IRRIGATION
INSIGHTS

SUBSURFACE DRAINAGE DESIGN AND MANAGEMENT PRACTICES IN IRRIGATED AREAS OF AUSTRALIA

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Foreword

This Report has been prepared as part of an NPIRD LWRRDC project *'Best management practices for sub-surface drainage design and management'*. In this project current practices are to be reviewed and then a 'Best Practice Manual' developed for design, installation and management of subsurface drainage in irrigated areas. Other objectives are to identify knowledge gaps and scope future research and development for subsurface drainage, and facilitate the future exchange of information by establishing a network of people involved in subsurface drainage.

This report is the first part of that exercise in bringing together all the available knowledge regarding subsurface drainage for irrigation. This document was reviewed and provided the basis for discussion at a national workshop on 6 to 8 June 2000 at Tatura, Victoria when the requirements of the ' Best Practice Manual' and future research and development requirements were discussed. This report has been added to and revised as a result of the discussions held at the workshop.

THE REPORT IS IN TWO SECTIONS:
PART 1 provides a summary and comparison of the range of practices across Australia

PART 2 presents the regional reports prepared by experts from each region. These provide detailed information regarding subsurface drainage practices for each region.

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Part 1.

SUMMARY OF SUBSURFACE DRAINAGE FOR IRRIGATED AREAS IN AUSTRALIA

Introduction

Introduction

It is widely understood that irrigation development results in deep percolation past the rootzone, which recharges the groundwater. With flood irrigation, watertables often rise at around 0.5 m a year until a new equilibrium is established where the watertable fluctuates from the soil surface to around 3 m deep. A significant part of all irrigation areas in Australia are currently in this condition or approaching such equilibrium. Irrigation areas in southeastern Australia, particularly in the Murray Darling Basin (MDB), have 75% or more of their areas in this shallow watertable regime.

With the onset of shallow watertables, waterlogging and salinisation follow. To treat these symptoms subsurface drainage systems have been installed in many areas. They are usually associated with high value crops such as perennial horticulture, cotton, sugarcane and perennial pasture for dairying.

These drainage systems can be horizontal pipe drains, which are often used for perennial horticulture and pumping from tube wells or spearpoints, often used in dairying.

This use of subsurface drainage has been the historical remedy for poor irrigation practice. However, since the 1980s more emphasis has been placed on improved irrigation practices. Since the 1990s Land and Water Management plans have been developed in all irrigation areas. Their aim is to improve the sustainability of irrigation, mainly by improving irrigation efficiency.

A major physical constraint to expanding subsurface drainage, especially in the MDB, has been the limits set on salt disposal to the river systems. This has led to a search for alternative saline drainage mechanisms. Reuse of drainage water conjunctively with fresh irrigation water is widely practised with groundwater pumping. Evaporation basins have been used, allowing 40,000 ha to be drained in the Wakool area (into a 2,100 ha basin) and continued drainage from perennial horticulture along the lower Murray and in new horticulture in the Murrumbidgee Irrigation Area. Other options such as disposal to woodlots and serial biological concentration are being considered.

This report details the implementation of subsurface drainage for irrigation in eleven regions (Figure 1).

1. Burdekin River Irrigation Area (QLD)
2. Emerald Irrigation Area (QLD)
3. Kerang Irrigation Area (VIC)
4. MacAlister Irrigation Area (VIC)
5. Mid Murray Irrigation Area (NSW)
6. Murrumbidgee/Coleambally Irrigation Areas (NSW)
7. Ord Irrigation Area (WA)
8. Riverland Region (SA)
9. Shepparton Irrigation Area (VIC)
10. South West Irrigation Area (WA)
11. Sunraysia Irrigation Area (VIC)

Figure 1.

FIGURE 1. IRRIGATION REGIONS WITH SUBSURFACE DRAINAGE

These regions have different types of subsurface drainage, covering areas from hundreds to tens of thousands of hectares. The Ord Irrigation area at present has not implemented any subsurface drainage, but appropriate methods are being investigated due to shallow groundwater levels developing within the area.

The regional reports provide where possible information on the following aspects of subsurface drainage within that region:

> description of local and/or regional hydrogeology
> which crops are drained and management (especially irrigation) of those crops
> description of drainage problem
> description of drainage method used
> drainage design, including site investigations
> drainage water quality, quantity and disposal
> drainage system management and monitoring
> funding arrangements
> current issues and trends
> research requirements.

