CSIRO LAND and WATER

Design and Management of Subsurface Pipe Drainage to Reduce Salt Loads

Final report of project: I5021 'Reducing discharge from subsurface drains in new vineyards on clay soils'

Comissioned by the Natural Resources Management Strategy program of the Murray Darling Basin Commission

E. Christen and D. Skehan

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CSIRO Land and Water, Griffith NSW 2680
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SUMMARY

Large portions of irrigated areas on the Riverine plain of southeastern Australia have shallow water tables creating waterlogging and salinisation problems. These have been effectively controlled in perennial horticulture by the installation of subsurface pipe drainage 'tile drainage' systems. The nature of these subsurface drainage systems is such that large amounts of salt are exported off farm in the drainage effluent. This has a negative impact on down stream water users and as such there is increasing pressure to reduce the volume of saline drainage being discharged. Further to this, new horticultural developments are occurring on soils previously considered too 'heavy' for perennial horticulture. These soils are less permeable than the soils previously used for horticulture and as such are less easily drained and more prone to waterlogging.

This report details investigations in the Murrumbidgee Irrigation Area into improved subsurface pipe drainage systems that reduce the salt load in the drainage water whilst continuing to provide waterlogging and salinity control. In association investigations were undertaken into the effects of irrigation system design and management on drainage and also the financial attractiveness of various measures to control drainage.

Existing drainage installations on vineyards using different irrigation methods were monitored to develop an understanding of factors affecting the drainage water quantity and quality. In this regard it was found that drip irrigation resulted in negligible drainage compared with conventional furrow and flood systems. With the surface irrigated systems increased irrigation resulted in increased drainage. This was further investigated by water balance modeling which found that seasonal conditions were important as irrigation interacts with rainfall to generate drainage. It was found that in wet years the drainage volume was more sensitive to irrigation management than in dry years.

Monitoring of the drainage systems also found that drainage water salinity increased with the depth to the water table. This is due to deeper water flow paths to drains as water tables recede to drain depth. These deeper flow paths transport greater quantities of salt to the drain than shallow flow paths from the upper part of the soil profile because greater concentrations of salt are stored deeper in the profile.

The results from these studies were used to design a replicated field trial in a new vineyard that compared various drainage design and management options. The management options were also tested on a whole farm basis in a new vineyard that had recently installed tile drainage and was generating high salt loads. The management changes to the irrigation and drainage system on the whole vineyard case study were successful in greatly reducing the drainage volume and thus salt load.

In the field trial both improved design and management of subsurface pipe drainage systems were tested in a replicated field experiment on a new vineyard which was established on what was previously a rice farm.

Improved design and management was tested against the current pipe drainage practice of deep, 2 m, widely spaced, 20 – 80 m, drains which are allowed to flow without control. These systems although effective in protecting the farm, mobilise large amounts of salt from deep in the soil profile. The improved drainage design was to use shallow, 0.9 – 0.6 m, closely spaced, 3.65 m, drains which would protect the root zone only. In order to be cost effective this system was a composite of mole drains, flowing into pipe and gravel collector mains. Improved management of the current practice type system was to prevent drainage once the water table reached 1.2 m deep or when an irrigation event was occurring. These treatments were also compared with an undrained control.

With the current practice drains without management, flowed continuously during the irrigation seasons with a salinity of around 11 dS m^{-1}. This resulted in a drainage salt load over two seasons of 5867 kg ha^{-1}. The management measures were able to reduce the volume of drainage and hence salinity, resulting in a 50% reduction in the salt load. The shallow drainage system performed best as it only flowed directly after an irrigation or rainfall event and had a low drainage salinity, around 2 dS m^{-1}. This resulted in a 95% reduction in salt load compared to the unmanaged deep drains. All the drainage treatments controlled waterlogging satisfactorily, but the shallow drains performed best.

The field trial showed that shallow drainage systems minimise potential salt loads and if mole drains are used they are also the most cost effective option for waterlogging control. The field trial also showed that by managing the drainage system to drain the root zone only and not drain when irrigation water is being applied there is great potential for reducing salt mobilisation and export. This finding will be useful for the large areas of existing deep pipe subsurface drainage systems.

Analysis of various drainage management options found that improved irrigation management, using drip irrigation, was the most financially attractive. Improved irrigation management must be the primary method of reducing drainage.

The results of the work were used to develop a set of subsurface design and management guidelines.

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Collaborators

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1 INTRODUCTION

The irrigation areas in south eastern Australia have developed shallow water tables to the extent that about 80% of most irrigation areas have water tables within 2 metres of the soil surface and the area with water tables within 1 metre is increasing. These water tables create serious problems of waterlogging and land salinisation. Waterlogging has in the past been controlled by the installation of subsurface drainage (tile drainage) which lowers water tables. This has been successful in horticultural farms of the Murrumbidgee Irrigation Area (MIA), Shepparton Irrigation Region and the Riverland along the Murray River. However, the nature of subsurface drainage is such that large amounts of salt are exported in the drainage effluent and at the time of installation these downstream consequences were not considered. Action to reduce this export of salt is now being demanded by down stream water users to improve their water quality and ensure sustainability. Subsurface drainage schemes have been targeted as areas for salt export reduction, as the drainage is normally an order of magnitude more saline than surface drainage waters. In the MIA, the Land and Water Management Plan (L&WMP) identifies subsurface drainage as a major salt exporter from the area. About 29% of the salt load leaving the area is from subsurface drainage, although only 7% of the area has subsurface drainage installed. The MIA L&WMP sets out as a goal a 25% reduction in the salt load from existing subsurface drainage. Further to this, all subsurface drainage from new horticultural developments in the MIA have to be stored in on-farm evaporation basins. These new horticultural developments are to a large extent on the heavier soils that were previously used for annual crops such as rice and vegetables. These soils are quite different from those previously associated with horticulture, which were more freely drained lighter textured soils.

Considering these factors, there is a need for irrigated agriculture to develop new subsurface drainage methods that account for the heavier soils and minimise salt loads from these developments. Furthermore, better drainage management is required that when implemented can reduce the salt loads from existing subsurface drainage schemes.

Previously, in arid areas subsurface drainage philosophy has generally been on the basis of maintaining a mid drain watertable below a “critical” depth. This critical depth has been derived from field based studies of capillary upflow from a static watertable under conditions of low evaporation. This has led to critical depths based upon soil type that ensure that the rate of capillary rise is low enough to prevent root zone salinisation. Talsma (1963) determined that the critical watertable depth was one that resulted in capillary rise less than 0.1 mm/day. The critical depth for various soils in the MIA is shown in Table 1-1.

Table 1-1. Critical watertable depths (< 0.1 cm/day capillary rise) for soils of the MIA (m) (Talsma, 1963)

E_o (cm day^{-1})	Yandera loam	Banna sand	Camarooka clay loam	Tuppal clay	Jondaryan loam
0.10	2.01	6.60	1.17	1.32	0.95

These critical depths have led to drainage systems that typically have laterals a minimum of 1.8 - 2.0 m deep and mains 1.8 - 2.4 m deep. The drain spacings, depending upon soil type and depth to impermeable layer, range from 20 - 180 m apart. These systems were installed with no management mechanisms for controlling the water table depth as no form of drainage management to control water tables was intended. Once installed, the drains were to discharge freely to maintain water tables as deep as the prevailing conditions would allow.

This philosophy for drainage in arid areas has served the primary purpose of preventing land salinisation extremely well. Lands that were once threatened with salinisation have been protected and areas that were previously saline have been reclaimed to full production. However, the design and management of these systems has led to the export of salt, trace elements and nutrients. This export of salt and other chemicals has detrimental downstream effects and as such there is mounting pressure to reduce drainage volumes. A reduction in the downstream effects can potentially be achieved by altering drainage design and management as shown by previous research into water flow patterns to drains and water table management within a drained area.

Research into the water flow paths to subsurface drains have shown that drain spacing and depth controls the quality of the drain water, since deeper soil layers are usually more saline. Deverel and Fio (1991) investigated the hydrologic processes of deep and shallow flow to drains 1.8 and 2.7 m deep. They found that between irrigations 30 % and 60 % of the drain flow was from below 6 m for the shallow and deep drain respectively. During the period of an irrigation the contribution of flow from below 6 m reduced to 0 % and 30 % for the shallow and deep drains respectively. This showed that at high drainage flows more drainage water is from the shallow soil layers and at low flows more drainage water is from the deeper soil layers. This leads to higher salt loads from deep drains compared to shallow drains.

More recently work by Muirhead *et al* (1995) has shown that in a heavy clay soil, shallow drains at a close spacing have significant advantages over deep drains at a wide spacing. These advantages are that more rapid drainage of the root zone is achieved and the total salt load from the shallow drains is significantly lower, only 10% of the salt load from deep drains. In addition the shallow drains were more effective in controlling soil salinity in the root zone. This work showed that there is an opportunity to improve drainage design to reduce salt loads whilst still controlling waterlogging and salinisation. However, shallower drains must be closely spaced to be effective which is more expensive than wide spacings. Thus mole drains, which are unlined soil channels about 0.6m deep and spaced about 2m apart (Spoor, 1994) are the most cost effective drainage for heavy clay soils.

Mole drains were tested by Christen and Moll (1996) in a vineyard and found to reduce the soil salinity compared with areas of no drains, Figure 1-1. However no comparison with pipe drains were undertaken although the potential advantages of mole drains were stated as; drainage of the root zone only and thus less salt export, and closer spacing combined with a higher drainage rate resulting in good control of waterlogging.

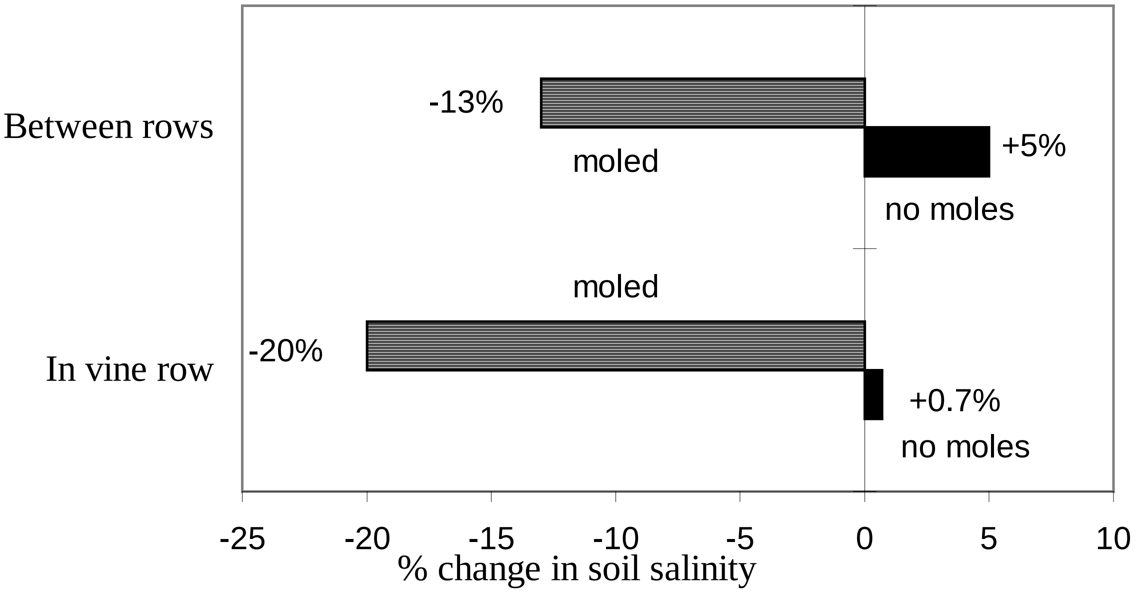

Figure 1-1 Mole drainage reduces soil salinity

In situations where mole drainage is not appropriate then pipe drains need to be deep and fairly widely spaced to be cost effective. To reduce drainage and thus salt load from these systems the integration of drainage management into the irrigation practice has recently been investigated for arid areas. Unlike the management of drainage systems for irrigation in humid areas, which has long been in use (Fouss *et al.* 1990) the management of water tables in arid areas is relatively untested. However, the incorporation of a shallow groundwater component to crop water use has been investigated by Ayars & Hutmacher (1994), Mateos *et al.* (1990) and, Meyer *et al.* (1990).

These authors have shown that crops have the potential to use water from shallow water tables but had not specifically managed the water table to achieve this. However, Ayars (1996) showed that by combining irrigation management and actively managing the watertable depth with the subsurface drainage system, through valves on the drain laterals and weirs on the main, significant savings in irrigation water and also decreased drainage volumes could be achieved.

These developments demonstrate that alterations to drainage design and management can drastically alter the functioning of drainage systems in terms of quantity and quality of the drainage outflow. However, drainage systems for arid areas have been designed to ensure that water tables do not exceed a critical depth, or only for short periods after irrigation and rainfall. Drainage design has estimated the volume of deep percolation from irrigation and rainfall and determined a drain spacing and depth that will remove it in a short period, in order that the water table remains below the critical depth. This system of design has not intended for any interaction between the irrigation and drainage system.

This report details the results of research investigating the effect of altering subsurface drainage design and management on drainage and irrigation management on drainage water quantity and quality. This research was conducted in the Murrumbidgee Irrigation Area, New South Wales for application to heavy clay soils in the Riverine plain of southeastern Australia generally.

2 LITERATURE REVIEW

2.1 Combining surface irrigation and subsurface drainage system management

Due to the depth of subsurface drainage systems the drainage effluent is often highly saline as salt that has accumulated in the soil profile over thousands of years is leached out. New drainage installations in the MIA can have drainage water salinities up to 50 dS/m, however they are commonly 10 - 30 dS/m, Hoey (undated). Once the soil profile has been leached the drainage water salinity may come into an equilibrium with the irrigation water. Subsurface drainage systems that have been installed for long periods thus fully leaching the profile, e.g. about 30 years in the MIA, reach salinities of 1 - 2 dS/m depending upon the irrigation management, Hoey (undated). This is 5 - 10 times the concentration of the supply water, 0.12 dS/m. In comparison surface drainage water from non saline areas is in the order of 0.2 - 0.5 dS/m, MIA L&WMP (1998).

Due to salinity the use of drainage water for recycling has severe limitations compared to the use of surface run off. However, by combining irrigation and drainage system management crops may be able to use water from a high water table if it is not too saline. Recent work in Australia (Meyer *et al.* 1996) and the USA (Namken *et al*. 1969, Kruse *et al*. 1985, Ayers and Schoneman 1984) has shown that crops can use significant amounts of water from shallow watertables. Furthermore, research by Rhodes et al (1989) has shown that most crops have a higher tolerance to water table salinity than previously thought. Hutmacher *et al.* (1989) showed that tomatoes could extract 45% of their water requirement from a 5 dS/m watertable within 1.2 m of the soil surface. Thus shallow water tables can be seen as a potential resource if managed correctly. Doering *et al* (1984) and Benz *et al.* (1987) have shown that shallower drainage designs can be used to maintain a shallow water table and result in reduced irrigation requirements. Garcia *et al.* (1994) and Ayars and McWhorter (1985) have investigated drainage design methodologies that incorporate irrigation management and crop water use from the water table into the design.

Together with these investigations into alternative drainage design the integration of drainage management into irrigation practice has recently been investigated for arid areas, Table 2-1. Unlike the management of drainage systems for irrigation in humid areas, which has long been in use (Fouss *et al.* 1990) the management of water tables in arid areas is relatively untested. However, the incorporation of a shallow groundwater component to crop water use has been investigated by Ayars & Hutmacher (1994), Wallender *et al.* (1979), Meyer *et al.* (1996). These workers have shown that crops can use water from shallow water tables but have not specifically managed the water table to achieve this.

In a field experiment Ayars (1996) showed that by combining irrigation management to take advantage of a shallow water table and actively managing the subsurface drainage system to create a shallow water table significant savings in irrigation water and decreased drainage volumes could be achieved. To maintain shallow water tables Ayars (1996) put valves on the drain laterals and weirs on the main. To force the crops to use the shallow groundwater he adapted the crop factors for the depth and salinity of the water table resulting in a deficit irrigation schedule. A cotton crop was grown with a water table at 1.5 m with a salinity of 4 - 5 dS/m. The calculated crop water requirement was 510 mm fully irrigated but only 330 mm was applied in the deficit irrigation schedule. Despite this deficit irrigation the crop was not found to be stressed and the cotton yield was 1500 - 2300 kg/ha which compared well with the district average of 1500 kg/ha. In the following season the field was divided into three water table areas; shallow, medium and deep for comparison in a tomato crop. The shallow area started at 1.5m deep and finished at 2.2 m, the medium area went from 1.8 to 2.6 m whilst the deep area went from 2.2 to 2.6 m. The highest tomato yields, 114 t/ha were measured in the shallow and medium areas, whilst the yield in the deep area was only 63 t/ha. Maintaining the shallow water table reduced the tomato crop irrigation requirement by 141 mm.

Table 2-1. Crop water use on shallow watertables

Crop	Watertable salinity dS/m	Watertable depth (m)	Crop water use from watertable (%)	Reference
Tomatoes	3 – 8	1 – 2	17	Ayars (1996)
Cotton	4 – 5	1.5 – 2.5	35	Ayars (1996)
Tomatoes	5	1.2	45	Hutchmaker *et al* (1989)

2.2 Shallow water table management to increase crop water use

As discussed in the previous section a drainage system can be altered to perform as a supplementary irrigation supply system. This is achieved by allowing water tables to rise to a level whereby the water becomes accessible to the plant and crop water use from the watertable is encouraged by altering the surface irrigation practices. Greater crop water use from the water table is encouraged by restricting flow from the drainage system thus raising the water table and modifying the irrigation schedule to deficit irrigation. The benefit of managing shallow, less than 2 m, water tables in this way are that irrigation efficiency is increased and drainage outflows are reduced, thus reducing the impact of drainage on the surface water systems where the water is disposed.

Fouss *et al.* (1990) described methods for water table management as either passive or active. Passive management uses drainage structures and irrigation management to control the water table, whereas active control allows variable depth to the water table via a control structure. Ayars (1996) achieved active control by using valves on individual drain laterals and weirs in the main drainage line to actively maintain the water table depth.

Passive water table management is achieved by crop water use and drainage control structures. To achieve water table management the water must be accessible by the plant. How much water is available to the plant depends upon the rate at which water can be transmitted to the root zone, soil type and depth to water table. The volume of water used from the watertable by the plant depends upon the salinity of the water table and the irrigation scheduling at the surface. The irrigation interval needs to be increased beyond just using the water stored in the profile to a point that allows some plant water extraction from the water table.

2.3 The effect of irrigation management and lateral groundwater inflows on drainage volume

When determining the potential for reducing subsurface drainage water volumes through improved farm level water management it is important to understand the relationship between irrigation volume and the volume of water collected in the subsurface drainage system.

Subsurface drainage systems are designed to remove water, which would otherwise lead to high water tables under the crop. The sources of this water will include deep percolation from irrigation and rainfall, seepage from irrigation canals and drainage channels, and lateral subsurface flows. Lateral subsurface flows are due to a hydraulic gradient to the area with subsurface drainage from areas with a higher land elevation or higher water tables.

The volume of water which deep percolates past the root zone increases at an increasing rate as a function of water that infiltrates the soil surface. This nonlinear relationship indicates that water applied in excess of crop water requirements will generate more deep percolation than water applied to meet crop water requirements. Conceptual models that describe deep percolation as a function of applied water can provide estimates of the possible reduction in the amount of water moving past the root zone by improved irrigation practice. However, the actual reduction in the amount of water collected in subsurface drainage systems will depend upon a number of factors, including the age and design of the system, management of the system, soil characteristics and cropping. Lateral flows from fields at higher elevations or with high water tables and seepage from irrigation canals will also influence the potential to reduce the drainage volume.

The conceptual relationship between water drained from a system and the water applied can be described as

$\mathbf{D = f(I, R, C, S, L)}$ (Wichelns and Nelson, 1989)

where D is the drained water volume, I is the infiltrated irrigation volume, R is the infiltrated rainfall volume, C is the crop, S is the soil type and L is the lateral inflow volume (including lateral seepage from irrigation canals and drainage channels).

In this conceptual relationship the irrigation, crop and soil type are the functions controlling the slope/curvature of the relationship between irrigation and drainage volume, this can be termed *Irrigation Water Drainage* (IWD). The rainfall and lateral inflow terms determine the ‘baseflow’ and shift the whole relationship up, this can be termed the *Base Flow Drainage* (BFD). Examples of this relationship are shown Figure 2-1, the relationship between water applied and drained (IWD) is the same for both cases but vineyard B has no lateral inflow.

When considering this relationship it can be seen that for unit decrease in applied water will result in the same proportional unit decrease in drained water. However, the total change will be less in vineyard A than B. Thus analysis of the curvature of the relationship allows comparison of IWD between sites independently of subsurface inflows, Figure 2-2.

Analysis of the total change in drainage per unit change of irrigation enables the effect of the curvature and BFD in drainage reduction to be combined, Figure 2-3. These two measures of drainage water reduction are useful to identify vineyards with the greatest potential for drainage reduction by irrigation management alone, those with little inflow, and those that require a combination of irrigation management and measures to reduce inflows.

The IWD is a useful measure of changes to drainage as a result of changes in farm water management whereas the BFD is useful to measure changes in drainage over a whole area.

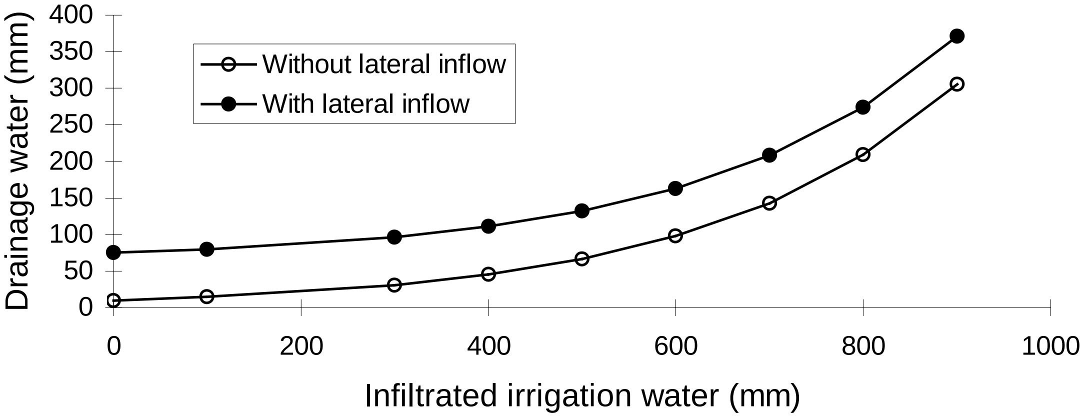

Figure 2-1 Example drainage relationships, with and without lateral inflows, after Wichelns and Nelson (1989)

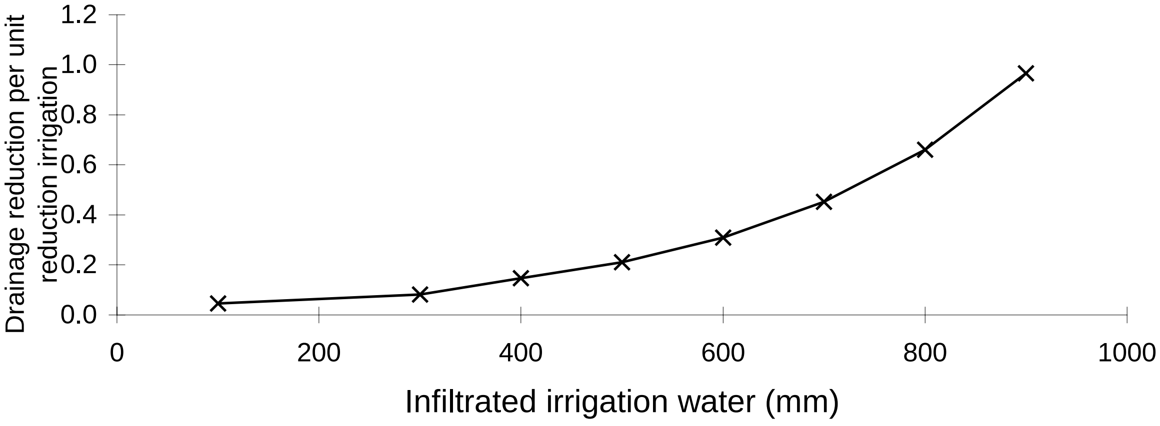

Figure 2-2 Drainage reduction per unit reduction irrigation water, after Wichelns and Nelson (1989)

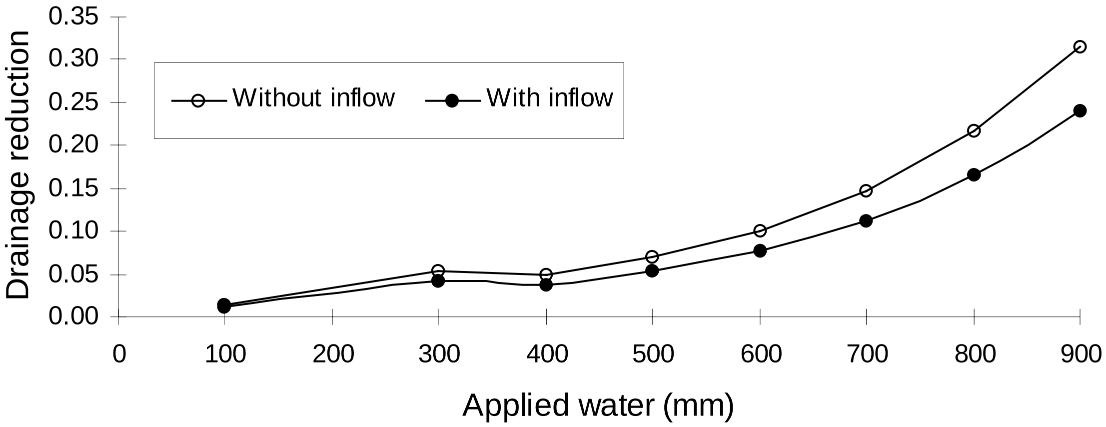

Figure 2-3 Drainage reduction expressed as a fraction of the total drainage, after Wichelns and Nelson (1989)

In a field study of subsurface drainage in the San Joaquin valley California it was found that out of 21 drainage systems only 3 of them contributed 39% of the total drainage volume (Wichelns and Nelson, 1989). Their analysis of the 21 systems found that the drainage amount was mainly a function of the irrigation water applied and rainfall. They estimated that 290 mm of drainage resulted from 1000 mm of rainfall. There were also significant differences between crops with melons generating more drainage than cotton, which in turn produced more drainage than sugarbeets. Estimates of the resulting drainage when 1000 mm of irrigation is applied to each crop is shown in Table 2-2.

