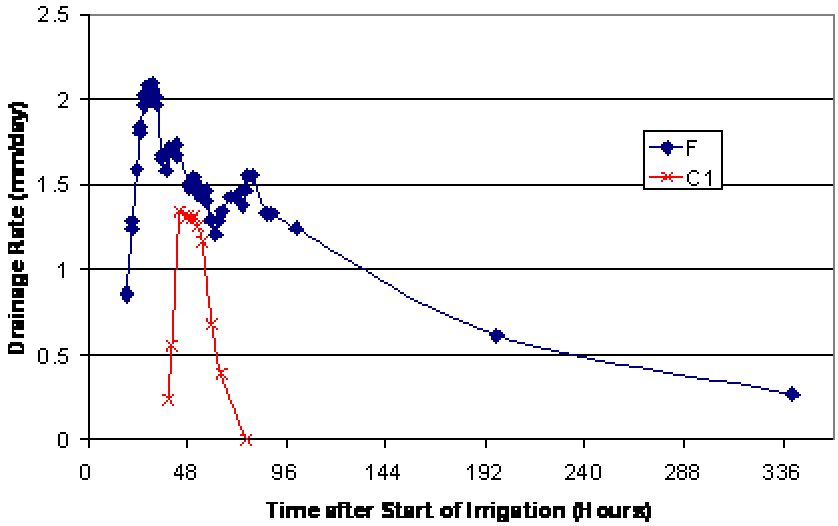


Figure 8 Drainage during the first irrigation of the 2000/2001 irrigation season

The different flow volumes had a large effect on the salt loads, Table 2. The free drainage removed significantly more salt than the controlled drainage treatment. The total irrigation applied was 120mm (EC 0.1 dS/m) resulting in a salt application of 77 kg/ha. It can be seen that free drainage removed more salt from the profile than was applied in the irrigation water.

Table 2 Total Drainage, average salinity and salt load for the 1st irrigation of 2000/2001 irrigation season

Treatment	Drainage (mm)	Average Salinity (dS/m)	Salt Removed (kg/ha)
F	9	2.84	164
C1	1	1.85	12
C2	1	2.03	13

3.3 Removing the pipe weirs

For the 2nd irrigation event of the 2001/2002 irrigation season the pipe weirs were removed from the controlled drainage laterals to allow the drains to flow freely and some salt leaching to occur. This provided the opportunity to compare the performance of those laterals with and without pipe weirs. This event can be compared to the 1st irrigation event of the 2000/2001 irrigation season as a high recharge event. Drain discharges and electrical conductivities from these two periods are shown in Figure 9 for the C1 plot.

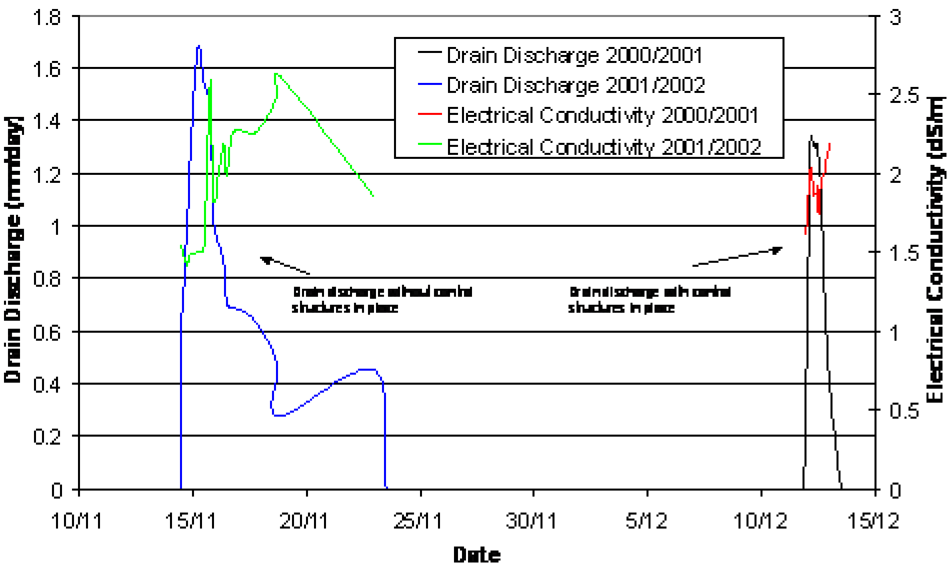


Figure 9 Drain discharge and electrical conductivity for the C1 treatment over the experimental period

It can be seen that the control structures had a significant effect in reducing the drainage discharge volumes. The irrigation applied was four times more when the pipe weirs were in place on the laterals and yet drainage volumes were still significantly reduced compared to the period when control structures were removed (Table 3).