The following section gives a brief summary for each region.

Regional summaries

Regional summaries

Burdekin River Irrigation Area (QLD)

BURDEKIN RIVER IRRIGATION AREA (QLD)

Subsurface drainage for irrigation is currently at an experimental stage in this area, concentrating on salinity problems in the Leichhardt Downs area. A pilot 250 ha area of groundwater pumping to protect sugarcane has operated since 1995. Extensive hydrologic modelling of the area was the basis for the pump positioning and extraction rates. This area has low transmissivity aquifers (∼10 m^2/day) and six shallow bores (30 m depth) were used with a design 12 L/s extraction, using airlift pumping. The long-term target is to maintain the watertable at 3 m deep to keep the saline groundwater (up to 21 dS/m) below the rootzone.

The drainage water from this pumping (∼6 dS/m) was to be 50% reused on-farm, however, this has not eventuated as there is no mechanism to enforce reuse by farmers. The drainage water eventually reaches the Burdekin River. An extensive land and water quality-monitoring plan is in place to ensure that soil salinity and watertables are controlled and water quality in rivers maintained.

Future development includes a further 500 ha of drainage in the Leichhardt Downs area and the success of the subsurface drainage trial may encourage further development of the Burdekin Irrigation Area. Key issues are the sustainability of irrigation and disposal of the saline groundwater.

Emerald Irrigation Area (QLD)

EMERALD IRRIGATION AREA (QLD)

In the late 1980s, about 500 ha of subsurface drainage was completed. This was in response to waterlogging and salinity problems caused by a midslope change in the soil profile resulting in high watertables at the lower ends of fields. Horizontal subsurface pipe drains were installed across the slope as interceptor drains. These drain by gravity to surface drains at the bottom of the slope. The design criteria were to keep the watertable below 1.2 m, the approximate rootzone depth of cotton. The drainage water from these systems is of good quality (∼0.6 dS/m) and is either reused for irrigation or drains to the river. Farmers were involved in this drainage scheme by monitoring the watertable before and after drainage. The State Government funded the project with contributions from landholders in the form of a Drainage Levy over ten years.

Kerang Irrigation Area (VIC)

KERANG IRRIGATION AREA (VIC)

This region has suffered extensively from salinity problems and has geologically been subject to regional groundwater discharge. Irrigation has increased this groundwater discharge resulting in soil salinisation. Extensive research has been conducted in the region into subsurface drainage methods. Both vertical and horizontal drainage has proven to be effective. Groundwater salinity is very high (∼20 – 50 dS/m) so that in most cases drainage water needs to be disposed to evaporation basins. Because of the high cost of subsurface drainage solutions and evaporation basins there are relatively few operating systems. Where the groundwater quality is good then conjunctive reuse on perennial pasture is successful.

Research into design criteria for the area suggests that the watertable needs to be controlled to about 1 m to control the rate of capillary rise to less than 0.1 mm/d. Experience has shown that very low drainage rates can be effective in pasture production situations. Leaching fractions of only 2 to 5% may be necessary, together with control of the upward (artesian) pressures. This may equate to an overall drainage rate of 0.8 mm/d (∼ 3 ML/ha/yr).

Research into vertical drainage with extended wellpoints and evaporation basin suggests costs of $1,380/ha, while horizontal drains with evaporation basin costs about $2,280/ha.

Future issues relate to reducing the cost of drainage by investigating the effectiveness of very low drainage rates.

MacAlister Irrigation Area (VIC)

MACALISTER IRRIGATION AREA (VIC)

Irrigation in the MacAlister Irrigation area has resulted in shallow watertables (< 2 m) in lowlying areas leading to soil salinisation. Shallow groundwater pumping (< 20 m deep) has been used in the lowlying areas or upslope of the lowlying areas or both to control soil salinisation. Siting of bores is based on groundwater modelling of catchment areas. The State Government funds groundwater pumps for salinity control (Public Pump) and operational costs are shared between direct beneficiaries, i.e. all landholders in the area and local government. Landholders also install private pumps and meet all the costs. These pumps are seen as a water supply (salinity 0.5 – 2.0 dS/m) by landholders who conjunctively reuse the water on perennial pasture.

Public pumps dispose of water into surface drains that eventually reach natural watercourses. Disposing water in this manner is a major issue.