Table 2-2 Drainage resulting under different crops in the San Joaquin valley, after Wichelns and Nelson (1989).

Crop	Drainage mm / 1000 mm irrigation applied
Melons	188
Cotton	120
Sugar beets	56

Lateral subsurface flows were found to be significant in some drainage systems, farms in the boundary area of the district adjacent to undrained fields and farms located adjacent to a main drainage channel were found to be most affected. Thus the percentage of drainage due to farm irrigation varied upon the location of the farm, Table 2-3.

Table 2-3 Effect of drainage system location on the percentage drainage due to irrigation alone, after Wichelns and Nelson (1989).

Drainage system location	Percent drainage due to farm irrigation			
	1986	1987	1988	Average
Central area	68	93	91	84
Boundary area	42	37	38	39
Near main drain	40	61	62	54

Their study estimated that a 100 mm reduction in irrigation application would result in a 240 mm reduction in drainage at the farm level (IWD) but that a 10% reduction in irrigation across the district would result in only a 15% reduction in total drainage water (BFD).

van der Lely (1993) in assessing new horticultural developments in the MIA, found that in areas where they would be surrounded by undrained land with high water tables there could be large volumes of lateral inflow to the drainage system, Table 2-4. This would result in much larger potential drainage volumes than where drainage was installed in a farm already surrounded by drained farms.

Table 2-4. Groundwater flow rates to drained horticultural developments (van der Lely 1993)

Situation	WT depth in surrounding development (m)	WT depth in Horticulture (m)	Transmissivity aquifer (m^2/day)	Resistance to flow in clays (days)	Drainage rate* (ML/ha/yr)
Bilbul area	1.3	1.6	<5	1000	<0.11
Kooba	1.2	1.6	100	500	0.93
Kooba	1.2	1.6	20	1000	0.32
Kooba	1.2	1.6	50	1000	0.60
West Hanwood	1.2	1.6	50	250	0.97
Whitton	2.0	2.0	200	200	0

* Assuming 20 hectares of horticulture, a 1000 metre length of effective perimeter for flow, a buffer area of 50 metres.

2.4 Drainage system design and effects on drain water volume and salinity

The salt concentration in drainage water depends upon the salt stored in the soil profile above and below the drains, the depth and spacing of the drains, groundwater flow and the irrigation management leading to various rates of water table recharge. Drain salinity from newly installed drainage systems is initially high and then declines to a fairly constant level, Johnston (1993). When analysing many drainage systems in an irrigated area Ayars and Meek (1994) found that despite the drainage flows varying widely, low flows in autumn and winter to flows 3-4 times higher in spring and summer, the salinity remained relatively constant, Figure 2-4. Thus the salt load from the drainage systems was linearly related to the flow volume, Figure 2-5.

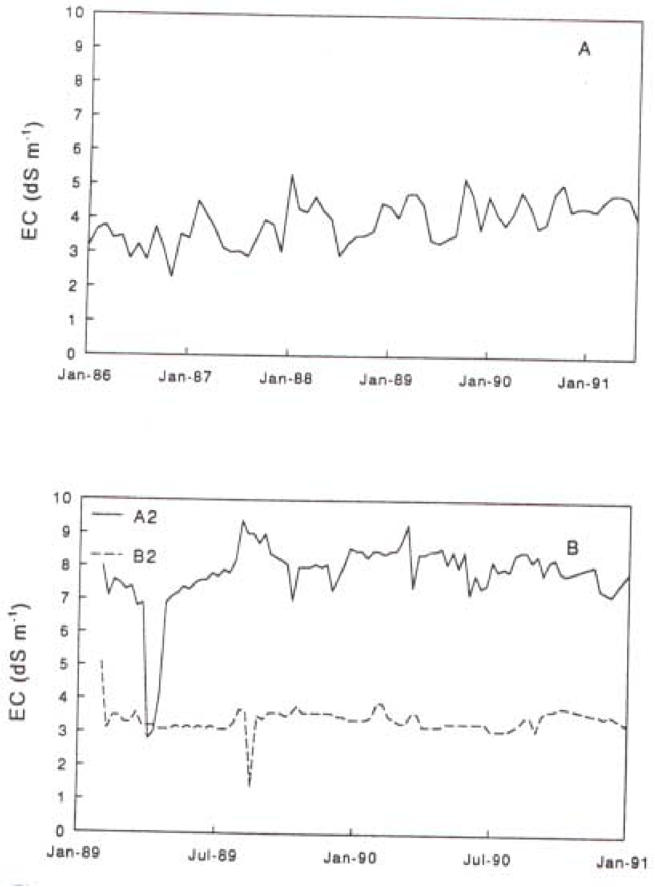

Figure 2-4 Electrical conductivity (EC) of the drainage water in the main drain (A) (Ayars and Meek 1994)

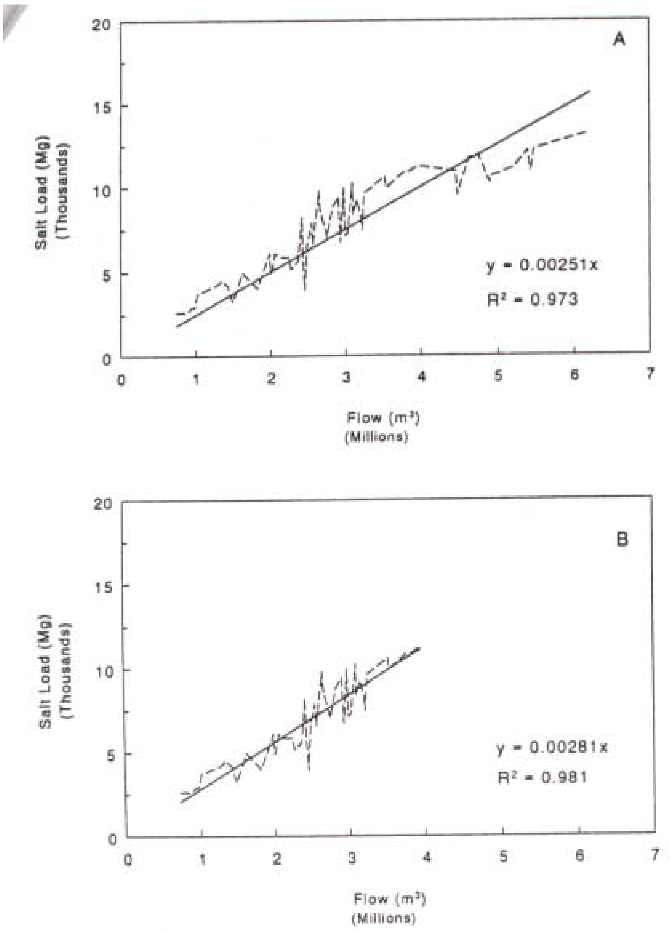

Figure 2-5 Load-flow relationship for monthly salt discharge from the Panoche Water and Drainage District for all flows (A), and for flow less than 4 million cubic metres per month (B) (Ayars and Meek 1994)

Thus reducing the deep percolation to only the amount needed for leaching of the root zone was defined as the easiest first step in reducing the salt load discharged. However, they found that each drainage system (57 were analysed) had a different load flow relationship, but that these could be clustered into 3 main groups. This was helpful when developing management recommendations. However, the usefulness of load-flow relationships relies on the assumption that the irrigation management is well established and that the soils are not undergoing reclamation after recent installation of the drainage system. The irrigation management and drain placement can also affect the load-flow relationship. Changing from surface irrigation with poor uniformity and large amounts of deep percolation to drip or sprinkler systems has the potential to reduce deep percolation and the total drainage flow. The flow paths to the drain will also change, which may alter the drain water quality depending on the soil salinity profile and also the previous contribution of preferential flow through the trench backfill ‘trench flow’ under surface irrigation. The long-term lower limit on the salt load from an area is equal to the salt imported in the irrigation water, unless there is opportunity for salt storage below the drains.

Shallow drain placement which reduces the depth of the flow lines and collection of deep groundwater, which is often more saline, will affect the relationship. During high drain flow rates the salt load-flow relationship is affected by the percolation past the rootzone suppressing the entrance of deeper groundwater.

Eching *et al.* (1994) developed a methodology for separating the contribution of regional groundwater from that of deep percolation in total drain flow by studying the drain flow and salinity relationship. They found that with drains 2.5 m deep and 150 m apart on a deep sandy loam soil, 64% of the drain flow was from regional groundwater. They were able to derive this by assuming that the increase in drain flow after irrigation is due to deep percolation. Also assuming that the salinity of the regional groundwater flow was that measured some time after irrigation when all the flow was from groundwater the salt load of the regional groundwater could be established by mass balance. Knowing the flow and salinity at the sump and the salinity and flow of the regional contribution the salt load from deep percolation was estimated.

2.4.1 Water flow to drains

The Houghoudt steady state drainage design was developed to remove water from the profile at a certain rate (Smedema and Rycroft 1988). For irrigation areas this has developed to a transient solution to drain spacing for a dynamic equilibrium, the Glover-Dumm solution. This dynamic equilibrium approach specifies a minimum mid-drain water table height, which will occur at the end of each irrigation season on the basis of expected drainage past the root zone (Smedema and Rycroft 1988). Again this design method is concerned with the drain depth and spacing in relation to the water table and is not concerned with the water flow paths.

Jury (1975) outlines the theory of solute travel time estimates for drained fields. By using Kirkhams steady state solution for the pressure potential and streamline distribution in the saturated zone he developed travel times for lateral distances from the top of the water table between tile lines, Figure 2-6. The travel times for water midway between the drains can take 41 times as long as for water at 0.1 of the drain spacing away from the drain, in a situation where the impermeable layer is only 0.1 of the drain spacing below the drain depth.

Where the impermeable layer is as deep as the drain spacing then the travel time from mid drain spacing can be an order of magnitude higher. The travel time for water through the unsaturated zone to the water table can be assumed to be uniform between the drains as long as the water table curve is not great compared to the drain depth. This travel time is a function the

1. percentage saturation of the unsaturated zone; and
2. the depth to the drain.

When analysing a ponded system the above analysis does not apply because the water does not infiltrate evenly at all points between the drains. In this case the analysis needs to include the depth to the drains and the flux entering at each distance from the drains. Figure 2-7 shows that for the same drainage system the ponded situation has preferential flow close to the drain, the flow time increasing as a power function with distance from the drain. In the unsaturated system the flow times only increase as a linear function of the distance from the drain. Thus at the quarter drain spacing position the flow times are over 10 times as long for ponded flow as for the unsaturated system. However, very close to the drain (within 0.1 of the drain spacing) the flow times for the ponded system are shorter than for the unsaturated system. Because of this the ponded system has rapid leaching near the drains and very slow leaching between the drains.

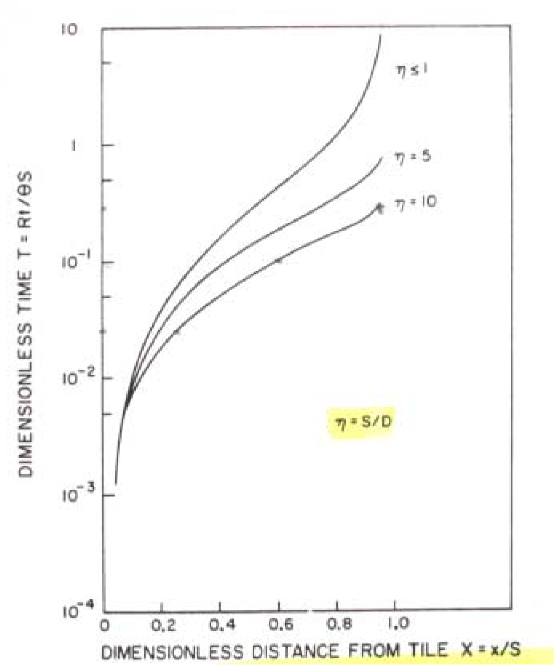

Figure 2-6 Dimensionless travel time between surface and tile line as a function of lateral distance from tile line for several values of barrier depth to tile half-spacing ratio n = D/S, where s = spacing, D = depth to barrier, x = distance from tile line (Jury, 1975)

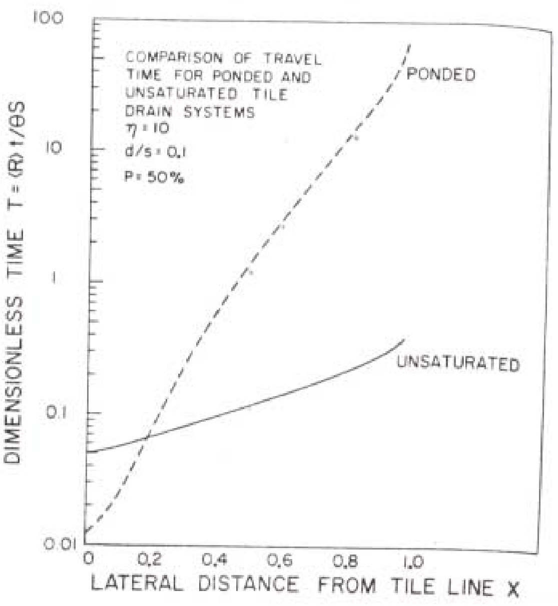

Figure 2-7 Travel time comparisons for ponded and unsaturated infiltration for the same tile line geometry and mean discharge rate. Unsaturated estimate includes travel time through the zone *d* above the tile assumed to be at *P* = 50 % saturation, where P = percentage saturation of the unsaturated zone (Jury, 1975)

Using finite difference models solving the Richards equation for flow through porous media the water flow paths and solute transport to subsurface drains have been investigated. Fio and Deverel (1991) used the MODFLOW model (McDonald and Harbaugh 1988) to investigate flow paths to drains at 1.8 and 2.7 m depth with assumed spacings of 92 and 216 m. Their results are summarised in Table 2-5.

Table 2-5 Flow conditions to drains at different depths, after Fio and Deverel (1991).

Flow factors	1.8m deep drain		2.7 m deep drain	
	Irrigated	Non irrigated	Irrigated	Non irrigated
Maximum flow depth (m)	6	7	10	14
Maximum travel time (years)	5	7	22	34
Flow rate per unit drained area (m3/m/yr)	0.293	0.043	0.292	0.213

These model results show that flow paths for the 2.7 m drain are twice as deep and five times as long as for the shallow drain under non-irrigated conditions. When irrigations are occurring, the depth and length of the flow lines are reduced. The drain flow for both drains is similar per unit area during irrigations, but when non-irrigated the deeper drains discharge more water. The deeper drains, which had longer and deeper flow paths, resulted in poorer quality drainage water. Pohl and Guitjens (1994) also used MODFLOW to model flow to subsurface drains in an area with regional flow. The flow to the drains after irrigation was local and then as this diminished the drainage flow was from the regional aquifer with very long flow paths. Fio (1997) again used MODFLOW to investigate drainage flow paths in sloping areas, the upslope areas recharged the water table downslope and water flow paths to the downslope drains were as much as 25 m deep.

Where clay soils overlay more permeable sands and the drains are on the interface Grismer and Tod (1991) showed that 90-93 % of the drain water flow was from the groundwater in the more permeable sand layers. Thus the drains in the clay were not effective in removing the root zone drainage. They also showed that because of the impermeable nature of the clay much of the water percolating past the root zone was also moving downwards past the drains. In a modeling exercise of these drains Tod and Grismer (1991) showed that the depth of clay below the drain controlled the amount of groundwater entering the drain. A clay layer 2 m thick with a hydraulic conductivity of 0.025 m/d was found to prevent groundwater entering the drains, whereas if the clay layer was only 0.3 m thick then the groundwater and deep percolation contributions to drain flow would be about equal. The thickness of clay required to reduce groundwater flow also depended upon the hydraulic conductivity of the clay.

2.4.2 Drainage of heavy clay soils

Subsurface drains in clay soils behave differently to that expected by drainage theory due to the low hydraulic conductivities and a high degree of anisotropy (marked difference between hydraulic conductivity in horizontal and vertical directions). Grismer and Todd (1991) studied a clay soil where the vertical conductivity was about 10 times lower than the horizontal in the topsoil layers and about 5 times lower in the deeper layers, Table 2-6. This results in preferential horizontal water movement in these types of soils, Figure 2.8.

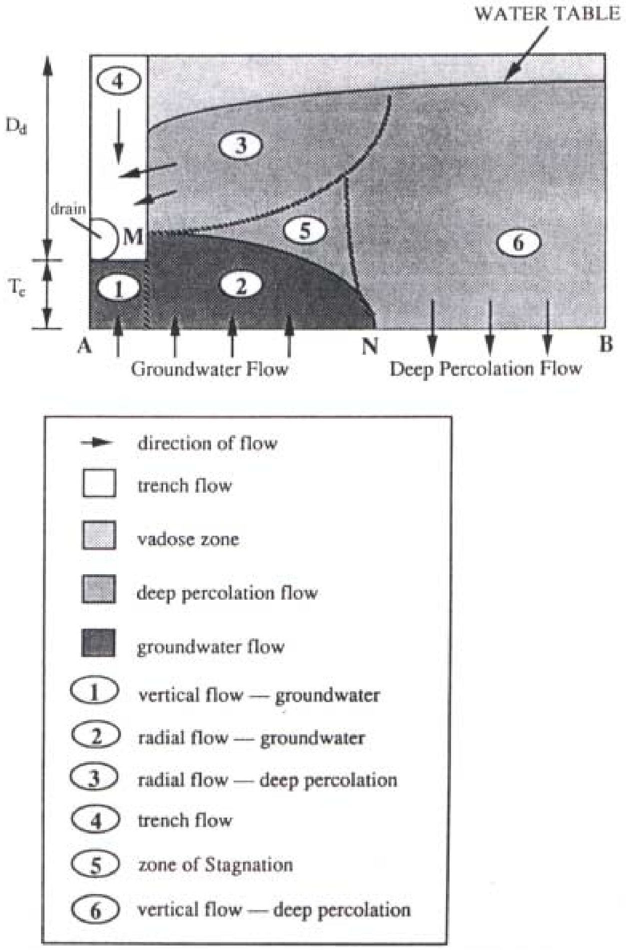

Figure 2-8 Sources of drainage flows, Todd and Grismer (1991)

Table 2-6 Vertical and horizontal soil conductivity with depth, after Grismer and Todd (1991).

Soil layers	Depth below ground level (m)	Vertical hydraulic conductivity (mm/d)	Horizontal hydraulic conductivity (mm/d)	Ratio Kh/Kv
Topsoil	0.13 - 0.7		149	13
	0.61	11.5		
Subsoil	0.38 - 1.7		22	5
	0.91	5.6		
	1.22	3.4		

The anisotropy in clay soils results in relatively flat water tables between drains with sharp draw down occurring very close to the drain. A typical water table draw down with time after an irrigation is shown in Figure 2-9. When water tables are high the water table is drawn down sharply above the drain but remains flat between the drains. At this time water flow is mostly horizontal. As the water tables decline and the anisotropy in hydraulic conductivity becomes less marked the water table shape becomes more curved.

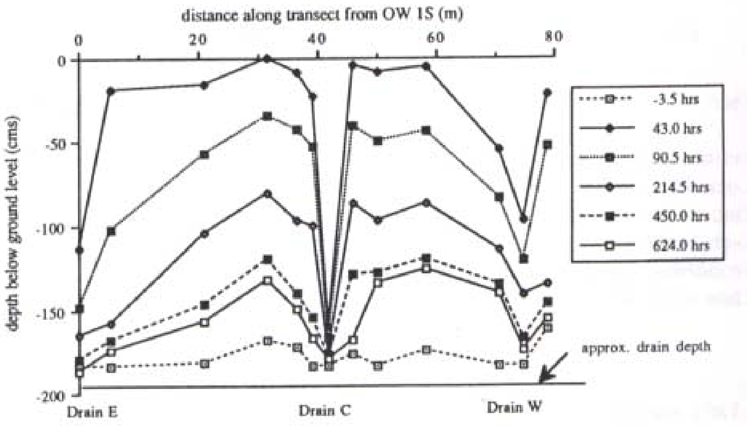

Figure 2-9 Watertable profiles with time after irrigation in a clay soil, Todd and Grismer (1991)

Todd and Grismer (1991) measured water table depth between drains, Figure 2-10, in the anisotropic soil (Table 2-6, which reflects the anisotropy of that soil). It can be seen that the water table recession rate decreases with time as the water table moves through deeper, lower conductivity soil. The water level decline in close proximity to the drain is due to the greater permeability of the backfill material in the trench over the drain. In this system the drainage flows increased to a maximum 5 - 10 hours after irrigation and the drain water salinity dropped sharply by about 2 dS/m during this time. After about 40 hours the drain flow was back to pre irrigation rates, the water table in the backfilled trench was at drain level. At this time the soil between the drains remained largely saturated, thus the drains were ineffective at drawing down the mid drain water table, Figure 2-11, further water table decline is by vertical leakage past the drains and upflow to the root zone. The drain flow rates were largely a result of flow down the backfilled trench.