Table 3 Water applied and percentage drained during controlled and uncontrolled irrigations

Plot	Drainage Status	Irrigation Applied (mm)	Drainage %
C1	**Controlled**	142	1
	Uncontrolled	32	6
C2	**Controlled**	93	1
	Uncontrolled	24	8

It can be seen from Table 3 that the control structures had a significant effect on reducing the drain flow and subsequently the amount of salt removed from the drainage system. Total drained amounts and the volume of salt removed from the plots over two irrigation seasons is shown in Table 4. Salt volumes were calculated based on relationship of 1dS/m = 640mg/L (Tanji 1990) for the irrigation and drainage waters and salt content of the rainfall was taken as 6.9mg/L based on studies undertaken by Blackburn and McLeod (1983) in the Griffith area.

Table 4 Drainage as percentage of irrigation and salt loads as percentage of salt applied for two seasons

Plot	Irrigation (mm)	Drainage %	Salt Load %
F	638	6	101
C1	694	0.5	5
C2	665	0.5	6

It can be seen that the free drainage plot (F) had significantly higher drainage and salt loads than the controlled drainage plots (C1 and C2). Drainage volumes measured during the experimental period were considerably lower than those typically found in subsurface drained fields in the area, due to significantly lower volumes of irrigation water applied to the vineyard than the area average. Previous monitoring of tile drainage systems in the area reported by Christen and Skehan (2001) and van der Lely (1993) measured drainage volumes between 14-22% of applied water. The large differences between these studies and results shown above were due firstly to irrigation volumes being considerably less in this study <350 mm/year compared to 600 to 1000 mm/year for the previous studies and secondly rainfall during the experimental period (322 mm for 2001 and 208 mm for 2002) was well below average (396 mm). The lower irrigation volumes applied to the treatment were due to high costs of available irrigation water and low returns for the Cabernet Sauvignon wine grapes grown on the free drainage plot.

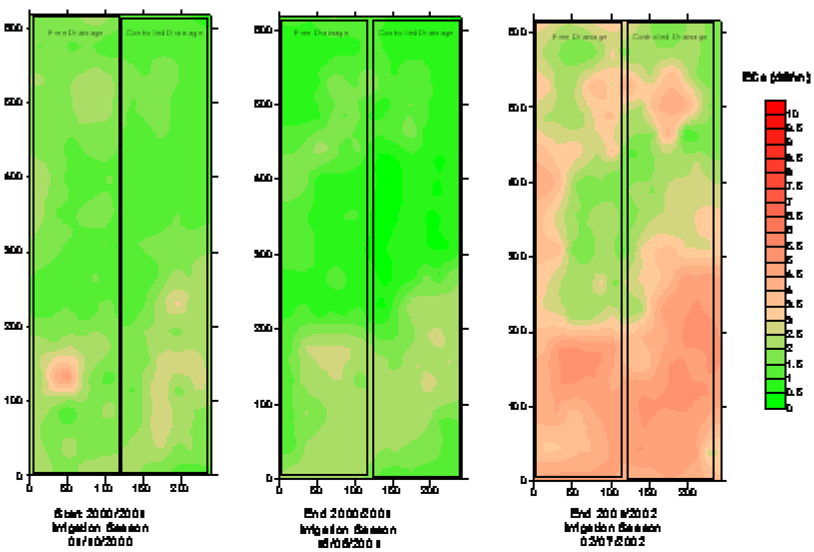
It can be clearly seen that controlled drainage was effective in increasing water table heights in the controlled drainage treatments and this reduction in drainage had the benefit of reducing disposal problems due to the decreased drainage volumes and subsequent lower salt loads. However, two issues need to be considered regarding the suitability of controlled drainage. Firstly, if controlled drainage management is to be successful then it relies on the crop being able to successfully use water from the water table to meet part of its evapotranspiration requirements, secondly, it can be seen from Table 4 that salt accumulation occurred in the controlled drainage treatments (only 5 % of applied salt was removed). Therefore, the effects of controlled drainage on soil salinity levels need to be thoroughly investigated in order to assess the sustainability of the system.

3.4 Soil Salinity

Soil salinity was monitored over the experimental period using EM38 surveys, calibrated with soil coring undertaken at selected well positions. The ESAP software program (Lesch, Rhoades and Corwin, 2000) was then used to create spatial maps of soil salinity for the field. A general trend was observed over the entire field of increasing soil salinity. This can be attributed to the upflux of water from the groundwater table, which occurred to meet crop water demands.