Groundwater pumping in the region has been successfully promoted and implemented. The major future challenge is ensuring a match between landholders pumping for irrigation supply purposes and the overall salinity control objective.

Mid Murray Irrigation Area (NSW)

MID MURRAY IRRIGATION AREA (NSW)

As a result of irrigation recharge, extensive areas in the Mid Murray region have shallow watertables. Subsurface drainage to address this problem has been in the form of shallow groundwater pumping. This pumping strategy has been to maintain watertables at about 2 m under rice and pasture dominated cropping. Groundwater pumping has been dominated by the Wakool-Tullakool scheme providing protection to about 30,000 ha of land, which drains to a 2,100 ha evaporation basin. This scheme was developed in the 1980s and has successfully reduced the area of high watertables. The State Government funded this major development.

Since that time there has been numerous private groundwater pumps installed. These are for conjunctive reuse or disposal into surface drains and irrigation channels. Much of this water is saline and has high sodicity levels. In recent times of restricted surface irrigation supplies there has been an increase in groundwater pumping for irrigation use.

Future issues are associated with the high reuse levels of poor quality groundwater, which may be unsustainable in terms of soil salinisation or sodification and maintaining aquifer quality. Research into conjunctive reuse is required to clarify these issues. It is planned to construct more evaporation basins to receive groundwater, as increased groundwater extraction is seen as essential for future irrigation sustainability.

Murrumbidgee/Coleambally Irrigation Areas (NSW)

MURRUMBIDGEE/COLEAMBALLY IRRIGATION AREAS (NSW)

Most of these areas have shallow watertables, which have not dramatically affected much of the rice based farming systems, but have previously caused widespread losses in perennial horticulture.

In rice based farming systems, where rice is the main crop, some subsurface drainage has been undertaken by shallow groundwater pumping. This was using shallow spearpoints but has been discontinued because of the high salinity of the discharge water and uncertain benefits in rice based farming systems. Other investigations and experiments have been done on the use of shallow vertical pumping and horizontal drainage with disposal to evaporation basins or reuse or both. These proposals have not been implemented because of the high costs compared to relatively low benefits in rice based farming systems. Future research should assess the very low drainage rates for this type of cropping system.

In the Coleambally area, experimental deep groundwater pumping (>120 m) was done to assess the benefits for salinity control. There appeared to be a drawdown of 0.1 to 0.3 m over several years within 2 km of the experimental bore. The impact of such small drawdowns on salinity control is uncertain. It is clear that the link between deep and surface aquifers is poor at the experimental bore location and thus there is relatively limited potential for deep pumping to help control salinity in that area.

In the Murrumbidgee Irrigation Area there are about 10,000 ha of horticultural plantings with horizontal subsurface drainage. The impetus to install drainage occurred in the mid 1950s when waterlogging, associated with rainfall killed 50% of the tree crops. This led to a concerted research effort into horizontal 'tile' drainage and a system of Government loans for implementation. The research developed drainage criteria, methods for site investigation (hydraulic conductivity) and nomographs for design. Until recently it has been the norm to install subsurface drainage in all perennial horticulture, however, some vineyards now use drip irrigation and feel that subsurface drainage will be unnecessary. This assumption remains untested. Drainage from perennial horticulture (salinity 2 to 12 dS/m) was historically disposed of into the surface drainage system. The water was mixed with all other drainage (both surface and subsurface) from the region and was ultimately reused by the Irrigation Districts to the west of the Murrumbidgee Irrigation Area. However, in the early 1980s a moratorium on new drainage systems disposing of drainage off-farm has led to the development of 15 on-farm evaporation basins.

The major issue facing the area is disposing of subsurface drainage effluent. Drainage from existing systems needs to be reduced and future systems will have to use evaporation basins. An overall drainage management disposal plan is required.

Ord Irrigation Area (WA)

ORD IRRIGATION AREA (WA)

As the Ord is a relatively new and small irrigation area, drainage problems are isolated. Investigations into control options indicate that shallow groundwater pumping is the most likely. The good groundwater quality (< 0.3 dS/m) over most of the region indicates that conjunctive reuse will be the favoured disposal option, at least in the short term.