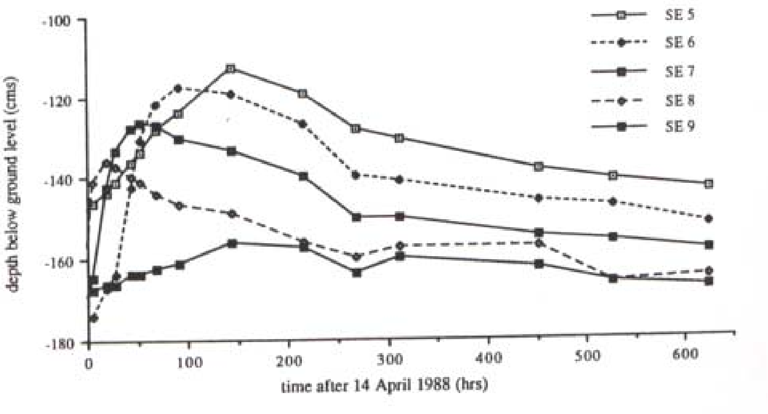

Figure 2-10 Watertable recession in clay soil, SE9 = piezometer closest to drain, SE5 = piezometer at mid drain spacing, Todd and Grismer (1991)

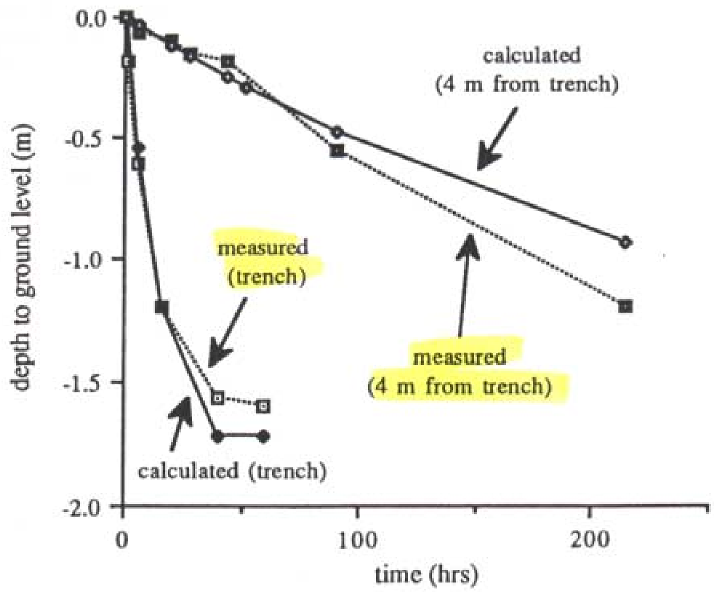

Figure 2-11 A comparison of measured and calculated water levels, Todd and Grismer (1991)

Trench flow occurs because the permeability of the backfilled material is significantly higher than that of the undisturbed surrounding soil. This results in large amounts of water flowing directly to the drain. Irrigation water becoming trench flow is not subsequently available for crop water use; neither does it leach salts from the soil profile outside the trench. Todd and Grismer (1991) found that in heavy clay soil, trench flow accounted for almost all of the drain flow for 40 hours after an irrigation. The drainage water from trench flow is less saline than later flows and thus is more suitable for reuse. Alternatively the drains maybe prevented from discharging during an irrigation to reduce this trench flow.

Hermsmeier (1973) investigated the performance of shallow drains in a soil with 50% clay. Normal drain design required that drains at 1.2 m depth be spaced only 6 m apart, this was deemed to be uneconomic and instead the drains were installed at an average depth of 1.14 m at a 61 m spacing. For a barley crop water tables started at 1.3 m depth and rose to only 0.15 m from the soil surface directly after the sixth and last irrigation. The water table shape was very flat with significant draw down occurring only within 6 m of the drain. The drains only removed 2.9 % of the 380 mm of net irrigation applied. This drain effluent removed only 42 % of the net salt added by the irrigation water. In a subsequent sugarbeet crop the drains only removed 0.35 % of the net applied irrigation water and 8 % of the net salt added. Measured soil salinities showed that the salinity levels in the top 0.3 m declined from around 15 dS/m to 10 dS/m after the first crop and then to 8.4 dS/m after the second crop. The soil salinities below 0.3m declined slightly although not significantly. As there was no control undrained area for comparison it is not clear whether the salinity in the top soil would have declined anyway due to deep percolation. It is clear however that drains at this spacing removed small amounts of water only, created significant water table draw down only close to the drain, approximately only 20 % of the cropped area, and removed only a small proportion of the salt applied. The larger amount of salt removed under the first crop was probably due to localised leaching of the soil above and near the drains, a more indicative value is that 8 - 12 % of the applied salt would be removed with this system. One positive aspect of these drains was that they stopped flowing between irrigations indicating that there was no regional groundwater flow component.

2.5 Conclusions from literature review

This review of past research and experience has revealed that drainage quantity is affected predominantly by irrigation management, as the main source of drainage water in arid regions. The efficiency of crop water use can be improved by managing the drainage system and altering irrigation practice in order that the crop recovers some water from the water table.

The other major component of drain flow is from regional groundwater. This flow into the drains is induced by high water tables outside the drained area caused by changes in topography, leaking channels and irrigation management in surrounding areas.

The quality of subsurface drainage water is profoundly influenced by the depth and spacing of the drains. Shallower drains result in less saline drainage water and flow less frequently than deep drains.

Overall, this review indicates that there should be a large potential to improve the design and management of subsurface drainage systems to provide better drainage, better irrigation water use efficiency and reduce the volume of drainage water.

3 OBJECTIVES

The objectives of the study were:

- To optimise the design and management of subsurface drainage to control waterlogging and salinisation with minimum salt mobilisation;
- To develop water quantity and quality targets for subsurface drainage water from new vineyards and other enterprises on clay soils; and
- To provide guidelines on best practice design and management of subsurface drainage systems.

4 GENERAL METHODOLOGY

1. On several vineyards in the MIA with different irrigation and drainage systems established on clay soils, measure irrigation applied and drainage volume and quality to establish relationships between irrigation and drainage

2. Use the information from 1. to:
   - Develop and validate drainage models, use the models to develop strategies for irrigation systems and drainage design to reduce the quantity and/or salinity of drainage water; and
   - Undertake benefit:cost analysis of options to reduce discharge from subsurface drains with improved irrigation and drainage management.

3. Test the best drain design and management strategies in field trials with farmer involvement.

4. Develop subsurface drainage design and management guidelines.

5 FIELD INVESTIGATIONS OF IRRIGATION SYSTEMS AND THEIR MANAGEMENT ON DRAINAGE QUANTITY AND QUALITY

5.1 Aim

The aim of these field studies was to determine the effects of several key factors, as identified in the literature review, on drainage water quality and quantity and also to understand the overall water table control and waterlogging status of farms with different irrigation and drainage systems and/or management.

Key relationships to be investigated were:

- Effect of irrigation management on drainage quantity/quality and waterlogging;
- Effect of the type of irrigation system on drainage quantity/quality and waterlogging;
- Effect of water table depth on drainage quality especially, but also quantity; and
- Impact of regional inflows on drainage quantity/quality.

To investigate these relationships several studies were conducted, each of which is reported separately in the following sections. In general terms these were:

1. Water balance comparison of various vineyards;
2. Water and salt distribution under different irrigation methods;
3. Financial analysis of irrigation systems; and
4. Drainage relationships of irrigation, regional inflow and water table depths on individual vineyards.

5.2 Water balance comparison of various vineyards

5.2.1 Methods

Three vineyards in the MIA were chosen for monitoring over one irrigation season. The vineyards were chosen with different irrigation systems, each farm chosen had a high level of management. The traditional irrigation method of flooding the entire inter-row, furrow irrigating a small area alongside the vines, called Riverina twin Furrow (RTF), which is becoming popular and drip irrigation which is used on many of the new large scale plantings were chosen. These three methods of irrigation were monitored for water use and the economics of each system also evaluated.

Other aspects of the vineyards chosen were:

1) Flood irrigated in broad based furrows wetting the entire vineyard floor

    - clay loam soil, minimum cultivation practiced
    - vine rows 100 - 150m long
    - mature vines – shiraz, cabernet sauvignon, barberra, semmilon
    - subsurface pipe drainage (clay tiles) about 2m deep and spaced 18m apart, pump left on at all times

2) Furrow irrigated (Riverina Twin Furrow), small furrows about 0.3m wide wetting about 0.6m either side of the vine row.

    - clay soil, extensive cultivation practiced
    - vine rows 400m long
    - mature vines – chardonnay, semmilon
    - subsurface pipe drainage (clay tiles) about 2m deep and spaced 40m apart, pump left on at all times

3) Drip irrigated, 3l/hr emitters at 0.75m spacing

    - clay soil, no cultivation
    - vine rows 400 - 600m long
    - two year old vines – chardonnay, semmilon, shiraz
    - limited tile drainage-interceptor around outside of farm and 5 laterals only

These vineyards were monitored in terms of:

- Quantity and quality of irrigation water applied
- Quantity and quality of surface drainage water
- Quantity and quality of subsurface drainage water
    - Water tables

5.2.2 Results and discussion

5.2.2.1 Run off

The flood irrigation system was well designed and managed, so the volume of run off was small as the farmer took care to cut off irrigations to prevent excessive loss of irrigation water. However, the total amount of tile drainage was about 4 times greater than the run off. This was probably due to the slow advance of irrigation water down the broad based furrows which resulted in excessive water movement past the root zone at the top of the row. Figure 5-1 shows the tile drainage, run off and water table hydrographs resulting from an irrigation event. These results show the difficulty in managing surface irrigation to reduce drainage. Surface drainage can be reduced by careful cut off times but it is less easy to control deep percolation. To do this would require very rapid irrigations for short time periods. This would then result in higher levels of run off and frequent irrigation, which is labour intensive.

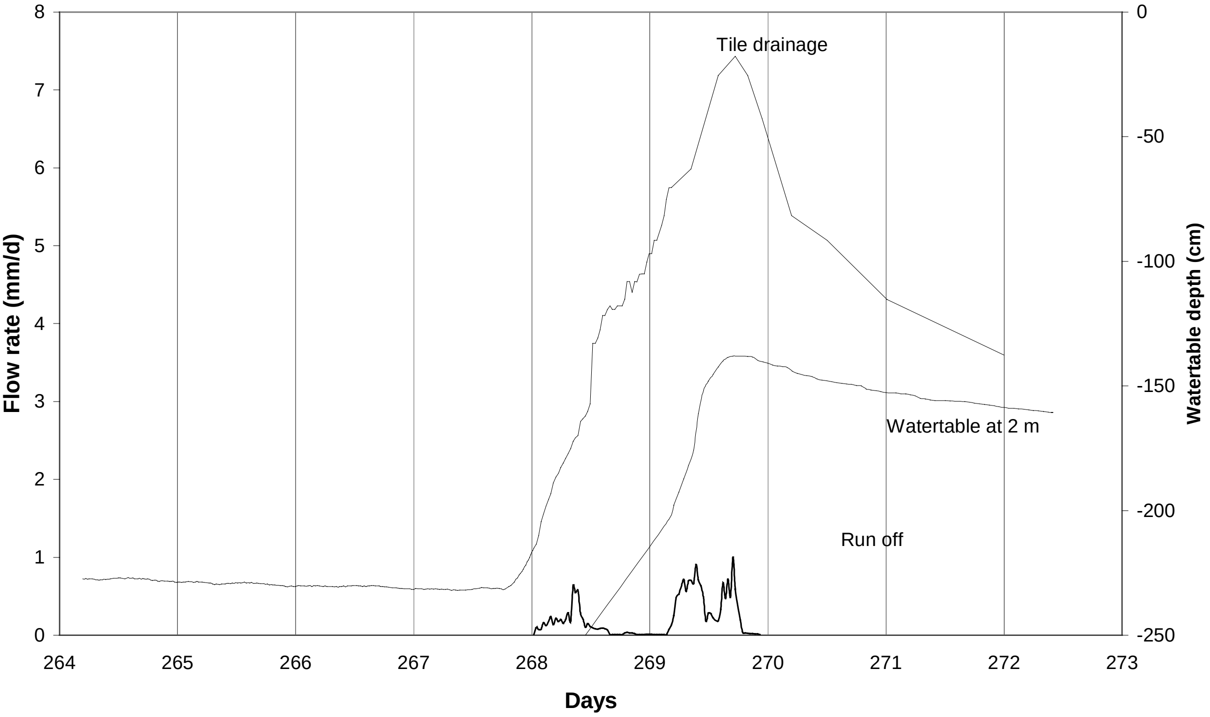

Figure 5-1 Tile drainage, run off and water table hydrographs under flood irrigation

The variable nature of run off from surface irrigation was also found when monitoring the furrow irrigated vineyard. This variation was caused by the management, which was trying to achieve rapid advance times, by high inflows into the furrow, Figure 5-2.

Only drip irrigation prevented surface runoff, this was clearly demonstrated when 65 mm of rain fell in 24 hours, resulting in only 1.5 mm of run off, the rest of the rainfall being absorbed in the dry inter-row area.

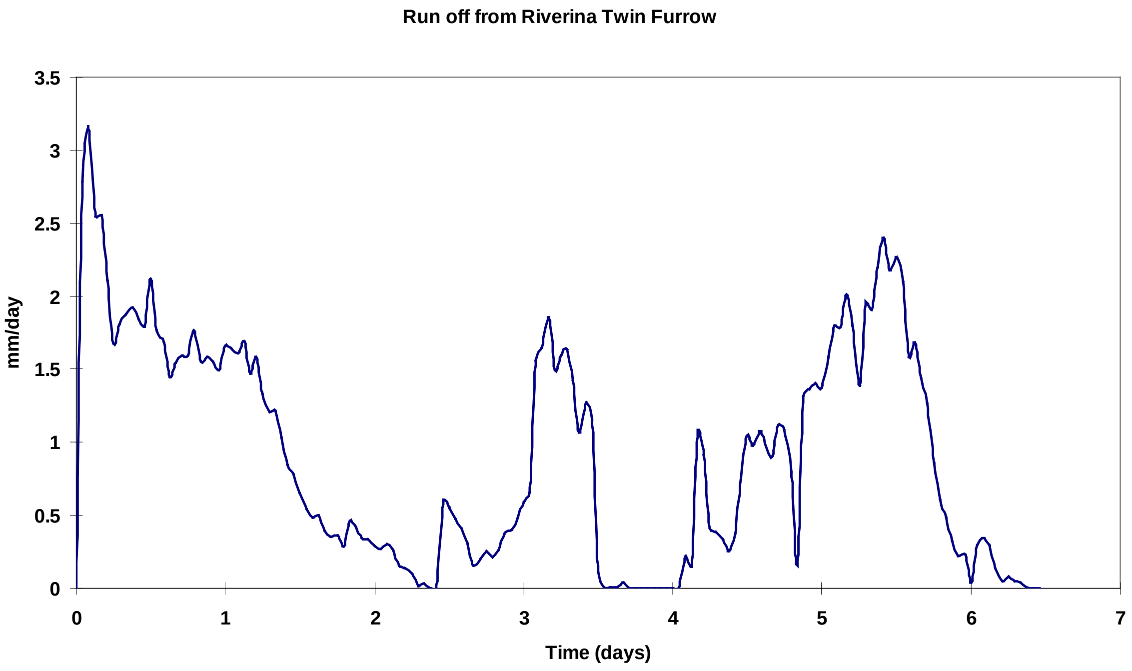

Figure 5-2 Run off during irrigation from vineyard using Riverina Twin Furrow

5.2.2.2 Water tables

Water tables under the surface irrigated vineyards fluctuated more over the season than under the drip irrigated vineyard. The flood irrigated vineyard had water tables generally about 2m deep, which would rise about 0.5m after irrigation, Figure 5-3. The water tables under the Riverina Twin Furrow vineyard fluctuated more widely than under the flood irrigated vineyard, often rising over one metre to within 0.6 m of the surface. This greater level of fluctuation was probably due to the longer row length allowing more deep percolation at the top of the rows and also due to longer irrigation set times.

The water tables under drip irrigation usually did not show any rise after an irrigation, indicating that the drip irrigation did not cause significant water percolation past the root zone. The only period when water tables fluctuated significantly was after 65mm of rain when water tables at the lower end of the farm rose by about 0.5m, Figure 5-3.

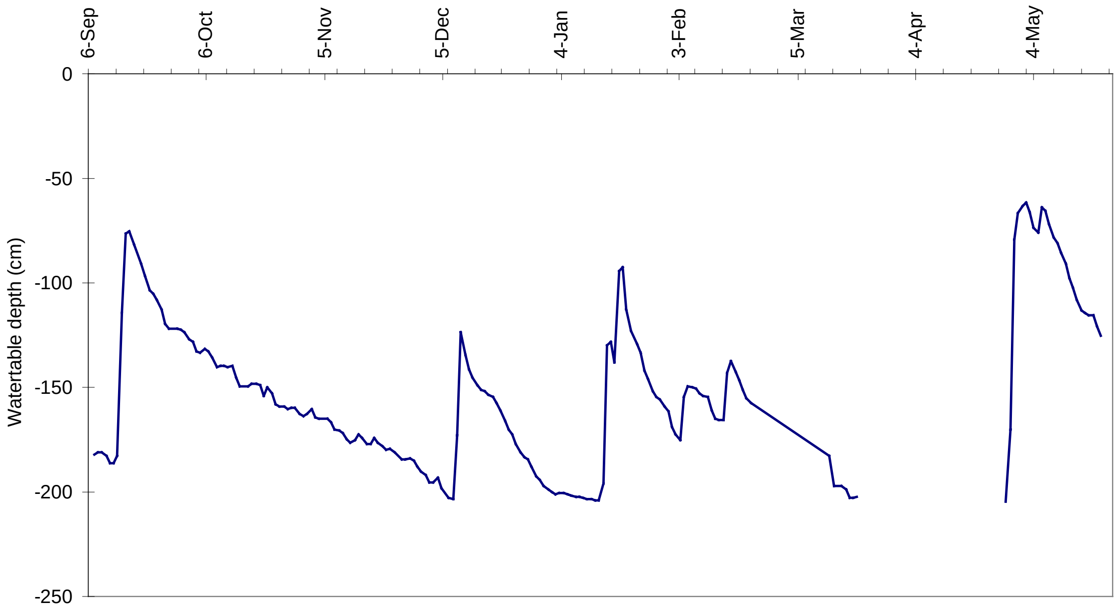

Figure 5-3 Water tables under Riverina Twin Furrow vineyard, drains 200cm deep.

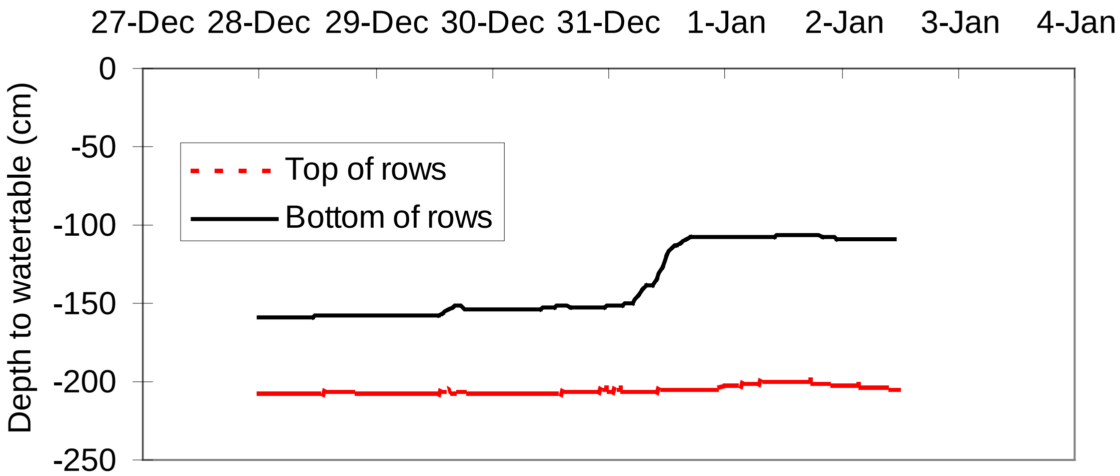

Figure 5-4 Water tables under drip irrigation, 65 mm rain 31st December

5.2.2.3 Season summary

The vineyards were monitored for a whole season; Table 5-1 shows a summary of water balance for each. Drip irrigation gave greater control over irrigation applications, small amounts of water can be applied frequently. This results in no run off or tile drainage when properly managed. This is in comparison to Figure 5-1 and Figure 5-2 , which show the run off during irrigation with Flood and RTF, the run off fluctuates widely which demonstrates the difficulty of getting good control of surface water.

Table 5-1 Summary of irrigation system performance

System	Number of irrigations	Depth of water applied, average mm	Water use Ml/ha	Run off from irrigation mm	Tile drainage per irrigation, average mm
Flood	7	82	5.8	14	28
RTF	6	115	6.9	48	24
Drip*	26	5	1.4*	0	0

* The drip irrigated vines were only 2 years old, the water use with drip irrigation would typically be 4-5 Ml/ha for mature vines

With surface irrigation the amount of water applied at each surface irrigation is more than is required to refill the soil which results in deep drainage through the tiles. Whilst the soil is draining back to field capacity through the tile drains the soil is waterlogged affecting plant growth.

During the season, more irrigation water was applied to RTF (373 mm) than flood (313 mm) with considerably less applied to the vines irrigated with drip (121 mm). Although the drip irrigated vines were younger, it is likely that at least part of the reduction in water use is related to the more efficient irrigation.

The number of irrigations varied from 26 with drip, 7 with flood and 6 with RTF. No surface runoff occurred with drip but the quantity of runoff with RTF varied from 5% to 20% of the applied water. Because of excellent management of the flood irrigation system, on average only 4% of the water applied was lost in surface runoff. However, about 14% of the water applied with flood and RTF was discharged from the tile drains.

5.2.3 Conclusions

From this data it can be seen that better water management can be achieved with well managed drip irrigation resulting in better conditions for plant growth and reduced drainage water. However, well managed surface irrigation can also result in minimal drainage, but not reaching the level of control found under well managed drip irrigation.

The results of these studies were publicised by:

1. Lets talk water and drainage field day - Griffith. 4/96, in conjunction with NSW Ag, over 100 participants
2. Newspaper article on field day - Area News, 10/6/96.
3. Newspaper article on field day. -Rural News, 8/5/96.
4. Television coverage of field day -MTN 9, 16/4/96.

5.3 Water and salt distribution under different irrigation methods

5.3.1 Methods

Flood irrigation in broad based furrows, Riverina Twin Furrow (RTF) and drip irrigation were evaluated on clay soils. Tensiometers were installed in a grid at 5 points perpendicular to the vine row at 5 depths and read daily from mid January to mid February, the peak of the irrigation season. Soil salinity was also analysed at each point grid. The distribution of vine roots was analysed by a qualitative scoring system of soil cores from each point.

5.3.2 Results

5.3.2.1 Soil Water Potential

Flood irrigation completely wetted the soil profile. Much of the soil was too wet (<20kPa), especially close to the vine and below 50 cm. RTF wetted the entire soil profile, however only below 50 cm was too wet (<20kPa) and the middle of the inter-row was drier than with flood irrigation. Drip irrigation produced a limited soil wetting pattern. The soil was too wet (<20kPa), except at the fringes of the wetted area. There was free water directly below the emitter at 50 cm depth.

5.3.2.2 Roots

Vines under flood irrigation had a large root zone. Roots were found from the surface to 60 cm depth, below this the soil was too wet. Vines under RTF had a large root zone. Roots were found from 10-60 cm depth. Surface roots had been destroyed by cultivation. Vines under drip irrigation had a limited root zone. The roots were growing in the very wet zone but avoided the area of free water.

5.3.2.3 Soil salinity

The initial soil salinity was very different at each site. The flood irrigation site had uniform soil salinity distribution. The RTF site showed that salt was leached away from directly under the vines where the water was applied. The drip site showed a build up in soil salinity at the soil surface.