Soil salinity increased in all layers, higher increases were observed in the upper soil layers, particularly in the 0-0.3m and 0.3-0.6m layers. While the increases in soil salinity did not reduce the measured vine yields, it is apparent that sustainability issues will need to be carefully considered when implementing controlled drainage. Both the free drainage and controlled drainage areas experienced an increase in soil salinity over the experimental period, due to the large irrigation deficits that were present, promoting capillary upflow from the water table.

Therefore, any implementation of strategies which aim to increase plant water use from a shallow groundwater source will need to carefully consider soil salinity increases and implement appropriate monitoring. While the increase in soil salinity is a drawback associated with controlled drainage, mitigation of its effects should be possible by implementing periods of leaching between periods of controlled drainage, e.g. allowing free drainage during the winter to allow leaching by rainfall, or allow free drainage during the first irrigation of the season.



0.175 m

0.45 m

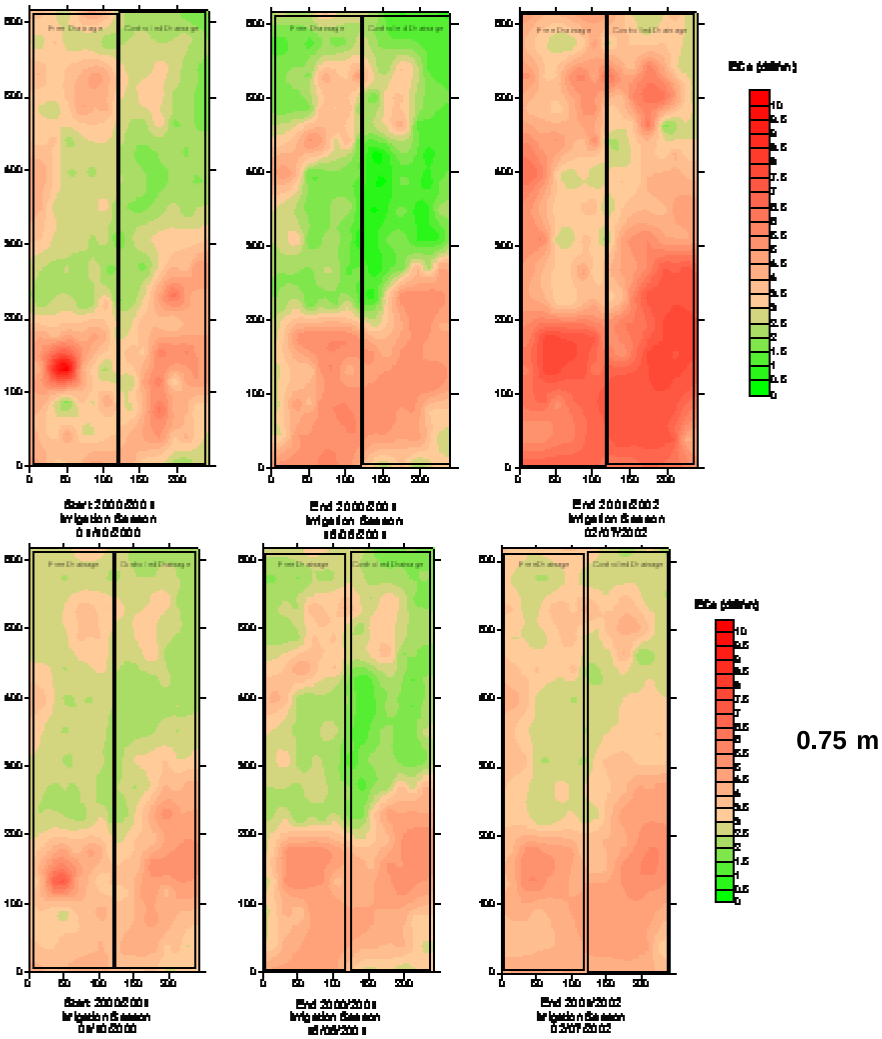


Figure 10 Change in ECe at 0.175, 0.45 and 0.75m depths

4 CONCLUSIONS

- Water table regimes and subsequently drain flow characteristics are significantly changed under controlled drainage practices
- Controlled drainage has the potential to reduce drainage volumes and subsequently salt loads
- The potential for root zone salinization will be a major consideration when developing management practices to ensure the sustainability of controlled drainage. Careful monitoring and management will be required when implementing controlled drainage

5 ACKNOWLEDGEMENTS

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