Riverland Region (SA)

RIVERLAND REGION (SA)

This area is dominated by perennial horticulture. Horizontal drainage has been installed to protect the region from waterlogging since the 1920s. Experiments were conducted to determine appropriate drain spacings according to soil type. The drainage water from these systems was initially disposed of by injection into deeper, more permeable aquifers or to the Murray River. The discharge to the deeper aquifers exacerbated the buildup of the groundwater mound under the irrigation area and increased the discharge of saline groundwater to the river. Now discharge is to evaporation basins located on the Murray River Floodplain or in highland areas away from the river.

Future issues will be in moving evaporation basins away from the river floodplain and reducing drainage flows.

Shepparton Irrigation Area (VIC)

SHEPPARTON IRRIGATION AREA (VIC)

Subsurface drainage in the Shepparton Region is a highly planned and coordinated program under the auspices of the Land and Water Salinity Management Plan.

Shallow watertables are present under most of the area as a result of irrigation. This has led to waterlogging problems for perennial horticulture and salinity problems for perennial pasture. Drainage in the horticultural areas was rapidly implemented after serious waterlogging in the mid 1970s. Shallow spearpoint systems were adopted where there were shallow pumpable aquifers, with horizontal drainage for other areas.

Pasture production areas were protected by a much larger drainage strategy of public groundwater pumps for salinity control and promotion of private groundwater pumps for conjunctive reuse. This groundwater pumping was from shallow aquifers (< 20 m) with relatively good aquifer quality, < 3.6 dS/m for private reuse. Water from public pumps is disposed of into the surface drainage network and the irrigation supply system. For very saline water, evaporation basins are required, and a 30 ha experimental basin has operated since 1982.

Overall there is a detailed plan, which has divided the area into four drainage classes with appropriate drainage systems for each class. Appropriate salinity levels have been developed for on-farm reuse, regional reuse (via drains and irrigation channels) and river disposal. The number of salinity credits available to the area limits river disposal. This is an issue for future concern as the available credits may be inadequate.

Mechanisms for distributing costs between direct beneficiaries, all landholders, Local Government and State Government have been developed.

Future issues include available salinity credits, disposal options, better estimates of safe salinity reuse levels and better information on the long term impacts of groundwater pumping on aquifer quality.

South West Irrigation Area (WA)

SOUTH WEST IRRIGATION AREA (WA)

Drainage problems in this area are associated with heavy winter rainfall and some transient waterlogging associated with irrigation. Small areas of subsurface drainage are installed, primarily horizontal drainage in perennial horticulture and some composite (pipe mains/mole laterals) systems for pasture.

Future drainage issues relate to drainage management and disposal (currently the river system) and developing better drainage criteria. Establishing the cost:benefit of subsurface drainage is also required.

Sunraysia Irrigation Area (VIC)

SUNRAYSIA IRRIGATION AREA (VIC)

This region is similar to the Riverland Region of SA in drainage problems and solutions. The area is dominated by perennial horticulture. Horizontal drainage has been installed as protection from waterlogging, since the 1920s. Experiments were conducted to determine appropriate drain spacings according to soil type. The drainage water from these systems is disposed of to the Murray River and evaporation basins.

Future issues are associated with continued river disposal and the development of new irrigation areas. These are required to set aside land for evaporation basins. However, many developments are using controlled irrigation and are suggesting that subsurface drainage will not be required. The long-term drainage requirements for perennial horticulture using controlled irrigation (drip/sprinkler) are as yet unclear.

Comparison of Subsurface Drainage in Irrigation Regions

Comparison of Subsurface Drainage in Irrigation Regions

This section compares subsurface drainage practices in different regions of Australia. Information from each region is presented in tables detailing factors such as drainage problem, design criteria, disposal method, costs and management.

In the tables, South West Irrigation Area has been abbreviated to SWIA and blank spaces indicate that data was not available.

CROPS, IRRIGATION AND DRAINAGE PROBLEM

The major cropping systems in the irrigation regions are given in Table 1 together with an indication of the irrigation water quantity and quality. The type of cropping (value) will affect the type of drainage system selected.

Table 1.