5.3.3 Conclusions

- Over irrigation occurred in some part of the root zone with all the irrigation systems; thus better management is the key to better irrigation, not the irrigation system in itself.
- Each system produced a different wetting pattern and root distribution.
- Drip irrigation had a restricted wetting pattern and root zone requiring different management from the other systems.
- Riverina Twin Furrow resulted in less wetting of the middle of the inter-row than flood, which would reduce water use.
- Point application of water results in uneven soil salinity distribution

The results of these studies were published in the following articles:

1. Cox, S. (1995) Soil water conditions and root distributions under grape vines with drips, Riverina Twin Furrow and flood irrigation. Vacation studendship report, March 1995, CSIRO Land and Water, Griffith.
2. Christen, E.W., Moll, J.L , Cox. S, Muirhead, W.A., Sinclair. P and McLennan. A, (1995*) Furrows that Trickle?* . Poster presented at 9th Australian Wine Industry Technical Conference. Adelaide. July 1995.

5.4 Financial analysis of irrigation systems

Vineyards can be irrigated with a range of systems including flood, furrow, spray, and drip. A financial analysis of these systems was carried out for a new vineyard development of 40 ha planted with the Shiraz variety. The analysis was carried out assuming the same yield under each system. The Net Present Value (NPV) was calculated by subtracting the total discounted costs (using a 7% discount rate) for the 15 years after establishment from the total discounted benefits. The NPV was the main method used to compare the performance of the systems.

The Drip and Flood systems produced similar financial results in terms of NVP. Although the Drip system was more expensive to install than the Flood system, the Drip's low annual operating costs outweigh its initial expense and make it the most financially and environmentally attractive system.

The other systems evaluated - Overhead Sprinkler, Undervine Microjet and Riverina Twin Furrow - produced lower NPVs.

The results of these studies were published in:

1. Moll, J. (1996). Financial analysis of new vineyard developments in the MIA. *CSIRO Division Water Resources Technical Memorandum* 96/3
2. Moll, J. (1995). Financial analysis of more efficient irrigation systems in new vineyards in the Riverina. *The Australian Grapegrower and Winemaker* (November) 42 - 46.
3. Moll, J. and Christen, E. (1996).Drip systems makes financial sense. *Power Farming Magazine* Feb 27 - 29.
4. Moll, J., and Christen, E. (1996) *Selecting the right irrigation system.* Farmers' Newsletter, No. 180 Horticulture, p22-24, September. 1996

5.5 Economic analysis of options for managing subsurface drainage

Having determined that drip irrigation is comparable to flood irrigation purely on a Net Present Value basis without assessing the benefits of reduced drainage a further financial study was undertaken to investigate the financial attractiveness of drip versus flood irrigation when drainage management costs are included.

5.5.1 Methodology

Two irrigation management options, each with two sets of constraints that aim to reduce the salt load leaving farms in subsurface drainage water were considered for both new and existing vineyards. The irrigation options considered were drip or flood irrigation with the constraints of holding drainage water on farm in an evaporation basin or discharging it to the surface drainage system with a fee per tonne of salt.

The drip irrigation system was analysed under two scenarios; firstly that there would be no drainage generated from the system and thus no drainage system required and secondly that there could be up to 67mm of drainage per annum which would be stored in an evaporation basin equivalent to 6.5% of the drained area. In comparison it was assumed that the flood irrigation system would produce between 67 and 167mm of drainage per year that would be stored in an evaporation basin equivalent to 10% of the drained area. In both cases the option of charging for the discharge of salt was analysed at a cost of $30/tonne of salt.

The analysis was undertaken for Shiraz grapes on a 40ha vineyard over a 15 year time period.

5.5.2 Results

Over the 15 year period, the nil drainage from drip irrigation was found to be the most financially attractive. This was due to the higher costs of the other systems and that the running costs of a drip irrigation system are lower. There would also probably be grape quality/quantity benefits with a drip system but these were not assessed.

If due to poor site selection or other factors drip irrigation did require subsurface drainage it was still more financially attractive than flood irrigation. This was the case for both the charging for discharge and evaporation basin option. The evaporation basin option in this analysis was more costly than paying for discharge.

These results were predicated on the price for Shiraz grapes averaging $400/t. However, the other benefits of improved irrigation management such as; quality, yield and consistent production were not considered. Other environmental benefits such as the negligible run off, even after heavy rain, were also not considered.

5.5.3 Conclusions

Drip irrigation in either a new or existing vineyard was more financially attractive method of drainage management when discharge of saline water incurs a charge or there is an on-farm retention constraint.

The charging for drainage option also makes drip the favoured option as it produces little or no drainage compared to flood irrigation.

In general terms it is clear that improved irrigation management is the most financially attractive method of reducing drainage discharge.

These results were published in:

Moll, J. and Christen, E. (1996) Financial evaluation of options for managing tile drainage water to meet environmental constraints. Technical Memorandum 96/20., pp 11. October 1996. CSIRO Division of Water Resources.

Moll, J., and Christen, E. (1996) The economics of managing tile drainage water in MIA vineyards to meet environmental constraints. The Australian Grapegrower and Winemaker, No. 395, p29-33, November 1996.

5.6 Factors affecting drainage water quantity and quality

5.6.1 Methods

On the surface irrigated farms described in section 5.1 more detailed studies were undertaken of the relationships between irrigation management and subsurface drainage quantity. The relationships between water table depth and drainage water quality were also investigated in order to determine methods for improving subsurface drainage management. Data from a survey of 50 horticultural farms with subsurface drainage undertaken by the Department of Water Resources in Griffith, NSW, was used to investigate the salt load-flow relationships for drainage in the area.

5.6.2 Results

5.6.2.1 Irrigation and drainage quantity

Intensive monitoring of subsurface drainage flows during and after irrigations found that there was a strong relationship between the amount of irrigation water infiltrated and flow from the subsurface drainage system. The results from monitoring irrigations over a season at the flood irrigated vineyard are shown in Figure 5-5. This shows that with increasing irrigation water infiltrated there was more drainage water.

The volume of drainage as a proportion of irrigation applied ranged from 10 to 18%, with generally a smaller proportion of the irrigation being drained when small irrigations were applied. However, the relationship was not clear, with there being a range of drainage measured for similar sized irrigations, Figure 5-6. This could have been due to variations in the irrigation management or the soil moisture conditions prior to irrigation.

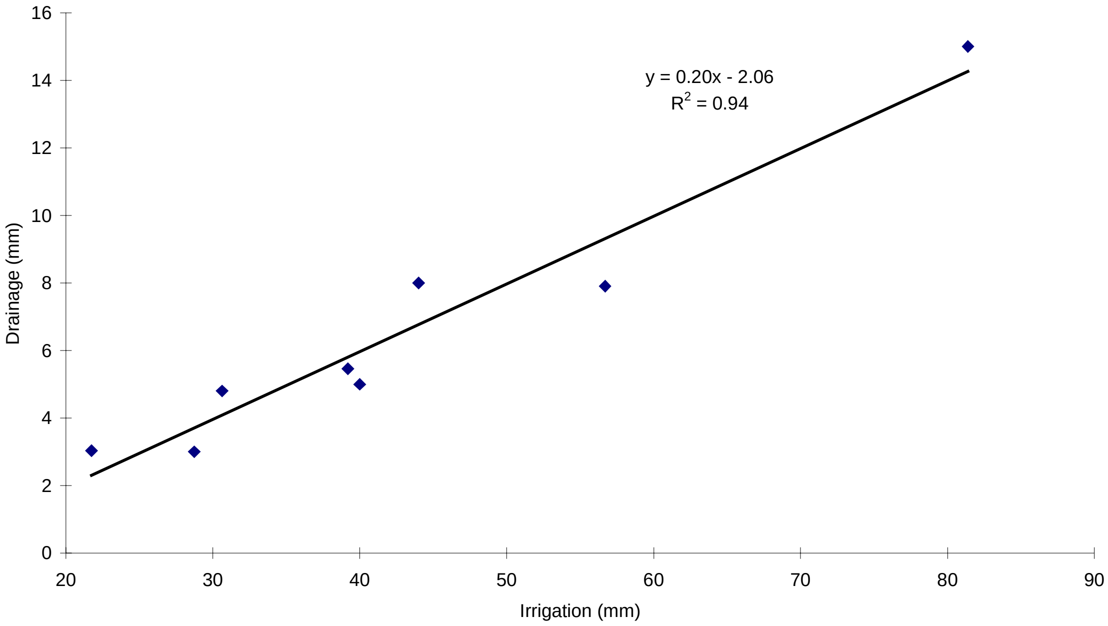

Figure 5-5 Subsurface drainage as a function of infiltrated irrigation

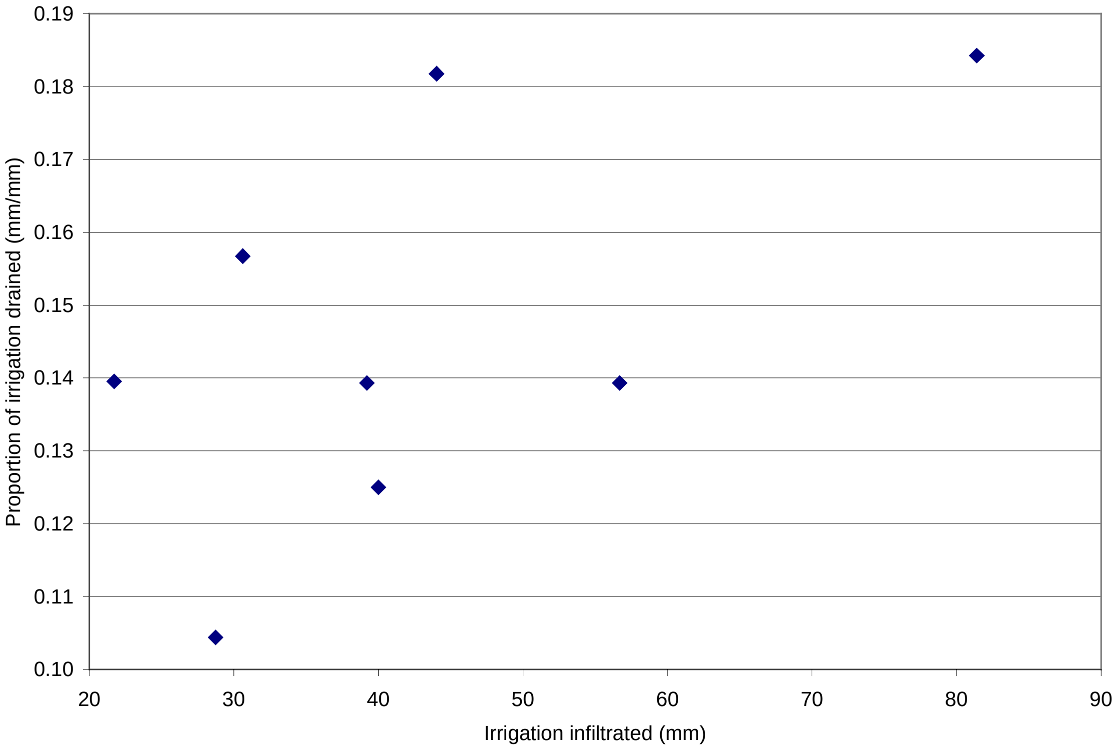

Figure 5-6 Subsurface drainage as a proportion of irrigation

The results from Figure 5-5 and Figure 5-6 were analysed to develop a model of the likely impact on subsurface drainage volume of changing irrigation practice. The result of this analysis is shown in Figure 5-7. In this case it was found that for irrigations of around 100mm a unit reduction in the applied irrigation would result in a 0.4 unit reduction in subsurface drainage. At the lower end of irrigation size, 30 –40mm, a unit reduction in irrigation only results in a 0.2 unit in reduction. This shows that there is declining benefit in continuing reduction of irrigation size. Even with small irrigations surface irrigation is always likely to produce some drainage due to the presence of macropores that will allow water to bypass the soil bulk and enter the water table.

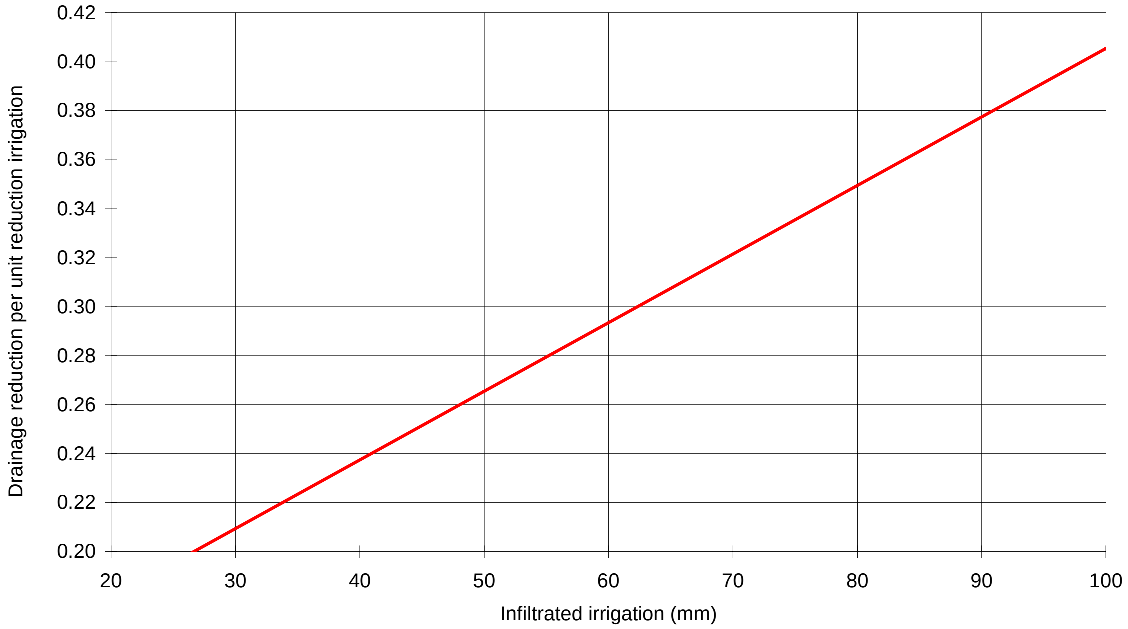

Figure 5-7 Potential subsurface drainage reduction by irrigation reduction, modeled

Further analysis of this data to a seasonal basis shows more clearly the level of drainage reduction possible by reducing surface irrigation, Figure 5-8. This data being developed from limited data over one season can only be indicative of the trends rather than providing an absolute definition of the relationships. The data indicates that at high seasonal irrigation, of 550mm or more, a unit reduction in irrigation will result in a more than unit change in drainage. In this example a unit reduction at these high levels of irrigation will in fact result in about a 1.65 unit reduction in drainage. This is possible because of the interaction between irrigation and rainfall in creating drainage. At high levels of irrigation, over irrigation, there is no capacity for the system to absorb rainfall and as such almost all rainfall becomes drainage, as well as the excess irrigation. This ‘saturation’ of the system is shown by the flat relationship with increasing irrigation above 550mm. Below 550mm there is a linear relationship. At about 300mm any change in irrigation results in about an equal unit change in drainage. Below this level there are diminishing returns from reducing irrigation.

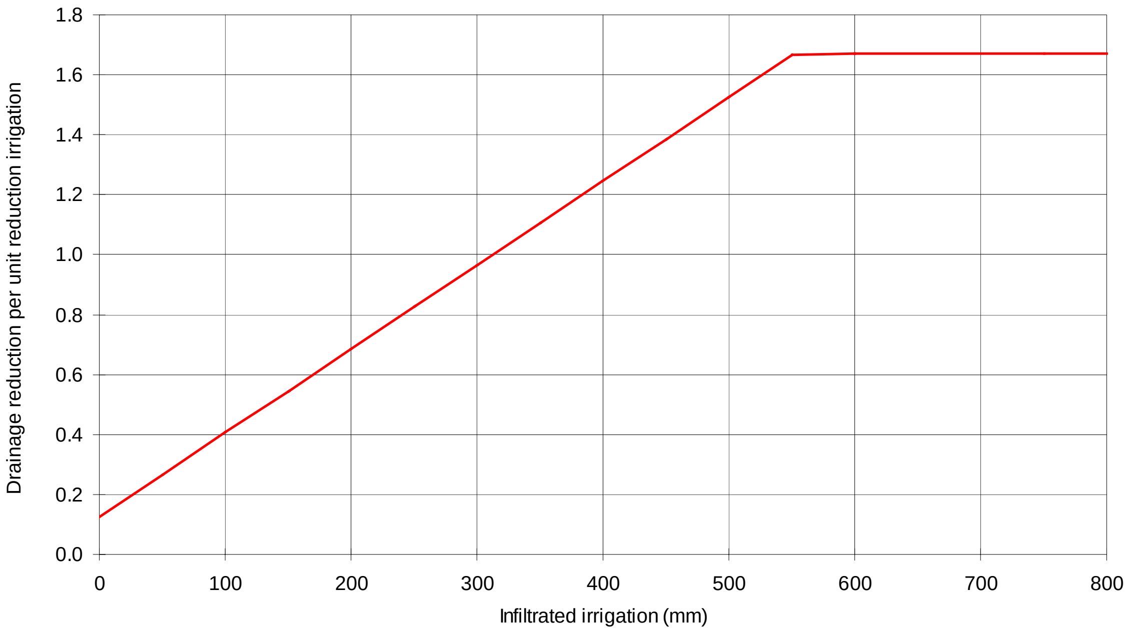

Figure 5-8 Seasonal drainage reduction as a function of irrigation, modeled.

The relationship between irrigation and drainage was further investigated using a water balance model that considered irrigation, rainfall and evapotranspiration on a daily basis to generate drainage flows. The irrigation-drainage relationship could then be investigated in ‘wet’, ‘dry’ and ‘average’ years, where wet and dry were taken as one standard deviation above and below average, Figure 5-9. The results show that the relationship between irrigation and drainage for a citrus grove in the MIA is highly influenced by rainfall patterns. In wet years the irrigation is lower and drainage higher than the average. In a wet year 400mm of irrigation could generate about 200mm of drainage, the same level of irrigation in an average year would generate virtually no drainage. The opposite occurs in dry years where for the same irrigation amount there is less drainage than in an average year. For example 700mm of irrigation in an average year may generate about 200mm of drainage compared to virtually no drainage in a dry year.

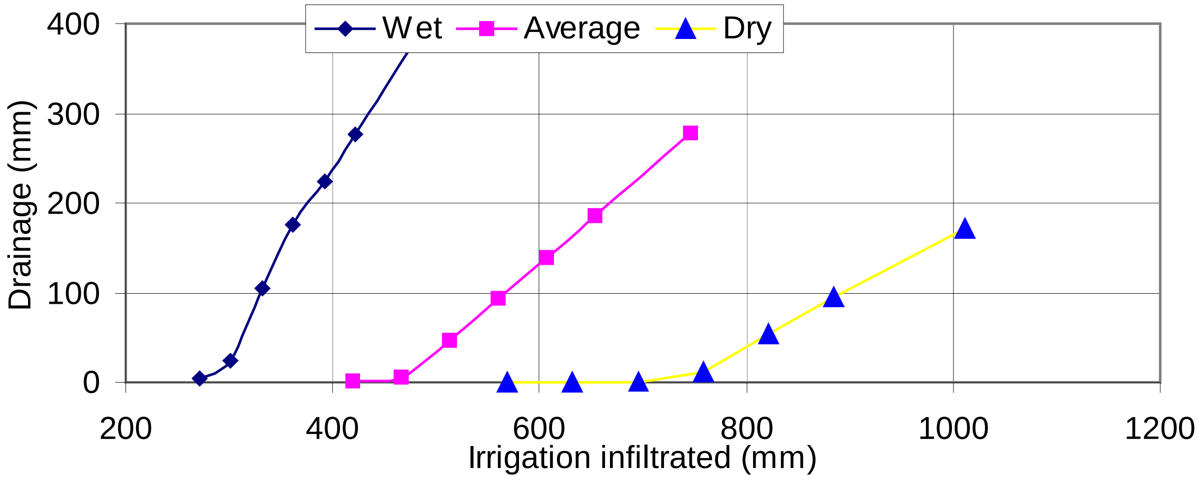

Figure 5-9 Relationship between irrigation and drainage for citrus in the MIA, modeled

The results of the field monitoring and modeling clearly show the importance of controlling irrigation to reduce drainage flows. With surface irrigation reducing drainage completely is very difficult and probably requires an unrealistic level of management combined with favourable physical conditions. With drip irrigation it should be possible to have no irrigation induced drainage flows provided there is a high level of management. However, irrigation together with rainfall at a farm level are not the only contributor to drainage flows. General accessions to the water table from sources outside the farm can also be a factor as shown in the next section.

5.6.2.2 Regional effects on drainage quantity

On-farm monitoring of drainage found that drain flow occurred in the periods intervening irrigations, as shown by the flows in Figure 5-10 where there is zero irrigation. These flows are caused by regional recharge to water tables generating drainage. This may be from general recharge on adjoining farms or recharge due to leaking supply channels.

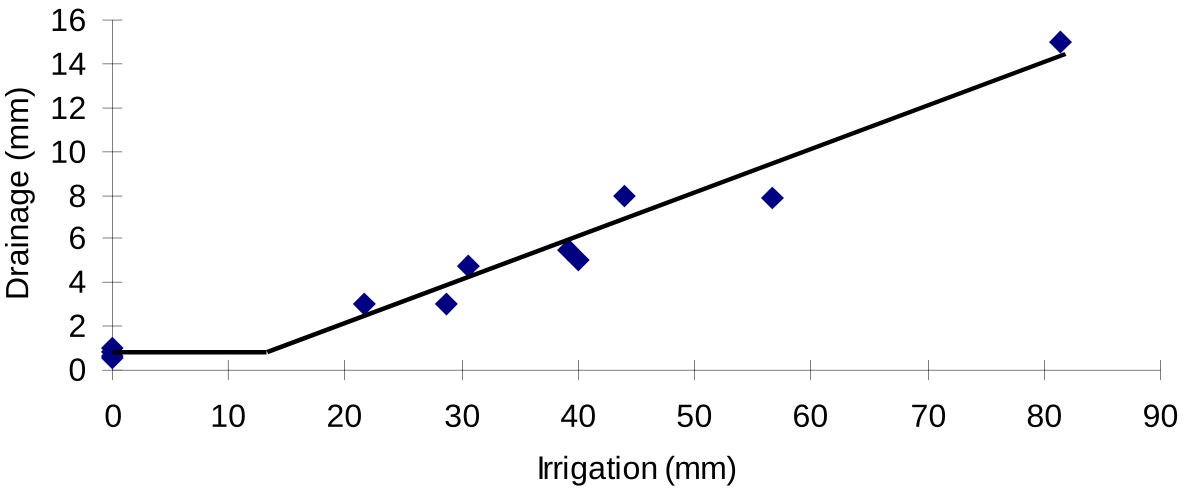

Figure 5-10 Relationship between irrigation and subsurface drainage (furrow irrigation)

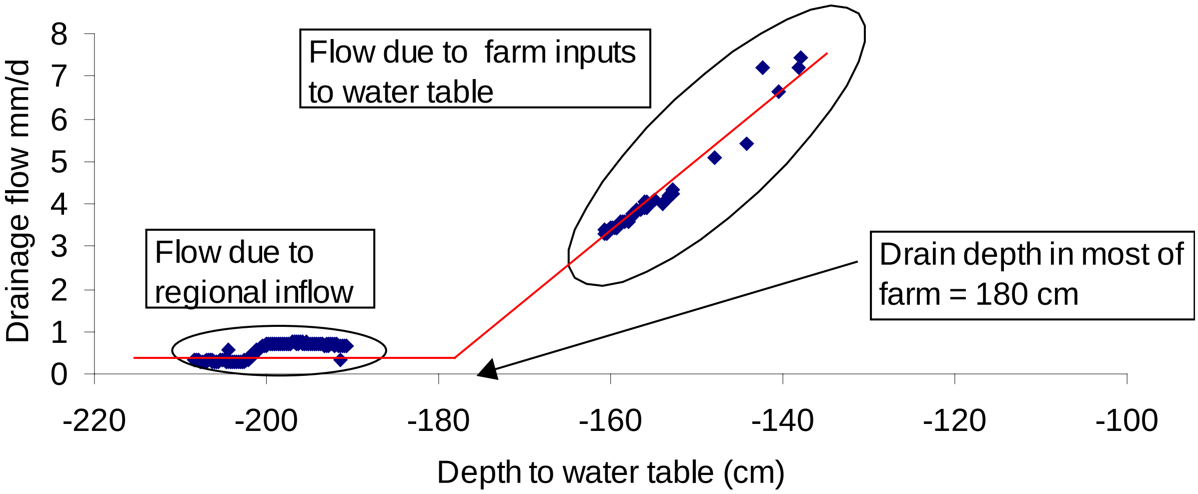

Figure 5-11 Farm and regional inputs to drainflow

When analysing drainage flows from the farm tile drainage system it was found that most drainage occurred when water tables were high on the farm after irrigation or rainfall. The relatively small amounts of drainage, about 0.5 mm/day, that occurred between irrigations occurred when water tables had declined to a deep level, below the level of most of the drainage system, Figure 5-11. In this situation the small amount of drainage generated must occur from the deepest part of the tile drainage system, in this case below 180cm, which is generally the main lines into which the shallower laterals drain. In this situation some kind of control that restricts drainage from the system once the water table has dropped adequately on the main part of the farm would be useful in reducing drainage volumes.

Drainflow from other sources may be significant as was found when monitoring the perimeter tile drainage line around the drip irrigated vineyard. Adjacent to the vineyard was a rice crop, which was slightly higher in elevation and located on soils with some prior stream activity. Figure 5-12 shows the drainflow whilst the rice crop was ponded with water and the decline once the rice crop was drained. In the following season when no rice was grown on the neighbouring paddock the flow from the drains fell to a negligible level.

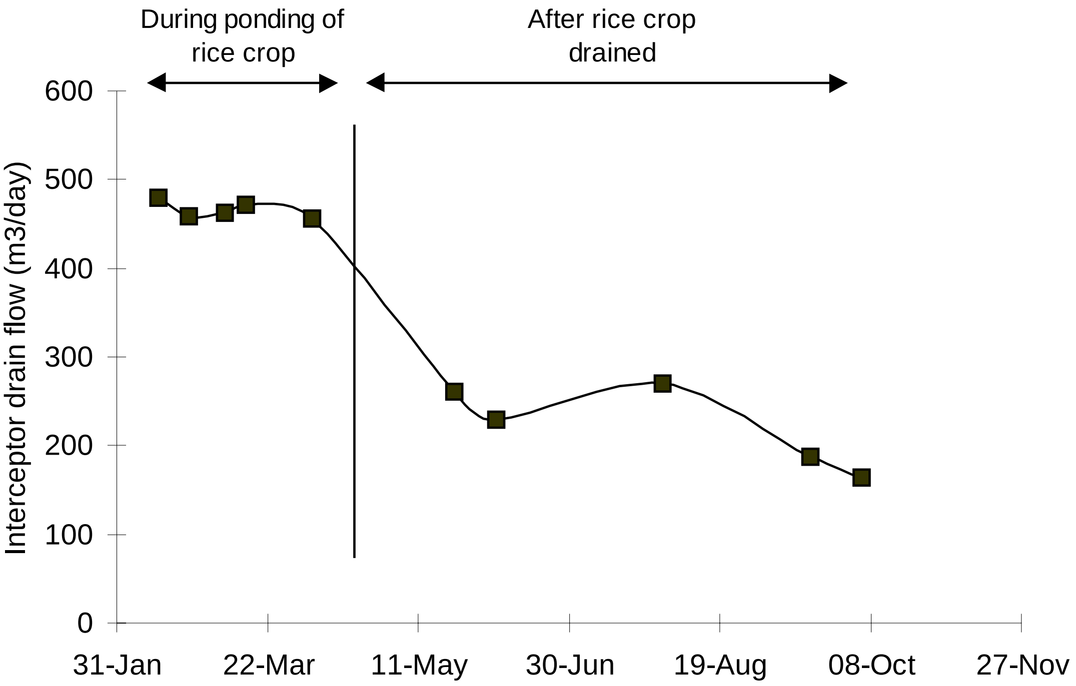

Figure 5-12 Perimeter drain receiving inflow from outside the vineyard

When considering regional water flow the effect of drain depth is an important factor. The deeper drains are installed the more drainage they are likely to generate due to regional effects. Figure 5-13 shows the drain flows that could occur if drains are installed below the regional water table level for horticultural soils in the MIA. At a typical drain spacing of 40m, if drains are 0.5m below the regional water table, then up to 1Ml/ha/yr (100mm/yr) of drainage could occur.

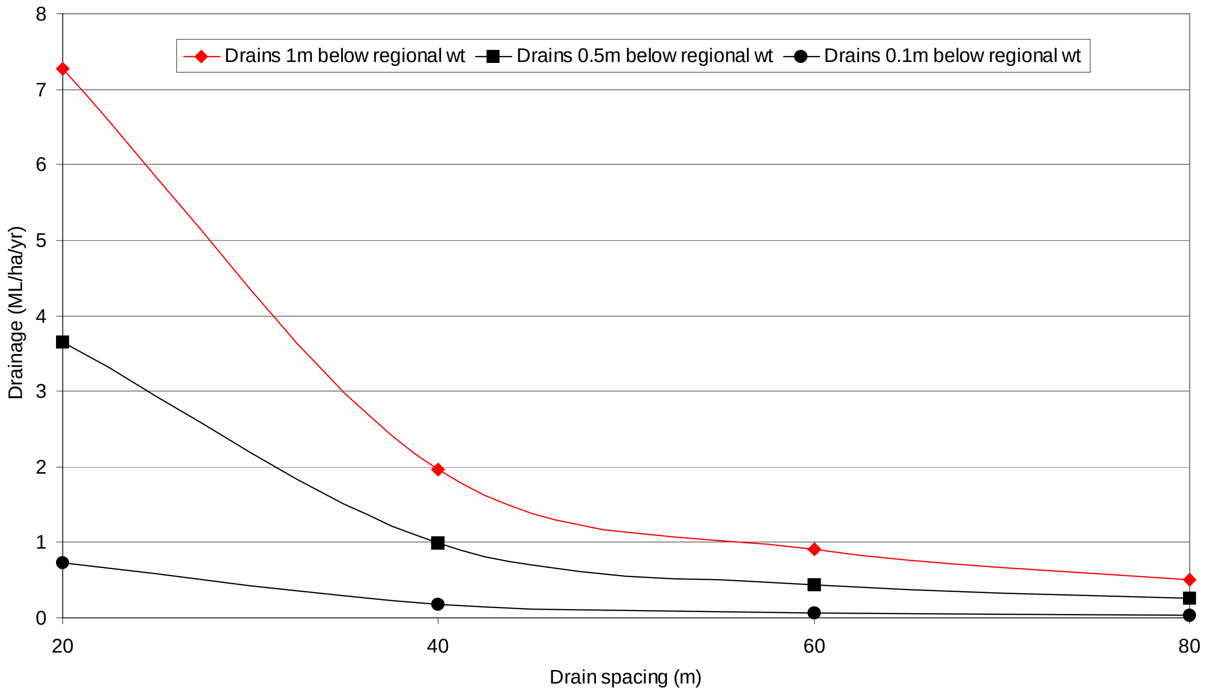

Figure 5-13 Effect of drain depth on flow due to regional influences

These results show the importance of site selection together with drainage design and management with regard to regional effects.

5.6.2.3 Drainage water quality

Drainage quantity can be reduced but is unlikely to be eliminated, so it is important to investigate the key factors affecting drainage water quality. Monitoring of the farm tile drainage systems found that in the furrow irrigated vineyard the drainage water salinity decreased at high water tables levels directly after irrigation or rainfall and then increased as water tables fell. The results of a 21day monitoring period are shown in Figure 5-14.

Using this data the direct relationship between water table depth and drain water salinity can be seen in Figure 5-15. This site had only been drained for about six years and as such is still in a leaching phase. The drainage water salinity was about 10 dS/m when water tables were shallow, 80 cm, and rose to over 13 dS/m when water tables dropped to around 170 cm, a 30% increase. This trend was not apparent on the flood irrigated vineyard as the drainage system had been installed for 35 years and as such the profile was fully leached, the drainage water reflecting the salt applied in the irrigation water rather than the salt stored in the profile.

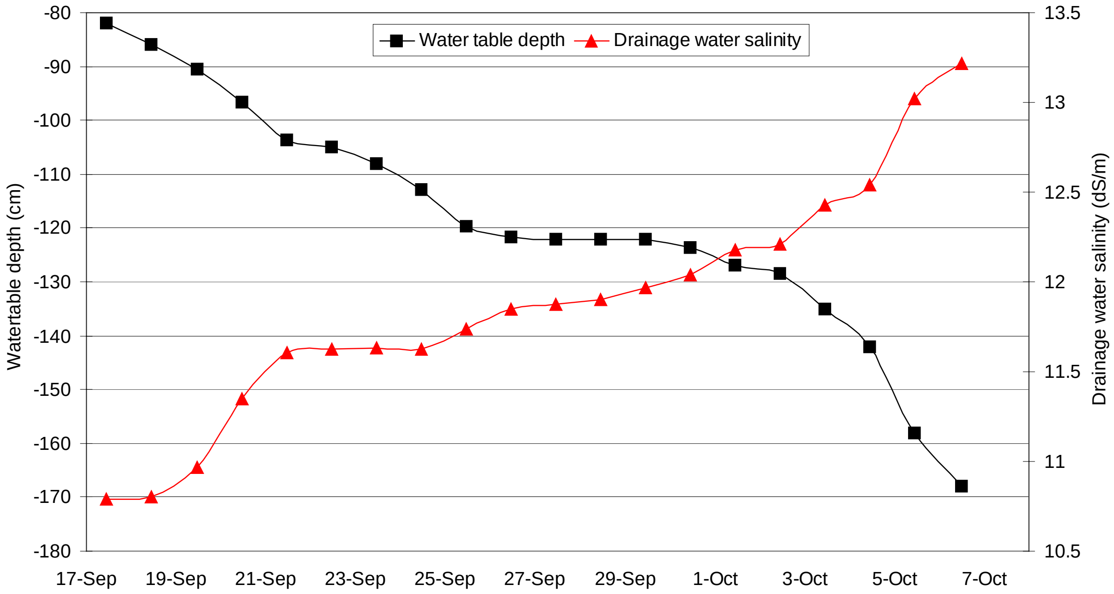

Figure 5-14 Change in drainage water salinity with water table depth

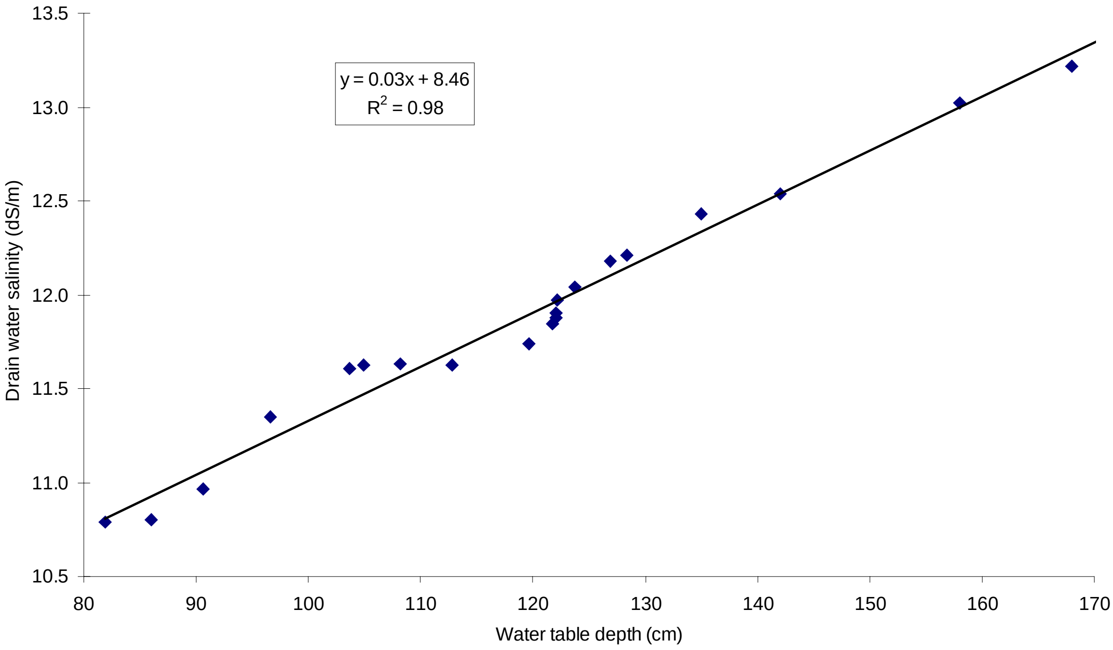

Figure 5-15 Drainage water salinity as a function of water table depth

The increasing drain water salinity with water table depth is due to the changing depth of water flow paths to the drains. As the water table drops the water flow paths to the drains become deeper. The drain flow at deeper water table depths has a greater dominance of deeper water flow paths, which move water through the deeper soil profile, which is more saline. At shallow water table depths the bulk of drainage flow is from shallow flow paths moving through less saline soil. The relationship between soil salinity and drain water salinity is shown in Figure 5-16. The difference in absolute value is due to the higher water content of a saturated paste extract compared to the field water content above the drained upper limit (Field Capacity) and some contribution to the drainflow from flow paths below the drain depth (180cm). However, the close correlation between the soil and drainage water salinity, as shown in Figure 5-17, would indicate that very little of the drain flow in this case is from below drain depth. This is to be expected when drains are installed in a soil of low permeability such as this.

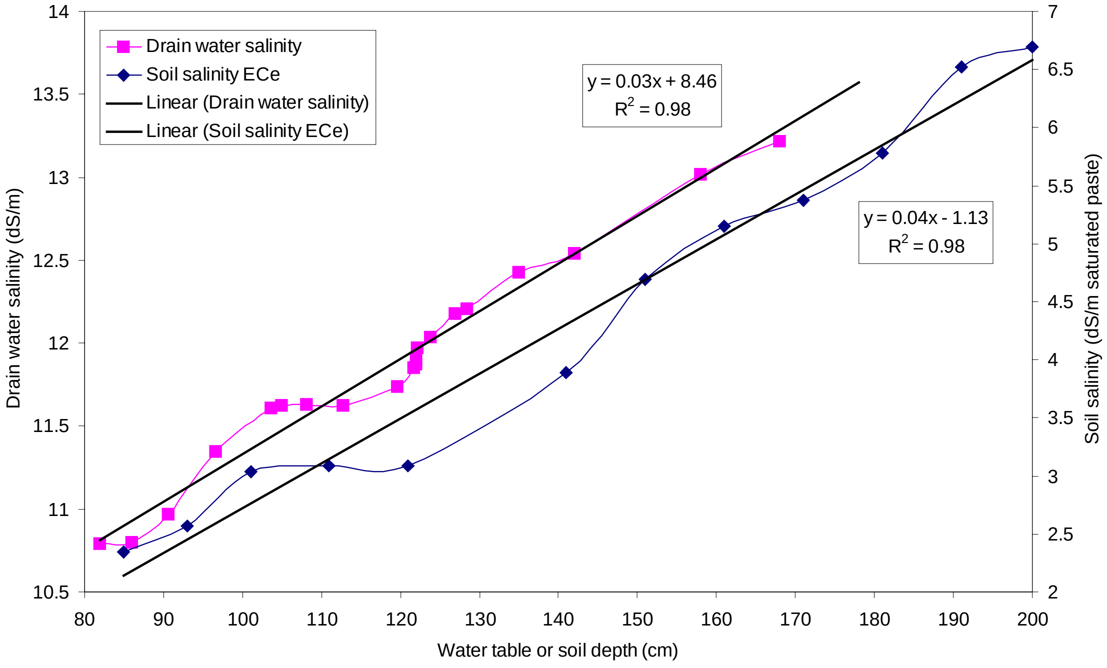

Figure 5-16. Drain water salinity and soil salinity

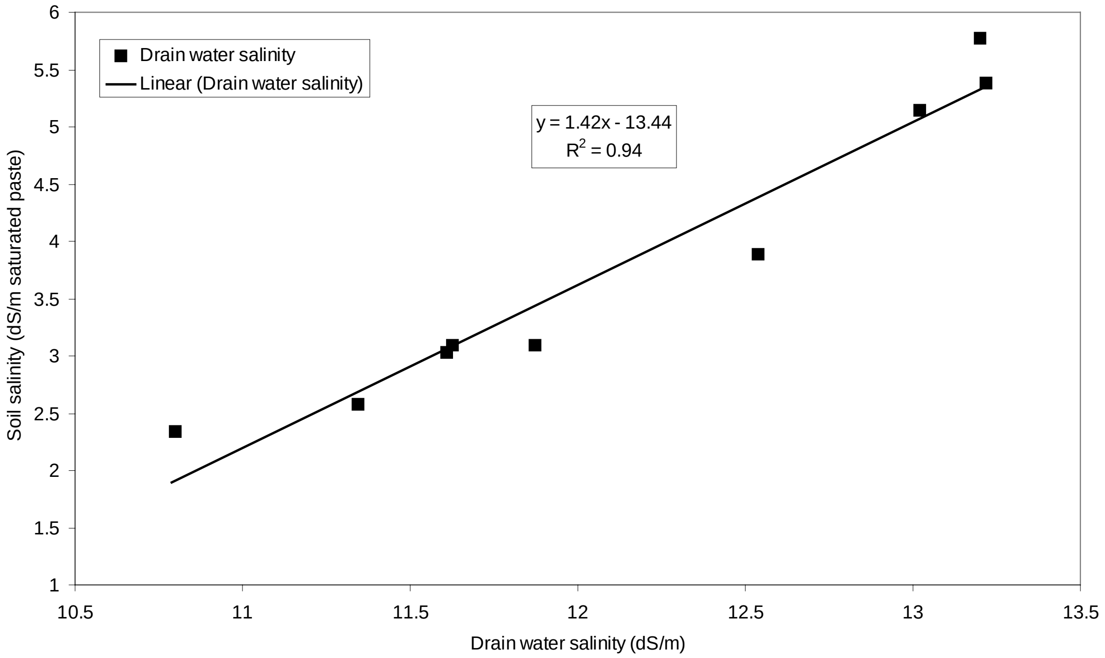

Figure 5-17 Drain water salinity as a function of soil salinity

The potential depth of water flow path to a subsurface drain is not only a function of the drain depth itself but is also greatly influenced by the drain spacing. Wider drain spacings create deeper water flow paths. Theoretically, the deepest water flow paths to any subsurface drain can be up to a quarter of the drain spacing below the drain, so drains spaced 40m apart can generate flow paths up to 10m deep. Figure 5-18 shows the influence of drain spacing, and hence maximum drain water flow paths on the potential for salt removal. This chart uses soil data from a new vineyard compared to a theoretical fully leached profile to arrive at the amount of salt that would potentially be leached.

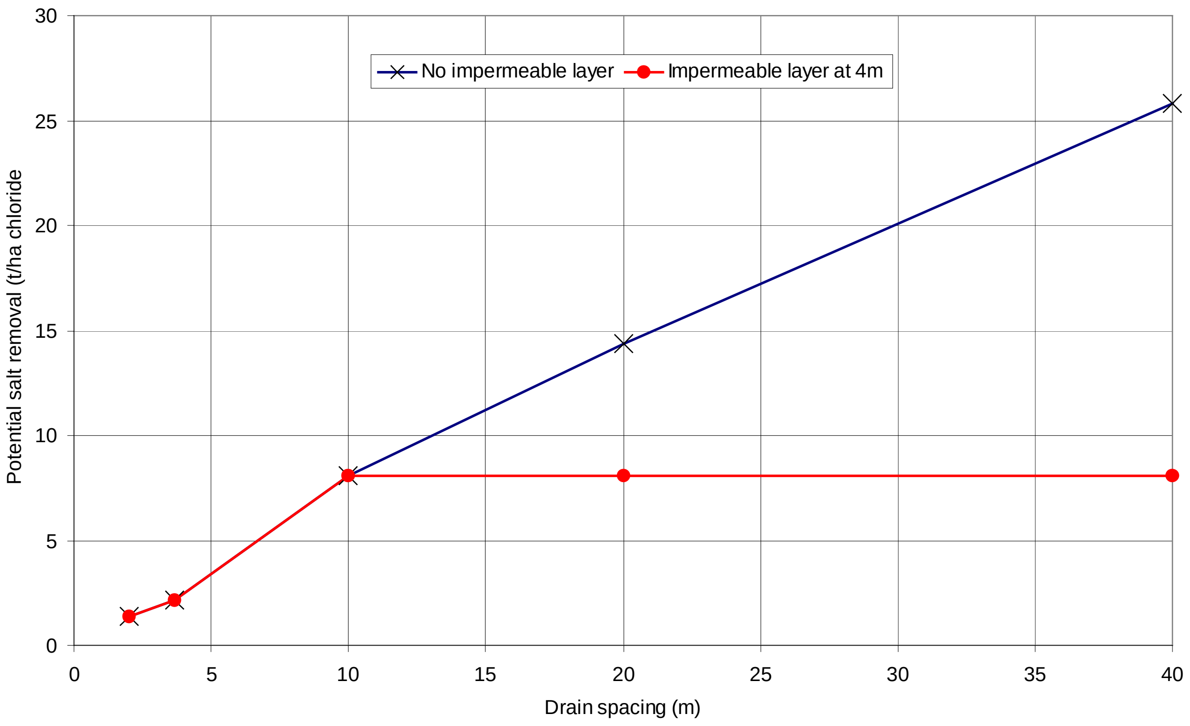

Figure 5-18. Potential salt removal with drain spacing – depth of flow path

It is however rare for a soil profile to extend to great depth without a layer of low permeability in the soil profile which limits the depth of flow path. In the MIA the maximum depth of the limiting layer is about 4m below drain depth. This has been included in Figure 5-18 to give a more realistic representation of the amount of salt that can potentially be removed by subsurface drainage systems.

This relationship between drain water salinity and water table depth has implications for drainage design and management. It shows that drains that concentrate water flow paths in the shallower less saline part of the soil profile will generate drainage water of lower salinity. This can be achieved in design by having shallower more closely spaced drains and in management by preventing flow from drainage systems when the water flow paths are in the deeper more saline parts of the soil profile.

5.6.2.4 Drainage flow and salt load

The salt load from a drainage system is the mass of salt transported by the drainage water. This is a function of the drainage volume and water salinity. In established drainage systems where the leaching of stored salt is past the initial stages then the salinity of the drainage water varies little. Thus the salt load is then linearly related to the drainage volume. In a study of subsurface drainage flows during 1991/92 the Department of Water Resources in Griffith, NSW collected drain water salinities and flows from numerous subsurface drainage systems. From this data a general relationship between flow and load was developed for all the farms involved, Figure 5-19. This relationship may be used as a general indicator of likely changes in the salt load with general changes in drainage volume in response to management or climate variations. However, this relationship is not useful in determining which particular farms or groups of farms contribute the greatest salt loads.

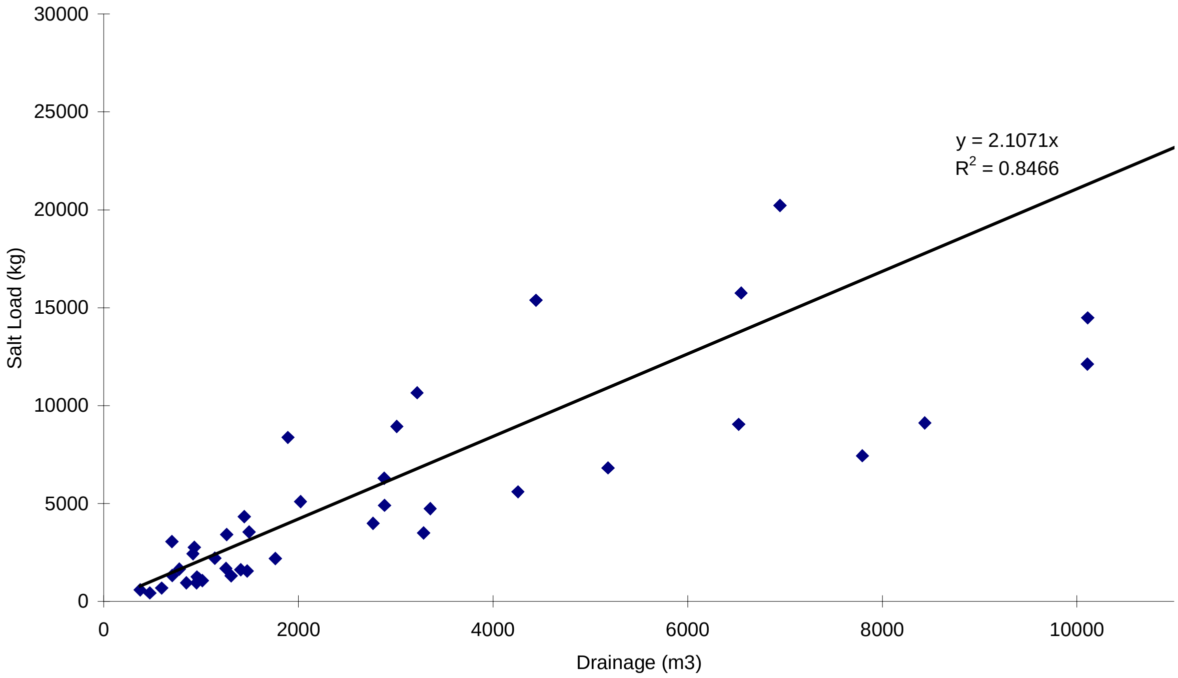

Figure 5-19. Drainage salt load-flow relationship for all farms monitored, DLWC (1992)

To determine which particular farms are contributing most to salt loads in the drainage system then individual salt load-flow relationships need to be developed for each farm, Figure 5-20. The individual farms can be seen to have very different salt load flow relationships with varying slopes, indicating varying water salinity, and varying ranges of flows. These differences are due to physical differences between soil types, hydrogeology, drainage system design and water management. With this information those farms which have high salt loads and steep slopes for the load-flow relationship can be targeted first to reduce drainage flows and get most reduction in salt load.

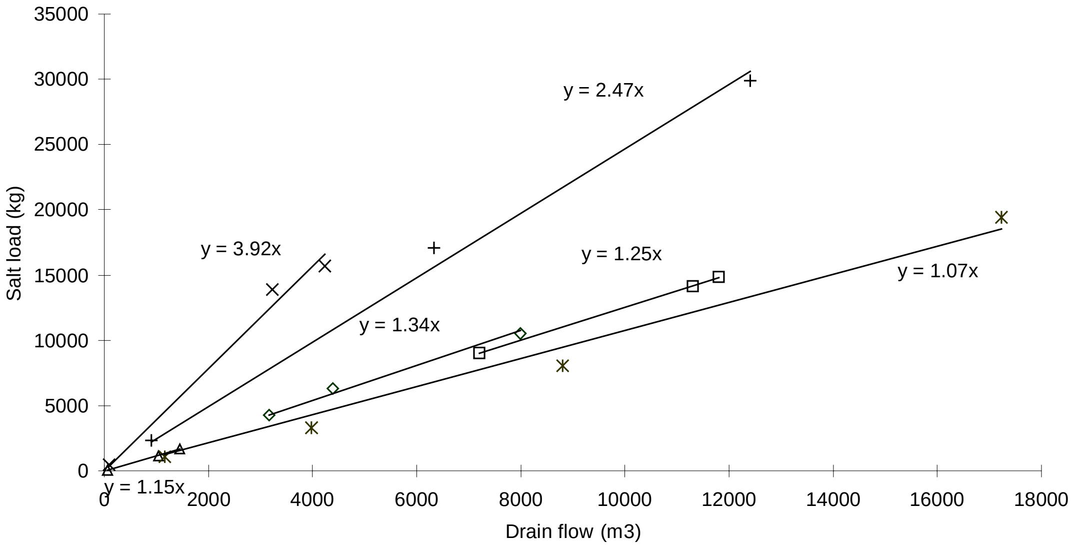

Figure 5-20. Salt load-flow relationships for individual farms

The linear relationship of these load-flow relationships indicates that these farms are not in the initial leaching phase, where there would be a non-linear relationship between flow and salt load because the drainage water salinity would change markedly between high and low flows. However, the load-flow relationship will change over time as salts are leached from the profile, as this occurs the slope of the load-flow relationship will reduce. Figure 5-20 shows the decline in salinity of drainage water from four farms in the MIA over time. The initial decline is quite rapid and then flattens off. Eventually an equilibrium may be reached whereby the salinity of the drainage water reflects only the salt inputs to the system from irrigation, the leaching fraction. In this example, farm 77 drainage salinity has declined to about 2dS/m which would be representative of a 5-10% leaching fraction with 0.12 dS/m irrigation water. Thus this system has been fully leached and is in equilibrium with irrigation water. There is little scope in this situation for reducing the overall salt load except by attempting to store salt below the rootzone or by encouraging deeper flow past the drains if possible. Farm 513 may still be in a leaching phase, or the latest salinity measurement may be the equilibrium drain water salinity, further significant leaching after 23 years of drainage is unlikely. In the leaching situation, which is the initial phase for all drainage systems, there is an opportunity to reduce the salt load by preventing removal of salt stored deeper in the profile. Salt leaching from the root zone is necessary but removal of salt from deep in the profile and even below drain depth is unnecessary. This removal can be reduced by improved irrigation water management which reduces water moving past the root zone and also by management of the drainage system to prevent drainage once water tables have fallen to a safe level.

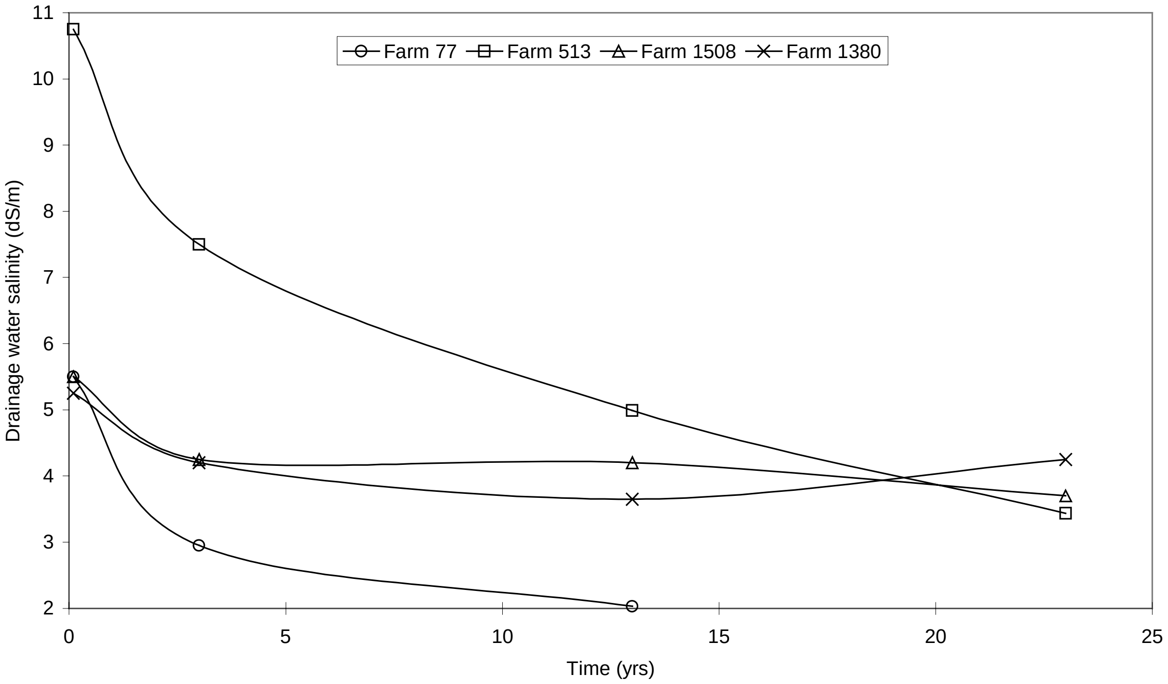

Figure 5-21. Drain water salinity reduction over time, data from Hoey (undated) and 1991/92 survey

Farms 1380 and 1508 appear to have had relatively stable drain water salinities after only a small initial drop after drain installation. The drain water salinity is around 4 dS/m, if this salinity were due only to irrigation water applied (0.12 dS/m) then this would represent a leaching fraction of only 3%. For farm 1508 this appears feasible from recent drainage records, however for farm 1380 drainage records show a leaching fraction more in the order of 12-20%. This scale of leaching fraction should result in drain water salinity in the order of 1 dS/m if only salt from the applied irrigation water is considered. Since the drainage water salinity is around 4 dS/m the source of salt must be in the soil profile, however the salinity has been relatively static for quite a considerable time indicating that continued leaching of the soil around the drains is not occurring. The relatively high drainflow and drain water salinity shows that on this farm there must be an outside influence on the drainage system generating these flows and salinities. In this case changes in on-farm irrigation water management may not have a significant effect on the drainage salt load. To reduce the salt load in this situation will require management of the drainage system. The drainage system management needs to try and maintain the water level above the drains at a high enough level to suppress the regional influences. This could be done using a weir structure or by changing the height to which the water table is managed. As the root zone must still be protected there may be a limit in this situation to the level of drainage salt load reduction possible.

As the load-flow relationships are in general linear, reducing water movement past the root zone to only that amount needed for leaching would be the easiest first step in reducing the salt load from these farms. However, irrigation system management can also affect the load-flow relationship. Changing from surface irrigation to drip systems with high uniformity and low deep percolation losses, if managed correctly, will change the flow paths to the drains, which might result in changes to the drain water quality depending upon the distribution of salt in the soil profile.

5.6.3 Conclusions from on-farm monitoring to reduce salt loads from drainage

- Subsurface drainage flow can be reduced by improved irrigation management. Improved irrigation management is important when irrigation management is poor but there are diminishing returns in terms of drainage reduction when irrigation management is of a reasonable standard.

- Seasonal impacts on drainage are important, irrigation management is significantly more critical to reduce drainage flow during wet seasons than in dry seasons.

- Regional effects can contribute significantly to drainage flow. Site selection should avoid areas where there is likely to be significant outside influences on the drainage system. System design and management by keeping drains above regional water table levels or controlling drain flow can be used to reduce the impact of regional influences. With new developments installing subsurface drainage there should be an aim to continue this general trend of not intercepting large flows from the regional groundwater by careful site selection and drainage design. This will enable the farmer to have control over the volume and quality of the subsurface drainage, which would not be possible if there were large inputs of regional flow to the drainage system.

- Drainage water salinity increases with the depth of drainage. To avoid highly saline drainage shallower drainage systems are preferable. Drainage system management to avoid draining areas deeply can be used to reduce the impact of deep water flow paths to drains that move through the most saline parts of the soil profile.

- The depth of drainage increases with drain spacing (unless there are shallow limiting layers of low permeability) which will increase the depth of water flow paths and hence drainage salinity. To reduce the depth of flow paths to drains the drain spacings should be reduced as far as possible.

- The salt load from most existing drainage systems in the MIA are linearly related to the drainage flow. So, the first step to reducing drainage loads is to reduce the volume of drainage, manipulation of the drainage quality from a particular drainage system is not possible. The volume of drainage can be reduced by improved on-farm irrigation management and by reducing regional effects on drain flow by using shallower drains and avoiding pumping water levels down below the minimum level necessary to protect the root zone.

These results were published in:
Christen, E. and Moll, J. (1996) *Drainage systems for new vineyards on heavy clay soils.* Farmers' Newsletter, No. 180 Horticulture, p6-7, September. 1996

Christen E. (1998). *Subsurface drainage* - Information paper to the NSW Rural Assistance Authority for use in educating loans administrators on the purpose of subsurface drainage and good drainage practices.

Lets talk water and drainage field day	Griffith. 4/96.
Lets Talk Water 1998 field days	Griffith, 6th May & 13th May 1998

6 TESTING DRAIN DESIGN AND MANAGEMENT STRATEGIES

The design and management factors and strategies discussed in the previous section to reduce drainage salt loads were tested with farmer involvement by using a case study vineyard and a replicated field trial in a vineyard.

6.1 Imposing irrigation and drainage management changes on a vineyard

The case study vineyard

A 50 ha vineyard on clay soil using flood irrigation on 400 m rows was experiencing difficulty in controlling water tables, and the large amounts of saline (13 dS/m) subsurface drainage were causing concern. The irrigation method was by broad-based furrows that wetted the entire floor area of the vineyard. Irrigations were scheduled by the farmer using “gut feeling”. The two main problems associated with this method were:

1. The vines were watered too frequently
2. The irrigation was not even, the tops and bottoms of rows getting far too much water

There was no management of the tile drainage system, the pump was left to run all the time to maintain the watertable at tile drain level (2 m).

6.1.1 Methodology

Monitoring of the irrigation applied, tile drainage and water tables was intensively undertaken during the period January to May for the 1997 season and then for the 1998 season when the management changes were made. The management changes are outlined below.

6.1.2 Improved irrigation and drainage management changes

Irrigation system:

The old system of flooding the whole area between the vines was replaced by narrow furrows either side of the vine “Riverina Twin Furrow”.

Irrigation management:

Blocks of tensiometers were installed in each variety in the vine row. Three tensiometers were installed at each block: 0.3m deep, 0.6m deep and 0.9m deep. The tensiometers were monitored leading up to irrigation and directly after. Around flowering the profile was kept quite moist around 10kPa, then between fruit set and harvest was allowed to dry to 80 kPa but no further, as recommended by Hardie and Martin (1993) see table at end of section.

Drainage management:

The tile drainage pump was carefully managed throughout the season. During irrigations the pump was turned off and also when the water level in the sump fell below 1.2m. The water table on a vineyard with clay soil needs to be kept below the root zone but does not need to be very deep. In this vineyard, as in many others, most roots were in the top 0.9m and so keeping the water table below 1.2m in the pump sump was safe. As the pump sump was the lowest point in the farm the water tables around the farm were in fact much deeper than the sump level.

6.1.3 Results

The results from the changes to the irrigation and drainage management are given below:

6.1.3.1 The irrigation system:

The main effect of changing the irrigation system was that only about one third of the vineyard soil was wetted, compared to wetting the whole vineyard area with the old wide furrows. The wetted strip with the Riverina Twin Furrows was only about 0.6m either side of the vine row, leaving the middle 2.4m of row dry. Also, the water reached the end of the rows much more rapidly down the narrow furrows than with the old wide furrows, reaching the end in about half the time, or with extra siphons about one third the time, Table 6-1.

6.1.3.2 The irrigation management:

The main effect of the irrigation management change was to increase the irrigation interval by about 6 days, from 11 to 17 days in peak season. This required that the vines start using water in the last third of the root zone, between 60 and 90cm. Previously, the vines would only have been using water in the top two thirds of the root zone, down to 60cm, never using moisture from below 60cm. As a result the soil moisture tension was increasing to 80kPa at 30 and 60cm and to about 40 kPa at 90cm, Figure 6-1.

Table 6-1 Effect of furrow size and siphons on time for water to reach end of 400m row

Furrow used	Number of siphons 25mm	Time to end of row Hours
Broad base	2	15-18
Riverina Twin Furrow	2	8-10
Riverina Twin Furrow	4	6

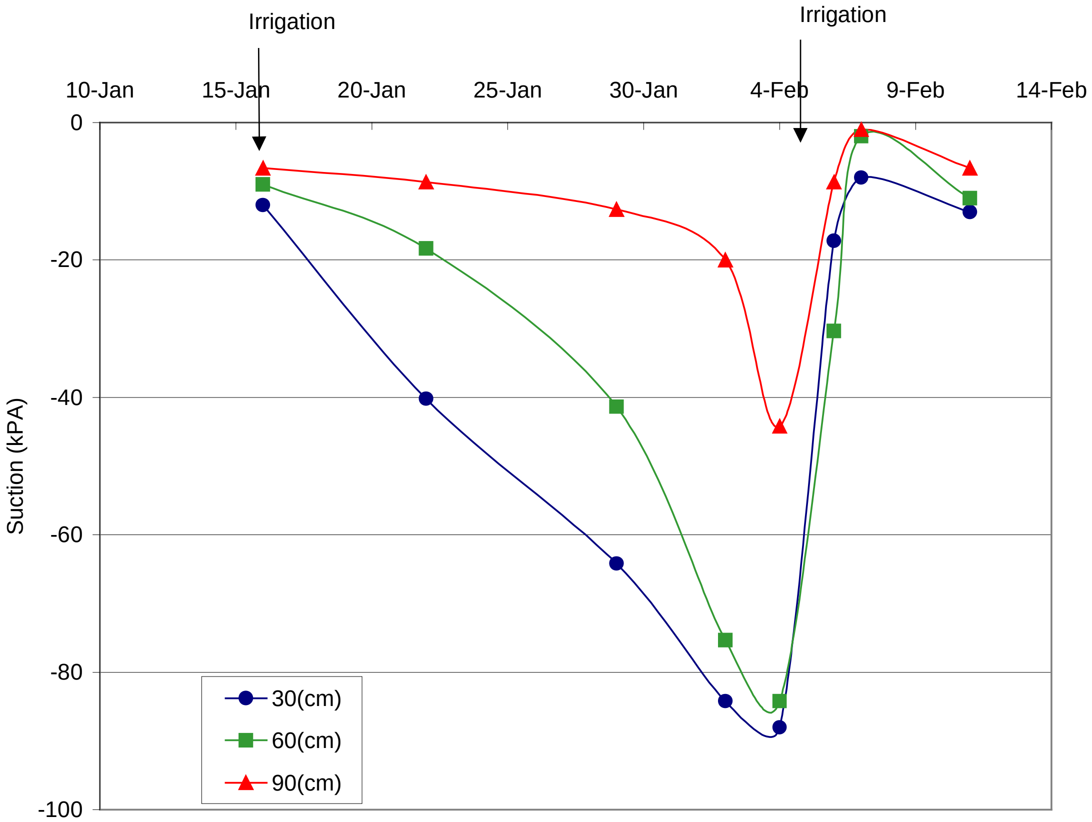

Figure 6-1 Tensiometer readings before and after an irrigation

6.1.3.3 The tile drainage management:

The main result of the changes to the tile drainage pump management was that the pump was off more than it was on. Early in the season the water tables were high and so the pump was switched on, but as the vines grew and started to use more water the pump was not needed even after irrigation. In fact the water tables were drawn quite quickly even without the pump being on. The water tables hydrograph is shown in Figure 6.2. Note that the water level in the pump sump also shown in Figure 6-2, is always higher than the water tables in the farm and so was quite safe to use for control purposes.

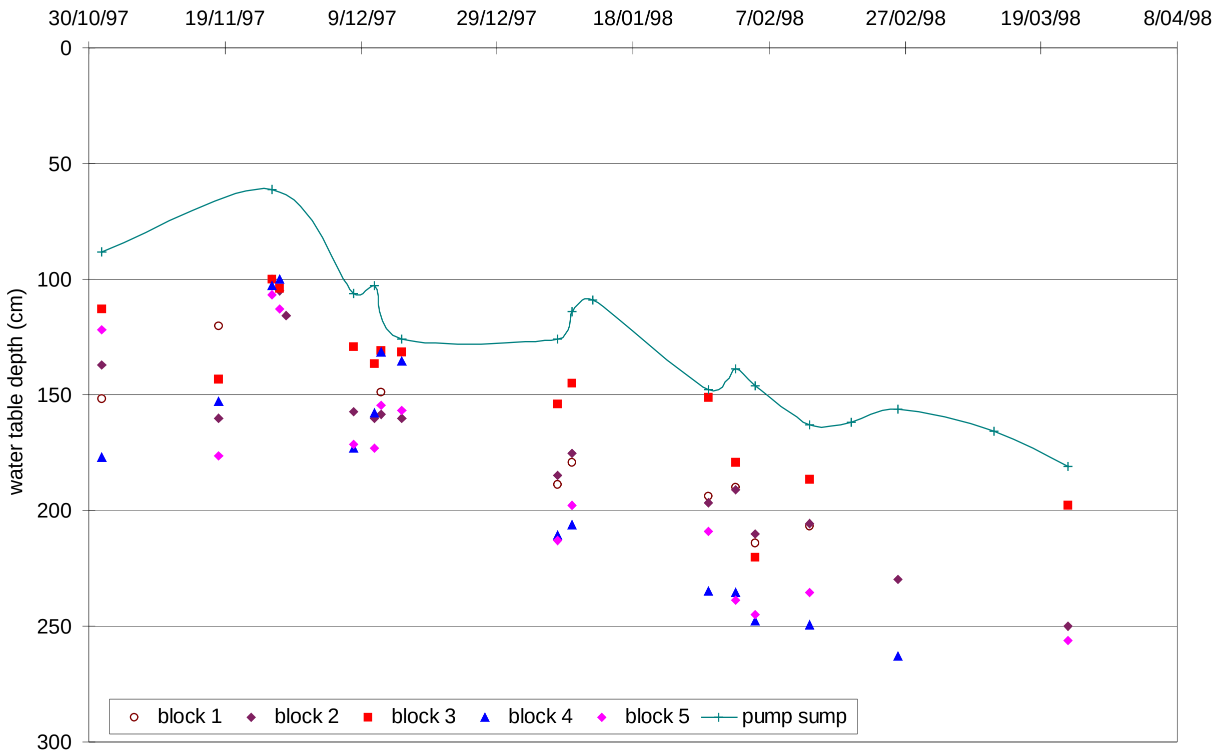

Figure 6-2 Water tables with improved irrigation management

6.1.4 Summary of the results of improving the irrigation and drainage management

When comparing the two seasons it was found that there were some key differences, these are summarised in Table 6-2. The two periods that were monitored were similar in terms of crop water requirement, although there was more rain in the season with improved management. The results show that the total irrigation applied was reduced by about 33%. This was achieved mainly by increasing the irrigation interval by 54% in the peak season and improving the irrigation practice by using Riverina Twin Furrows and getting the water to the end of the row quickly.

The improved irrigation practice resulted in a large overall improvement in the water use efficiency. Matching the irrigations to the crop water requirement better and also making better use of rainfall achieved this. With the improved management there was about 10% extra water applied above crop requirements which allowed a little for leaching of salt. By reducing the water applied to the vineyard the amount of salt brought into the vineyard in the irrigation water was also reduced, by 40%.

By improving the drainage management whilst improving the irrigation management the total amount of drainage from the vineyard was reduced by 88 %. The reduced use of the drainage pump also meant that the amount of salt removed by the drainage system was only 3 times more than that brought in by the irrigation water, previously the system removed 15 times more salt than was brought in, an 80% reduction.

Table 6-2. Summary of changes caused by improved irrigation and tile drainage management

Factors	Management		Change
	Previous	Improved	
SEASONAL			
Monitoring - January to May (days)	150	150	
Potential Evapotranspiration (mm)	951	887	
Rainfall (mm)	93	132	
Crop water use (mm)	481	443	
IRRIGATIONS			
Irrigation applied total (mm)	590	354	Down 33 %
Amount per irrigation (mm)	56	66	Up 18 %
Irrigation interval (days)	11	17	Up 54 %
Irrigation compared to requirement (irrig. Applied / crop requirement)	23 % too much	20% too little	Down 43 %
Water use efficiency (irrig. + rainfall / crop requirement)	42 % too much	10 % too much	Up 32 %
TILE DRAINAGE			
Water table depth (m)	1 - 1.8	1.5 - 2.3	Down 30 %
Tile Drainage (mm)	73	9	Down 88 %
Salt removed by tile drainage (kg/ha)	6655	711	Down 89 %
Salt applied by irrigation (kg/ha)	453	272	Down 40%
Salt removed by tile drainage compared to salt brought in	15 times more	3 times more	Down 80%

Table 6-3 A strategy for vine growth regulation by soil water management, after Hardie and Martin, 1993

Development phase	Soil water status
Budburst – flowering	Winter and spring rain is usually predominant. Maintain soil water tension below 30 kPa. Avoid waterlogging
Flowering – fruit set	Maintain soil water tension at 10 kPa throughout the root zone.
Fruit set – veraison	Allow root zone soil water tension to increase to a Maximum of 80 kPa (i.e. the limit of the tensiometer range). If irrigation is necessary wet no more than 25 % of the root zone to 10 kPa.
Veraison – harvest	If irrigation water is readily available, maintain soil water tension at 80 kPa. If water is scarce, allow root zone water tension to increase to a maximum of 200 kPa. (Instrumentation additional to tensiometers needed).
Harvest – leaf fall	Autumn rain is usually predominant. Avoid root zone soil water tension greater than 200 kPa
Dormancy	Winter rain is usually predominant. Avoid root zone soil water tension greater than 200 kPa. If root zone soil water tension is greater than 30 kPa shortly before bud burst, thoroughly wet the root zone to 10 kPa. Avoid waterlogging

Hardie, W.J. and Martin, S.R. (1993) Proceedings of Seventh Australian Wine Industry Technical Conference, p51-57.

These results were published in:

'A Case study of improving irrigation and tile drainage management in a vineyard' Soil moisture monitoring for quality winegrapes, April 29th, NSW Ag. Griffith

Christen, E. and Skehan, D. (2000) *A case study of improving irrigation and tile drainage management in a vineyard* Irrigation 2000, Conference of the IAA, Melbourne May 2000

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6.2 Drainage design and management field trial

6.2.1 Methods

The drainage design and management strategies were also tested in a replicated field trial on a vineyard in the MIA. The new design and management strategies were tested against current design and management practice, and a no drainage scenario. These are summarised in Table 6-4.

Measurements were taken over three years from 1996 to the end of the 1998 season, this period included three irrigation seasons. Measurement on individual drainage treatments involved; irrigation and rainfall, run-off, drain flow, drainage salinity, water table depth, and soil salinity.

Table 6-4 Drainage treatment summary

Treatment No.	**1**	**2**	**3**	**4**
Treatment name	**Deep Drains**	**Shallow Drains**	**Managed Deep Drains**	**Undrained**
Drain type	slotted PVC pipe	Unlined soil channel (mole)	slotted PVC pipe	none
Depth (m)	1.8	0.7	1.8	
Diameter (mm)	100	65	100	
Spacing (m)	20	3.65	20	
Length (m)	70	70	70	
Management	unrestricted flow	unrestricted flow	flow only when water table is above 1.2m, and not during irrigation events	

6.2.2 Results and discussion

The different drainage treatments resulted in markedly different drainage volumes and salinities, and hence salt loads, Table 6-5. The differences in flow resulted from the drain position in the soil profile and the management of the drains. The Deep Drains flowed continuously for the irrigation seasons, a small saline flow being sustained between irrigations and a large flow during and just after irrigation, Figure 6-3. The Deep Drains continued to flow long after an irrigation had ceased because they were draining a larger soil volume, down to 1.6-1.8 m, and they were influenced by regional groundwater pressures. This was despite the area having no significant shallow aquifer systems and being in a fairly flat area so that hydraulic gradients from neighbouring farms and channels were small. That there were some regional effects was demonstrated by the rise in piezometric levels at the beginning of the irrigation season in the experimental area before any irrigations had been applied. The Managed Deep Drains were less influenced by these regional effects and the Shallow Drains were completely isolated from them.

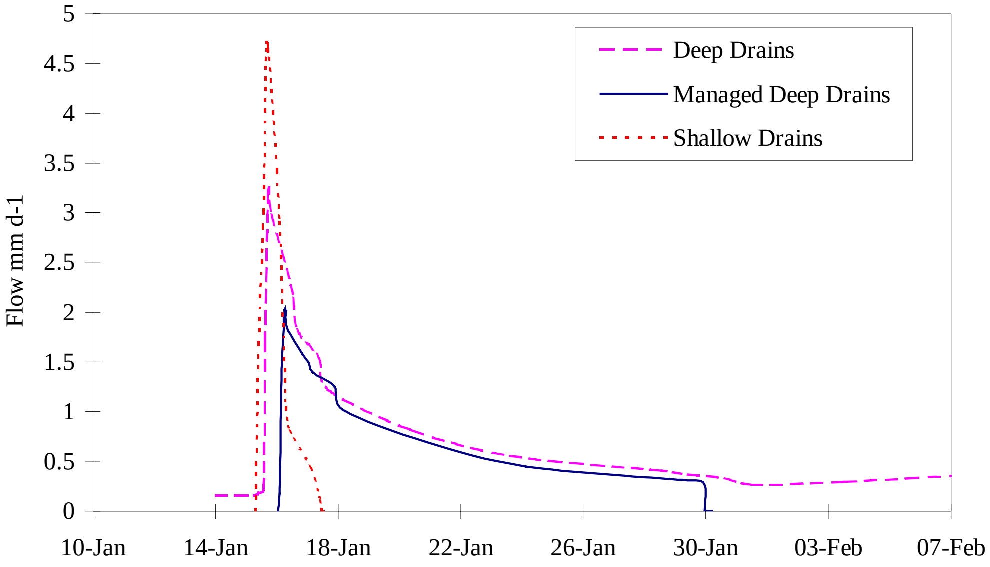

Figure 6-3 Drainage treatment hydrographs during and after an irrigation

The Deep Drains removed the most water and at the highest salinity, about 11dS m^{-1}, and hence had the highest salt load, Table 6-5. The Managed Deep Drains had 33 % less flow than the Deep Drains at a lower salinity, 7–8 dS m^{-1}, resulting in a 49 % reduction in salt load. The Shallow Drains removed 78 % less water than the Deep Drains at a significantly lower salinity, about 2 dS m^{-1}, resulting in a 95 % reduction in salt load. The large amounts of water removed by the Deep Drains leads to reduced overall water use efficiency and increased farm costs in terms of increased pumping and nutrient loss. The extra salt removed by the Deep Drains compared to the Shallow Drains and even the Managed Deep Drains doesn't have a negative impact on the drained area but will adversely affect the receiving waters. If in the future farmers are charged for the amount of salt they export off farm then this extra salt export will have a negative effect upon farm income. Where farms are denied the option of off farm disposal of drainage water, then the use of shallower drains will be advantageous in reducing the overall volume requiring disposal and also the lower salinity of the drainage water will leave more options open for reuse.

Table 6-5 Drainage treatment salinity

Drainage Treatment	Drainage Volume (mm)	Average Drainage Salinity (dS/m)	Total Salt Load (kg/ha)
Deep Drains	70	11	5867
Managed Deep Drains	47	7 – 8	2978
Shallow Drains	15	2	319

Of the three drainage treatments tested only the Shallow Drains came close to a salt balance with the irrigation water, removing 0.7 of the salt applied in the irrigation water. This is actually a small accumulation of salt, but this was in absolute terms a very small amount 170 kg ha^{-1}, and was not accumulated in the root zone. The Deep Drains removed 11 times more salt than was applied, a large net leaching of salt. This leaching was not reflected in a large relation in soil salinity in the top 2 m, thus this salt was from below drain depth. This was somewhat reduced by the managed treatment which exported 5 times more than the salt applied, still a large net export. This shows that drains placed deep in the soil profile will export large quantities of salt over and above that applied in the irrigation water. Assessment of the drainage water salinity with depth of water table confirms this. When the water table was at one metre below the surface the drainage water salinity from the Deep Drains was around 8 dS m^{-1}; as the water table fell to 1.6 m below the surface the salinity increased to around 11 dS m^{-1}, Figure 6-4**.** This is consistent with the suggestion that deeper drainage intercepts deeper water flow paths that move through much more saline portions of the soil profile.

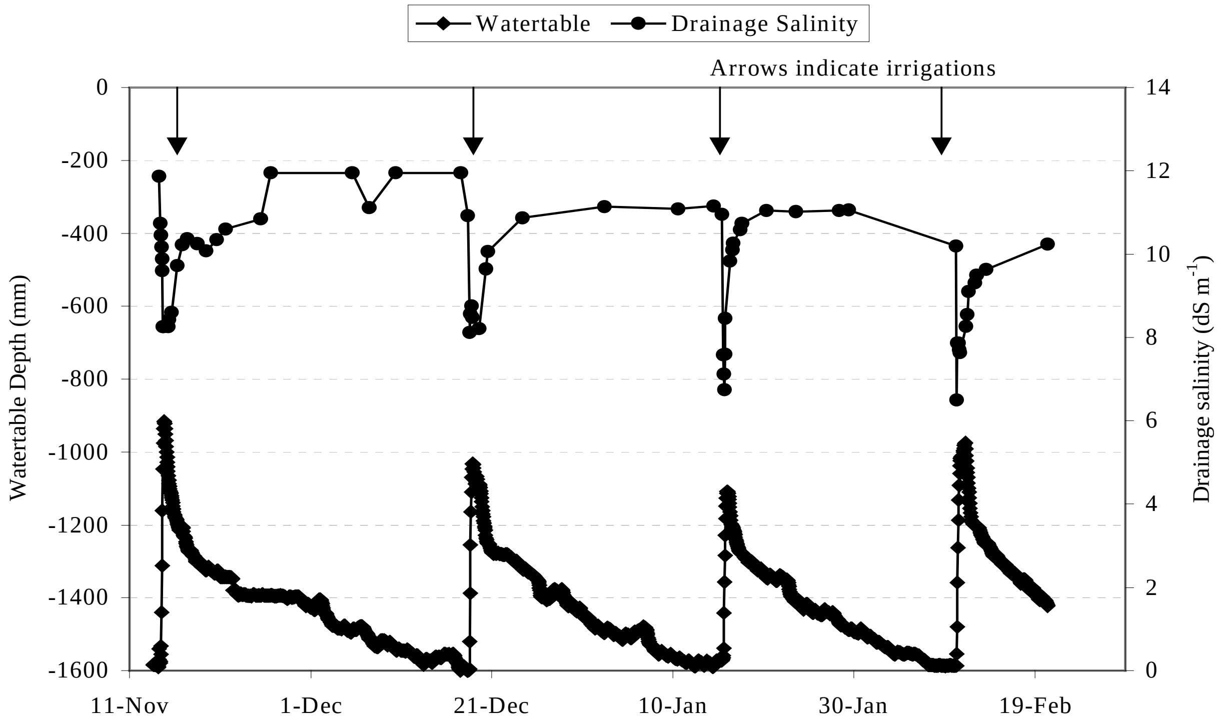

Figure 6-4 Drainage water salinity and watertable depth between drains

In terms of water table and waterlogging control the Deep Drains were adequate in reducing the periods of high water tables and waterlogging to a negligible amount, Table 6-6. The management changes used to control water flow from deep drains had only a small effect on waterlogging, about an extra day of waterlogging during the irrigation event itself. This minimal increase in waterlogging is a small trade off for the benefits of less water drained resulting in a greater water use efficiency, lower operating costs and improved downstream water quality. At this stage in the development of the vineyard this small increase in waterlogging had no effect on vine leaf chlorides or yield. The Shallow Drains as expected gave the best control of root zone waterlogging, the water table did build up beneath this treatment but was controlled at mole depth.

Table 6-6 Duration of water tables above specified depths

	Water table depth (mm)		
Treatment	**300**	**500**	**1000**
	Number of hours		
Deep Drains	70	86	156
Managed Deep Drains	26	60	207
Shallow Drains	13	27	64
Undrained	70	168	859
	Percentage of time		
Deep Drains	3	4	8
Managed Deep Drains	1	3	10
Shallow Drains	1	1	3
Undrained	3	8	42

These varying water table regimes resulted in some differences in the root zone soil salinity trends over the two seasons monitored, Figure 6-5 and Figure 6-6. The Undrained treatment soil salinity remained static, whereas all the drained treatments showed a decrease in salinity after the first season. In both the Shallow Drains and Managed Deep Drains there was a rise after the second season resulting in no net change. For the average salinity down to two metres this picture was similar except the Deep Drains showed a fall in salinity after both the first and second seasons. These results are somewhat unclear in terms of the possible effects of the different treatments on long-term soil salinities especially since the undrained treatment did not show any change in salinity over the experimental period. However, there is an important outcome from this analysis in that, the drainage treatments had only small effects on the root zone salinity, no measurable effect on vine health over the experimental period, but still drained water and salt from the area. So over this particular time the water drained, salt removed, costs incurred and downstream impacts of drainage water resulted in little benefit to the farm. Under these circumstances of small benefit from a drainage system, which can occur due to site factors, dry climatic conditions and plants not highly susceptible to waterlogging, it is even more important that the drainage system incurs the least downstream impacts and least costs to the farmer.

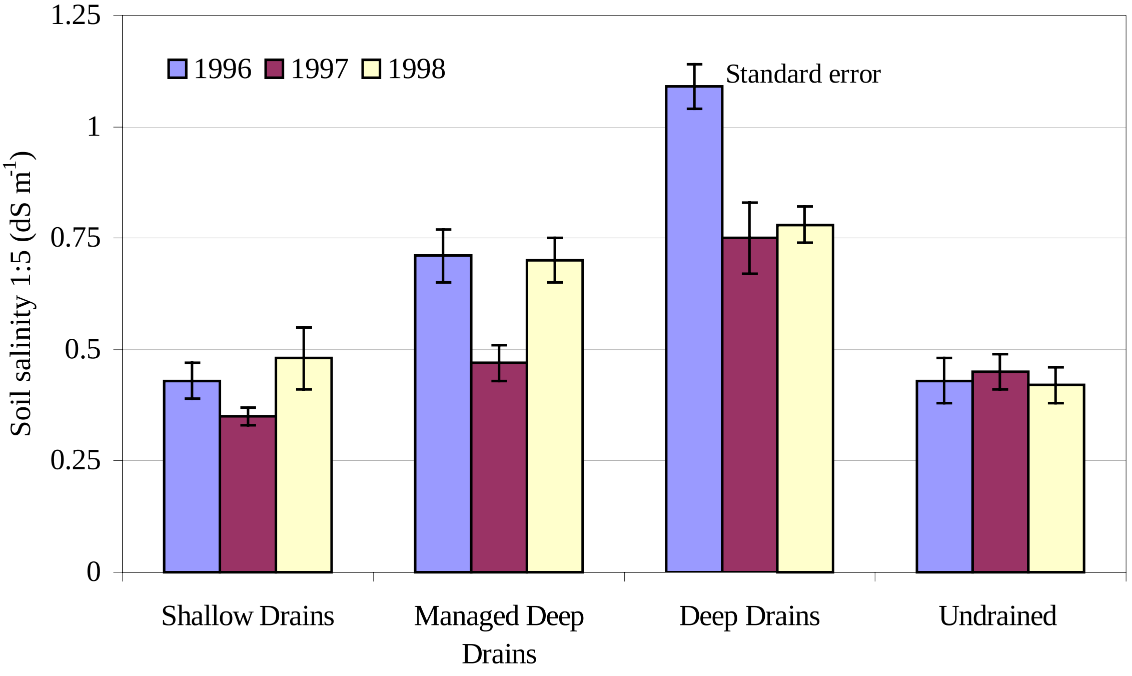

Figure 6-5 Change in salinity in the top 600 mm of soil

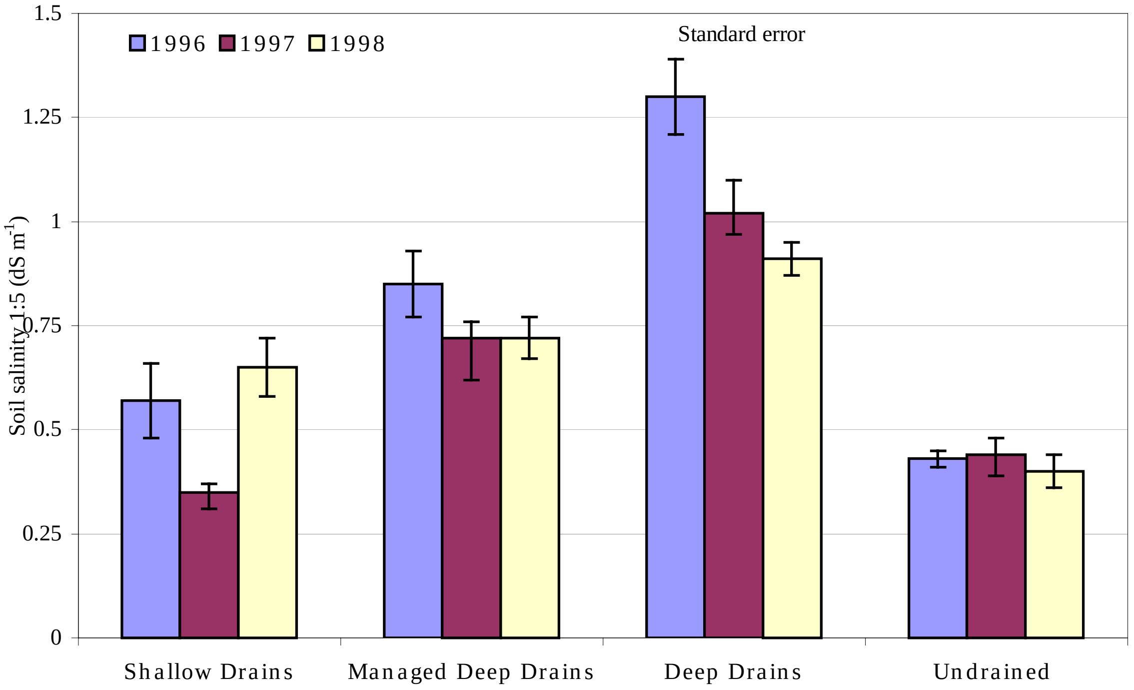

Figure 6-6 Change in salinity in the top 2000 mm of soil

6.2.3 Discussion

This field trial was conducted in a dryer than average year, the relatively low drainage flows and static soil salinities reflect this. During wetter conditions it is likely that the drainage water reduction would be greater than measured here and that there would be more soil leaching due to rainfall, both of which are positive. However, there may be negative effects due to the design and management suggested, such as increased waterlogging. These negative effects are unlikely to be great and with good management could be monitored and controlled. For instance if the water table was remaining high for too long on the Managed Deep Drains then the drainage depth could be increased to provide a greater soil buffer to store rainfall. The main negative effect of a prolonged wet period on the Shallow Drains would be an increased rate of collapse in the mole drains. At this site, the soil was quite stable and as such it is unlikely that the moles would collapse to the point of being ineffective within a single season. Obviously if a shallow pipe system was installed this would not be a concern.

Predicting the effects of wetter periods on the results of drainage design and management tested here is possible. The likely drain flow under wet conditions can be considered by analysing single high input irrigation events. Figure 6-7 and Figure 6-8 show the proportion of water applied that drained through the different drainage treatments at a particular event. During wet periods when the soil has a small storage capacity due to antecedent rainfall then a lot of the water applied that does not run off will be drained out, similar to irrigations 3 and 4 in Figure 6-7and the highest ranked drainage events in Figure 6-8. This gives an indication that under wet conditions it is likely that up to 25 % of water applied may be drained by a deep pipe drainage system, whether managed or not. The rate of drainage can be predicted by considering the drain hydrographs such as in Figure 6-3. The peak flow rates shown here are unlikely to be greatly exceeded, but the duration of the peak flows will be prolonged under wet conditions with high inputs of water. The effect of wetter conditions on drain water salinity can be considered using the drainage water salinity as a function of water table depth results. Since water tables are likely to be high during wet conditions the drain water salinity will be lower than dry periods when the water tables are deeper. The height and duration of water tables during wetter periods is harder to predict. Water table depth is a function of the time from the last recharge event, the drainage rate of the system and the combination of deep leakage and plant water use. If recharge events are larger and at shorter intervals then water tables will remain higher. Analysis of water table responses under a particular set of weather conditions can be undertaken using water balance models such as SWAGMAN Destiny (1996) and BASINMAN, Wu *et al.* (1999).

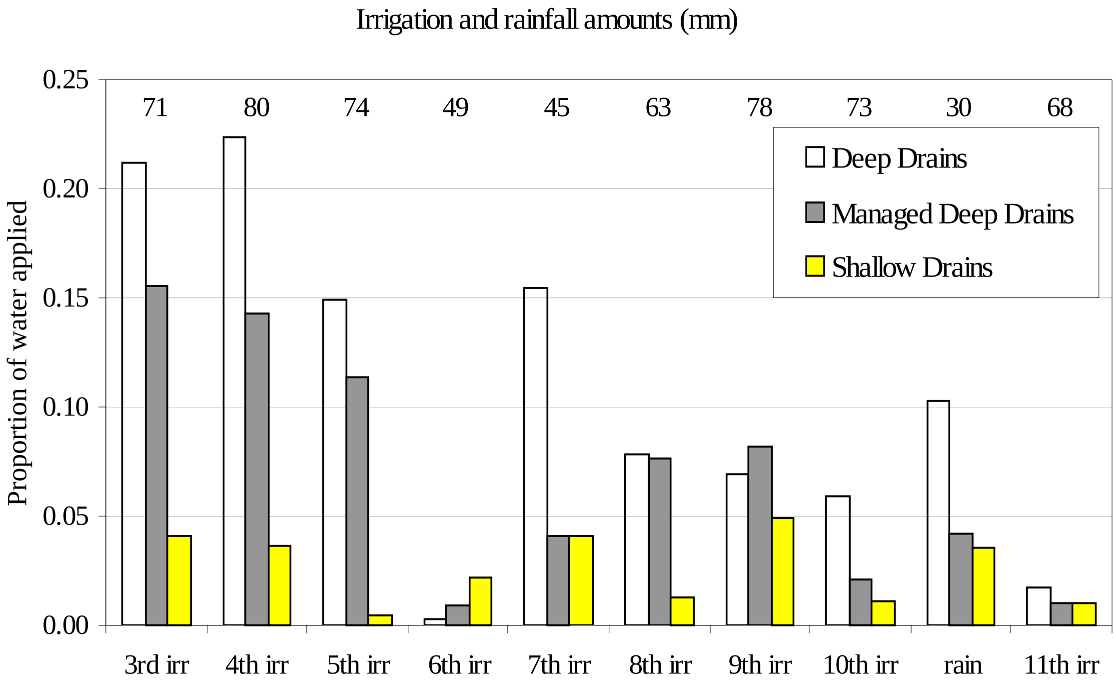

Figure 6-7 Drainage as a proportion of water applied at each event

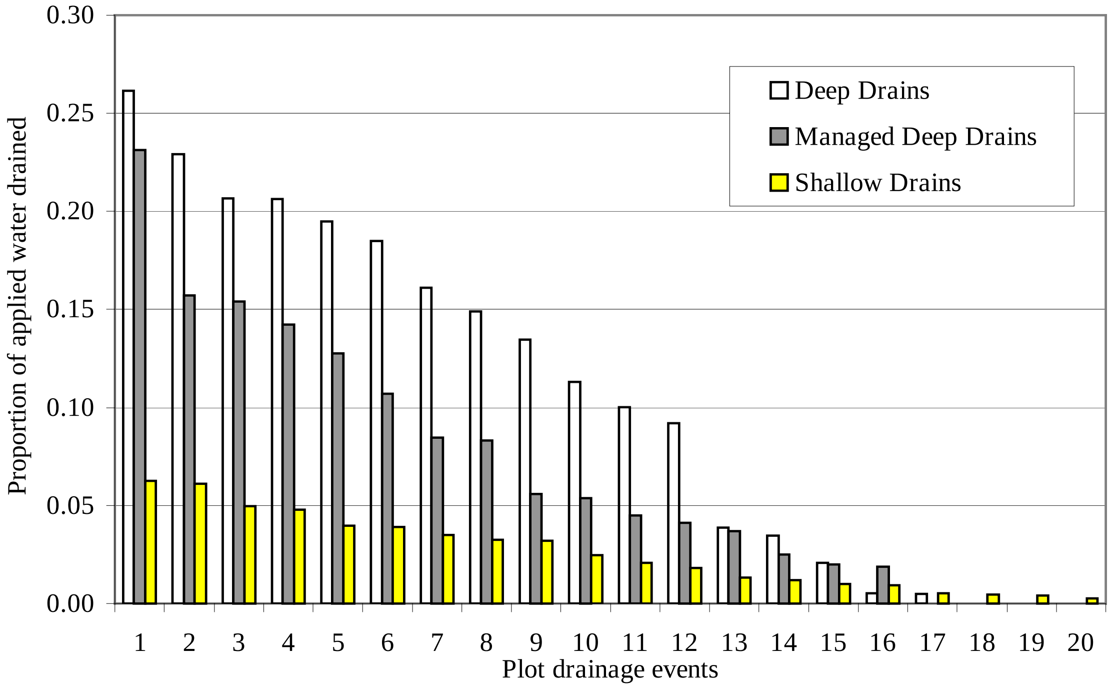

Figure 6-8 Water application and the proportion of water drained (individual plots)

In regard to minimising costs of a drainage system the Shallow Drain system of mole drains would cost about \$800 ha^{-1} for the collector mains and mole drain installation, whereas the pipe drains, installed 20 m apart to achieve an adequate degree of waterlogging control, would cost about \$2700 ha^{-1}. Thus a shallow drain system consisting of mole drains provides a much cheaper system of drainage as well as reducing the disposal problem of the drainage water. An indication of the impact of a drainage system on water use efficiency and hence total water costs is shown by the Deep Drains that drained 20 % or more of the water applied in 23 % of plot drainage events and drained 10 % or more in 65 % of plot drainage events. This is a considerable proportion of the water applied that was intended for use by the plant. Management of deep drains cut the proportion of plot drainage events draining more than 10 % of water applied to 37 % and events draining more than 20 % to 6 %. This is a significant improvement but does not match the Shallow Drains, which drained less than 5 % of the water applied in 90 % of plot drainage events.

6.3 Conclusions

Drainage systems for irrigated areas on clay soils in south eastern Australia can be designed and managed better than the currently accepted practices, so that detrimental downstream environmental effects due to excessive salt export are reduced, without affecting the productivity of the farm.

Changing drainage design from deep widely spaced drains to shallow closely spaced drains:

- Shallow drains remove less irrigation water than deep drains, thus reducing irrigation losses.
- Shallow drains have low drainage water salinity and remove smaller drainage volumes, thus reducing the salt load, with up to 95 % reduction compared to deep drains in this trial.
- Shallow drains control waterlogging better than deep drains.
- The cost of a shallow mole drainage system can be about 75 % less than deep pipe drainage (to provide similar waterlogging control)

Deep drains can take up to 32 years to leach all the salt from their capture zone and reach an equilibrium with irrigation water, whereas shallow drains can reach close to equilibrium within two irrigation seasons.

Managing deep drains by preventing discharge during irrigation and whenever the water table was below 1.2 m deep:

- Managed deep drains reduce irrigation water losses compared to unmanaged deep drains.
- Managing drains reduces flow and drainage water salinity compared to unmanaged drainage, resulting in a reduction in drainage salt load of 50 % in this trial.
- A more rapid decline in drainage water salinity can be achieved by managing deep drains.

A deep pipe irrigation system, without major groundwater inflow from surrounding areas, only needs to be run for 2 to 7 days after an irrigation to control the water table below the root zone and then can be switched off.

These results have been published by:

Christen, E. and Moll, J. (1996) *Drainage systems for new vineyards on heavy clay soils.* Farmers' Newsletter, No. 180 Horticulture, p6-7, September. 1996

Christen, E. and Skehan, D. (1998). *Subsurface drainage design and management trial to reduce salt loads from semi arid irrigation areas.* Technical report 6/99, February 1999. CSIRO Land and Water, Griffith.

Christen, E., Skehan D. and Enever, D. (2000) *Subsurface drainage design and management to reduce salt loads from irrigation areas in southeastern Australia* USCID International Conference Colorado, June 20-24, 2000. (In Press)

Skehan, D and Christen, E.W. (2000) Leave salt in the ground: improved subsurface drainage design and management. *Farmers' Newsletter, Horticulture*, June 2000. (In Press)

Lets talk water and drainage field day	Griffith.	4/96
Lets Talk Water 1998 field days	Griffith, 6th May & 13th May 1998	

7 CONCLUSIONS, GUIDELINES AND RECOMMENDATIONS

7.1 Conclusions

7.1.1 Irrigation management

The primary and most effective method of drainage reduction is by improved irrigation management:

- A high level of water management that minimises drainage can be achieved with surface irrigation, but is unlikely to reach the level of control found under well managed drip irrigation.

- Financial analysis clearly indicates that the most cost effective method of reducing off site drainage impacts is by improved irrigation water management.

Increasing control of irrigation water makes sense economically and environmentally, however there will always be a need for an appropriate amount of drainage as a leaching fraction to ensure salinity in the root zone is controlled. This may be provided by natural drainage or a subsurface drainage system.

7.1.2 Drainage system design and management

Drainage systems for irrigated vineyards and other crops on clay soils in the Riverine plain of south eastern Australia can be designed and managed better than the currently accepted practices, so that detrimental downstream environmental effects due to excessive salt export are reduced, without affecting the productivity of the farm.

This can be achieved by:

1. *Changing drainage design from deep widely spaced drains to shallow closely spaced drains*:

- Shallow drains remove less irrigation water than deep drains, thus reducing irrigation losses.
- Shallow drains have low drainage water salinity and remove smaller drainage volumes, thus reducing salt load.
- Regional water tables have less effect on shallow drains than deep drains thus reducing drainage salt loads
- In clay soils waterlogging is better controlled by shallow rather than deep drains.
- The cost of a shallow mole drainage system can be about 75 % less than deep pipe drainage (to provide similar waterlogging control)
- Deep drains can take decades to leach all the salt from their capture zone and reach an equilibrium with irrigation water, whereas shallow drains can reach close to equilibrium within a few years.

2. *Managing deep drains by preventing discharge during irrigation and whenever the water table is at a safe depth below the root zone (about 1.2 m for clay soils):*

- Managed deep drains reduce irrigation water losses compared to unmanaged deep drains.
- Managing drains reduces flow and drainage water salinity compared to unmanaged drainage, resulting in a reduction in the drainage salt load.
- A more rapid decline in drainage water salinity can be achieved by managing deep drains in a newly installed drainage system.
- Drainage systems, without major groundwater inflow from surrounding areas, need only be operated intermittently, for short periods after irrigation or rainfall.

7.1.3 Water quantity and quality targets

From the previous sections we can see that by improved irrigation management and changes to the design and management of subsurface drainage systems there is a broad scope for the reduction in salt load from subsurface drainage in the MIA.

Water quantity

Setting drainage water quantity targets is not straightforward. The minimum drainage required past the root zone, is the minimum leaching fraction that will ensure that the root zone soil salinity does not affect crop performance. In the MIA this will be 5 – 10% for grapevines and citrus. Thus the leaching fraction will depend upon the irrigation amount. For citrus in the MIA an average reasonable irrigation amount depending upon system and variety/planting is 6-8 Ml/ha, resulting in a required leaching requirement of 0.3 – 0.8 Ml/ha. For grapevines a reasonable irrigation amount depending upon system and variety would be 3 – 5 Ml/ha, resulting in a leaching requirement of 0.15 – 0.5 ML/ha.

However, subsurface drainage in perennial crops such as these is not merely for salinity control but more importantly for waterlogging control. The degree of waterlogging control required will depend upon the irrigation management and rainfall. Using the very best irrigation management very little water should percolate past the rootzone and thus waterlogging will be minimal. Thus drainage for waterlogging should only be required as a result of rainfall. The amount of drainage required due to rainfall will depend upon the distribution of the rainfall and the irrigation system and management. With drip irrigated systems or those using Riverina Twin Furrow much rainfall can be stored in the dry soil between the wetted areas under the crop rows. With a flood irrigated system there is little opportunity for soil storage so more drainage will result from rainfall.

These issues make it impossible to set upper limits on the volume of drainage that should be generated. However, it is safe to state that negligible drainage should occur due to application of irrigation water. Thus drainage should generally only occur after rainfall. It is not necessary in the MIA environment to have leaching associated with each irrigation event as there is adequate periodic rainfall to ensure that rootzones are leached of salts accumulated due to irrigation.

Thus it is only possible to state that drainage should be minimal between rainfall events.

Water quality

The quality of subsurface drainage water in terms of dissolved salts is largely a function of the historic salinity at the site. Thus in areas of high soil and groundwater salinity the drainage water quality will be poor. The drain water quality will generally improve with time as these salts are leached from the system. However, in some areas the drainage system may be influenced by groundwater inflows from elsewhere and as such this improvement in quality may be negligible

In the MIA subsurface drain water quality is likely to stabilise at 1 –2 dS/m when all historic salt is leached from the area.

Setting water quality targets for salts on a regional basis is not possible due to differences in the historic groundwater and soil salinity between sites. This research has shown that shallow drainage is the best tool for reducing drain water salinity. In existing systems this requires managing the drainage system to not drain as deeply and in new systems using shallower drainage. Thus although it is not possible to set specific water quality targets it should be stated that all drainage systems should be appropriately managed. This will minimise mobilisation of stored salts. For new subsurface drainage systems use of shallower drains should be encouraged. However, this will be more costly and at present there is no incentive (direct or indirect) to adopt such systems.

Guidelines and disposal

Due to these difficulties in setting absolute targets the guidelines developed in this project are the best mechanism for reducing salt loads. The overall outcome however relies upon continued improvements in irrigation management as well as these guidelines.

In the MIA new drainage systems outside the ‘gazetted’ horticultural areas must use evaporation basins to dispose of saline drainage water. This is an alternative mechanism to improve overall drainage water quality in the area. However, as a basin restricts the volume of disposal good irrigation and drainage system management is essential.

7.2 Guidelines for subsurface drainage design and management for improved drain water quality

7.2.1 Introduction

For the Riverine plain of southeastern Australia there is a need to consider drainage design and management with regard to water quality considerations. This requires that drainage designs include criteria that minimise salt mobilisation from outside the root zone and make management of the drainage system possible in order to manipulate the quantity and quality of drain discharge. This requires an approach that considers the design and management of the drainage system as an integral part of irrigation management. This approach also needs to always consider the potential for salt leaching and thus drainage disposal with any new drainage system.

7.2.2 Aim of the guidelines

To reduce subsurface drainage quantity and salinity from irrigated agriculture in the Riverine plain, to meet increasing disposal constraints.

7.2.3 Background

Research in the Riverine plain has shown that in general terms the following are true:

1. Deep drains (traditional tile or pipe systems about 2m deep and 20-40m apart):
    - Have high drainage volumes and salinity
    - Can unnecessarily extract large quantities of salt from the soil below the root zone
    - Can drain large volumes of water from sources outside the farm

2. Shallow closely spaced drains:
    - Drain less water at lower salinity than deep widely spaced drains
    - Have lower potential salt mobilisation than deep widely spaced drains
    - Are less likely to be affected by water sources from outside the farm area
    - Give the best waterlogging control in clay soils

3. By managing deep drains it is possible to:
    - Reduce drainage volume and salinity
    - Still control waterlogging and root zone salinity adequately

7.2.4 Guidelines for improving subsurface drainage design and management in the Riverine Plain

1. *New drainage systems should consider the potential for salt mobilisation:*

    - Avoid sites where large volumes of drainage may occur from outside sources
    - Install drains as shallow as possible
    - Design drainage systems into management units
    - Install drainage control structures to manipulate water tables
    - Main drains and sumps which are installed at depth should be sealed to prevent entry of saline water

2. *Existing drainage systems:*

    - Should where necessary, and possible, be divided into several management units
    - Should have water table management control structures installed where necessary

3. *Management of drainage systems:*

    - Drainage systems should be prevented from discharging during irrigation
    - Drainage systems should be controlled to maintain water tables safely below the root zone, not left to drain uncontrolled where water tables may fall much deeper than necessary.
    - Drainage systems should normally be kept closed or turned off and then turned on as needed, rather than being left running at all times without consideration whether the drainage is necessary

These results were published in:

Christen, E. and Skehan, D. (1999) *Reducing subsurface drainage salt loads: development of drainage design and management guidelines.* In: Murray Darling Basin Groundwater Workshop 1999, September 14-16,Griffith, NSW. p138-145

Christen, E., Skehan D. and Enever, D. (2000) *Subsurface drainage design and management to reduce salt loads from irrigation areas in southeastern Australia* USCID International Conference Colorado, June 20-24, 2000. (In Press)

Skehan, D and Christen, E.W.. (2000*)* Leave salt in the ground: improved subsurface drainage design and management. *Farmers' Newsletter, Horticulture*, June 2000. (In Press)

7.3 Recommendations

The project has been able to show experimentally that improved drainage management that reduces salt export without increasing root zone salinity is possible. Overall the results show that drainage systems that are installed at depth with no management result in the greatest wastage of irrigation water and create the largest drainage water disposal problem.

Improved management of such systems can significantly reduce their impact, however this does require extra time from the farmers to manage pumps and monitor water tables. To make such management commonplace an automated system of control that integrates the farm water table status together with an assessment of whether an irrigation is occurring would be advantageous. Research in this direction has started by considering the likely logic and instrumentation required to achieve automated pump control. **Continued support for this type of research would enable easier adoption by farmers of subsurface drainage management.**

A key factor in achieving good drain management is the selection of an appropriate water table management depth. The choice of water table management depth will depend primarily upon the soil type, but also needs to consider the farm topography, crop and irrigation system**. A decision support system is required whereby farmers can select an appropriate water table management depth for their farm.** Also required is an appropriate set of monitoring requirements, such as soil salinity testing, that ensures that the water table management is adequately controlling waterlogging and salinity.

Other design considerations are that main drains should only be used to collect water from laterals back to a sump and as such should be of sealed pipe. This will reduce the overall salt mobilisation from a drainage system in that the deepest parts of the system, up to 3.5 m deep, will not be draining these deep, highly saline sections of the soil. Furthermore control structures may need to be installed in large drainage schemes so that certain sections can be prevented from draining whilst others can keep draining. This situation is more complex than turning a pump on and off both in terms of infrastructure required and management decisions. **Future research in these areas is required to make drainage management a practical proposition.**

The best results in terms of drainage costs and minimisation of environmental impact for drainage systems on heavier soils is to use a composite system of shallow mole drains running into collector mains 50 to 100 m apart. This type of system provides excellent waterlogging control without mobilizing large quantities of salt. However, there is the necessity to renew the moles periodically, every 2 to 5 years at a cost of about \$140 ha^{-1}. This also requires extra equipment and time management, a significant deterrent to farmers who appreciate the convenience of installing an entirely piped system that once installed requires little maintenance. Mole drainage systems are only suitable in soils with at least 40 % clay and the soil must be relatively stable in water. In other soils shallow drainage can only become a reality when pipes can be economically installed at a very close spacing. **This will necessitate the development of very low cost pipe systems.**

The general results from this project together with the drainage design and management guidelines have been as widely publicised as possible, see publications list. **However, a series of workshops across the Riverine plain to publicise the results and guidelines would be useful in promoting the use of this information with farmers, drainage contractors, consultants and state agencies.**

Further to such a series of workshops, to further communicate the results of this project **a similar workshop between researchers and practitioners Australia wide would be useful in defining the areas where future subsurface drainage research should focus.**

7.4 Outputs

7.4.1 Scientific papers

1. Christen, E.W. and Spoor G. (1999) *Moling to maximise irrigation efficiency whilst still achieving rapid watertable drawdown.* ASCE J. Irrigation & Drainage, March/April
2. Christen, E.W. and Spoor G. (1999) *Improving mole drain stability in irrigated areas using an angled leg.* Agricultural Water Management (Submitted)

7.4.2 Farming journals

1. Christen, E. (1996). S*ubsurface irrigation pipe*. Power Farming Magazine. vol. 105. no 4, pp 27-29. December 1996.
2. Christen, E. (1998) *Drainage limits losses on waterlogged land.* Farming Ahead No.75, p10-12, March 1998.
3. Christen, E. and Moll, J. (1996) *Drainage systems for new vineyards on heavy clay soils.* Farmers' Newsletter, No. 180 Horticulture, p6-7, September. 1996
4. Christen, E. and Moll, J. (1996*) Is it a pipe dream? Subsurface Irrigation Pipe (SIP) in the MIA.* Farmers' Newsletter, No. 180 Horticulture, p15-17, September. 1996
5. Christen, E.W., and Moll, J., (1995) *Can Mole Drainage Reduce Waterlogging?* Power Farming, Vol. 105, No.2, p14-17, July 1995
6. Christen, E.W., Muirhead, W.A., and Moll, J.L (1995*) Yield Improvement with soil modification and drip irrigation*. Australian Processing Tomato Grower, Vol 16, September 1995.
7. Moll, J., and Christen, E. (1996) *Drip System makes Financial Sense.* Power Farming, Vol. 105, No.4, p27-29, January. 1996
8. Moll, J., and Christen, E. (1996) *Selecting the right irrigation system.* Farmers' Newsletter, No. 180 Horticulture, p22-24, September. 1996
9. Moll, J., and Christen, E. (1996) *The economics of managing tile drainage water in MIA vineyards to meet environmental constraints.* The Australian Grapegrower and Winemaker, No. 395, p29-33, November 1996.

7.4.3 Conference papers

1. Charlesworth P. B., Christen E. W. and de Vreis T. (1998) *Is S.I.P. (Drainage coil) a cheap alternative to drip irrigation?.* Irrigation Australia 98.
2. Christen E.W. (2000) *Subsurface drainage design and management to reduce salt loads from semi arid irrigation areas.* International Conference on the Challenges facing irrigation and Drainage in the New Millenium of the United States Committee on Irrigation and Drainage, Colorado, June 20-24, 2000. (In Press)
3. Christen, E. (1996) *Reducing discharge from sub-surface drains in new vineyards on clay soils.* In Irrigation Research Forum, Goolwa 1996, pp13-14, Murray Darling Basin Commission, Canberra
4. Christen, E. (1997) *Reducing discharge from sub-surface drains in new vineyards on clay soils.* In proc. 1997 Irrigation Environment Research Forum, (Eds. K.Dyer and T. Lawry), pp. 59-62, Murray Darling Basin Commission, Canberra
5. Christen, E. (1997) *Using mole drains in horticulture* In: Horticulture Downunder, a conference on sustainable soil and water management for commercial horticulture in south eastern Australia", November 25-26 1997, Barooga, p89-94
6. Christen, E.W., Moll, J.L , Cox. S, Muirhead, W.A., Sinclair. P and McLennan. A, (1995*) Furrows that Trickle?* . Poster presented at 9th Australian Wine Industry Technical Conference. Adelaide. July 1995.

7.4.4 Technical reports

1. Christen, E. and Skehan, D. (1998). *Subsurface drainage design and management trial to reduce salt loads from semi arid irrigation areas.* Technical report 6/99, February 1999. CSIRO Land and Water, Griffith.
2. Cox, S. (1995). *Soil water conditions and root distributions under grape vines with drips, Riverina Twin Furrow and flood irrigation.* Vacation studentship report, March 1995, CSIRO Land and Water, Griffith.
3. Moll, J. and Christen, E. (1996) *Financial evaluation of options for managing tile drainage water to meet environmental constraints.* Technical Memorandum 96/20., pp 11. October 1996. CSIRO Division of Water Resources.

7.4.5 Educational material

1. Christen E. (1998). *Subsurface drainage* - Information paper to the NSW Rural Assistance Authority for use in educating loans administrators on the purpose of subsurface drainage and good drainage practices.

7.4.6 Book chapters/sections

1. Christen, E. (1998) *Subsurface drainage systems for vineyards and vegetables in clay soils.* “Farm salinity field kit- horticulture” NSW Agriculture Salt Action publn. pp7. In Press.
2. Christen, E. (1998) *Drainage systems limit waterlogging losses* pp221-223. Section in ‘Liquid Assets - Water Management for Dryland Agriculture’, Ed Bourchier, J. Published by Kondinin Group, Australia. Aug 1998. ISBN 1 876068 55 8
3. McKenzie, D. (1998) Subsoil drainage systems, pp. 4-5 SOILpak-3

7.4.7 Field days and seminars

1. *Lets talk water and drainage field day* Griffith. 4/96.
2. *Mole drainage demonstration field day with Salt Action* Berriquin 6/96
3. *Lets Talk Water 1998 field days* Griffith, 6th May & 13th May 1998
4. Presentation regarding mole drainage to Riverina Branch meeting of surveyors 13/6/98
5. Skehan, D. and Christen, E. (1998). *Lets Talk Water MIA field days* Catchword No 60 April 1998 pp11

7.4.8 Television, radio and newspaper coverage

1. *Field day*. Area News, 10/6/96.
2. *Field day*. Rural News, 8/5/96.
3. *Irrigation and Drainage field day*. MTN 9, 16/4/96.
4. *Controlling water logging and salinity with mole drainage*. Area news, 23/9/96
5. *Mole drain may beat salt on border check pastures*. Rural News, 6/9/96

6. *Cheap drains to control waterlogging*.	The Land, 10/10/96.
7. *Salinity in towns*.	2WEB Radio, Bourke, 1/97.
8. *Plan to halt salt damage to cities*.	Melbourne Age, 6/1/97.
9. *Mole drainage for Wagga oval*.	ABC Radio, Albury 7/1/97.
10. *Field day*	Weekly times, 7/98
11. *Field day*	Rural News, 6/98

7.5 Research Outcomes

7.5.1 Reduced discharge from subsurface drains in existing horticultural farms

During the course of this project there has been extensive communication activities with growers in the MIA. This together with initiatives on improved irrigation management e.g. NSW Agriculture ‘Waterwise’ and water use efficiency e.g. MIA Council of Horticultural Associations ‘Drainage monitoring scheme’ have led to reduced irrigation water use and hence lower drainage volumes can be expected.

Quantification of these changes have been attempted in a National Heritage Project *‘The Murrumbidgee Irrigation Area, tile drainage monitoring 1998/99’.* This project was conducted by Murrumbidgee Irrigation. The project results need to be interpreted with caution as less than half the number of the growers involved in the previous survey volunteered for this survey, compared to the previous survey in 1991/92. These volunteers are likely to be the better farmers more likely to be practicing improved irrigation and drainage management. The results showed that the absolute drainage volume was 20 % less than the 1991/92 survey. However, there has been no attempt to assess changes in cropping, irrigation method or distribution of rainfall in order to understand whether this reduction is due to changed management or other factors. Also it is unknown how the group actually sampled relates to the previous sample group.

7.5.2 Education campaign

As part of the National Heritage Project *‘The Murrumbidgee Irrigation Area, tile drainage monitoring 1998/99’* conducted by Murrumbidgee Irrigation there is an education component to raise awareness of better subsurface drainage management amongst growers. For this an educational campaign *titled ‘Do you know what is coming out of your drains’* has been launched. This campaign is using the results of this project exclusively. This includes a mailout to all horticultural growers in the MIA of a flyer, sticker and stubby holder. This is supported by pieces in the general media and posters.

As such this project has provided useful and relevant results and outputs that Murrumbidgee Irrigation, the MIA Council of Horticultural Associations and the Irrigation and Research Extension Council can use. It is hoped that these efforts will help to achieve the desired outcome of this project to reduce salt loads from the subsurface drainage in existing horticulture in the MIA.

7.5.3 New research activities

- Mole drainage trials in a CSIRO/ACIAR Rice CRC project on crops after rice, to reduce recharge from rice based cropping systems

- New NPIRD/LWRRDC project funded *on Best management practices for sub-surface drainage design and management* (CLW 20). This project based at CSIRO in Griffith has Evan Christen as the principle investigator. Its' objectives are:

    1. In a single document present the subsurface drainage practices that have been employed nationally in tackling watertable and salinity problems in the irrigated areas of Australia. This will include the drainage design criteria adopted as well as the technology and drainage management practices.

    2. Convene a national workshop to examine past methods in subsurface drainage and determine the key current issues affecting subsurface drainage in the various regions across Australia.

    3. Develop 'Best Practice Manual' for design, installation and management of subsurface drainage in irrigated areas.

    4. Identify knowledge gaps and scope future R & D for subsurface drainage, and facilitate the future exchange of information by establishing a network of people involved in subsurface drainage.

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