TABLE 1. MAJOR CROPS AND QUANTITY AND QUALITY OF IRRIGATION WATER

Region	Major crops	Average annual irrigation ML/ha	Irrigation water salinity dS/m
Burdekin	Sugarcane	9	0.3
Emerald	Cotton	3.4	
Kerang	Perennial pasture	6–10	< 0.4
MacAlister	Perennial pasture	5	
Mid Murray	Rice Perennial and annual pasture	8–16	0.06
Murrumbidgee/ Coleambally	Perennial and annual horticulture Rice and pastures	4–8 8–16	0.05–0.15
Riverland	Perennial horticulture	6–12	0.3–0.8
Shepparton	Perennial pasture Perennial horticulture	10 7	0.05–0.15
Sunraysia	Perennial horticulture	6–14	0.3–0.6
SWIA	Perennial pasture Perennial horticulture	7–14	0.25–2

Table 2 describes the development of drainage problems and current status in each region. Most problems are related to watertable rise from irrigation recharge. The severity of the problem depends upon the local hydrogeology and history of high watertables.

Table 2.

TABLE 2. DESCRIPTION OF THE SUBSURFACE DRAINAGE PROBLEM

Region	Description of problem
Burdekin	In the BRIA, drainage has been required within the LDA. This area consists of uplands with shallow soils developed *in situ* on a granodiorite parent material, above lower areas featuring very heavy colluvial and alluvial material. Complicating this normal 'topo-sequence' type of formation is the widespread occurrence of dyking within the granodiorite parent material. The dyking has the effect of making the regional groundwater behave as a series of structural blocks, typically 0.5 x 1.0 km. The changes induced by land clearing pre-development have given rise to salinised discharge areas upstream of the dykes. Limitations to irrigation development are mainly from drainage problems associated with the topo-sequence geology, and the impact of the dykes.

Table 2.

Continued

Region	Description of problem
Emerald	Rising groundwater levels within the EIA are affected by local geology. These levels usually occur near the interface of shallow, lighter textured soils and where deeper, heavy textured, downslope soils intersect. Within the area shallow upslope soils are underlain by moderately fractured and weathered basalts, which provide a highly permeable aquifer through which the groundwater can flow. The deeper downslope soils are underlain by older and completely weathered basaltic clays that are less permeable. The less permeable downslope subsoil restricts groundwater flow and water rises to the surface, creating waterlogged areas. The sources of water include seepage from earthen channels, seepage from on-farm head ditches and tail drains, and deep percolation from irrigation and rainfall.
Kerang	Groundwater levels were between 7 and 10 m from the soil surface, before irrigation development. A shallow watertable was established soon after the advent of irrigation and currently from 65 to 75% of the region has a watertable within 2 m of the soil surface. Capillary rise of saline groundwater has resulted in secondary salinisation of 40% of the region. The problem is further exacerbated by regional groundwater flow in the deeper aquifer system at a depth from 50 to 120 m. In the northern part of the region, artesian pressure levels occur in the deep aquifer over most of the area. The high-pressure level in the deeper aquifer precludes natural drainage and results in a small upward flow of groundwater in areas of low elevation.
MacAlister	The introduction of irrigation resulted in increased recharge to the shallow groundwater system and subsequent salinity. Productivity decreases were recorded as a result of high watertables and consequent salinity problems soon after the development of the area for irrigation. The most evident salinity occurs not within the irrigated region but in the low-lying dryland areas downslope of the main irrigation areas.
Mid Murray	Groundwater accessions are a result of removing perennial vegetation and replacing it with annual crops and pastures, applying irrigation water, seepage from district infrastructure and disturbing natural drainage lines to develop public and private infrastructure. There is also a regional flow of groundwater from east to west. Groundwater salinity levels are extremely high, ranging from 0.5 to 66 dS/m.
Murrumbidgee/ Coleambally	Waterlogging of horticultural crops is caused by over-irrigation and combined with wet winters caused watertable problems in horticultural farms. Many supply channels had high seepage rates, which caused additional waterlogging and salinity. High value crops that are sensitive to waterlogging and salinity (e.g. citrus, stonefruit and grapevines) have been the focus of drainage in the past. Similar processes have occurred in non-horticultural areas with the advent of rice growing, which have seen watertables rise dramatically. The net groundwater movement is towards less intensively irrigated areas which are at risk of salting over a period of time. In summary, drainage problems within horticultural areas are mainly due to waterlogging and on large area farms salinity control is the main issue.
Ord	Since irrigation began in the Ord area, groundwater accessions from dry season irrigation have increased total annual accessions from rainfall and irrigation beyond the drainage capacity of the groundwater system, resulting in a net rise in groundwater levels. Before the development of irrigation in the area, wet season rainfall drained from the groundwater system throughout the dry season, resulting in groundwater levels at equilibrium well below the surface over most of the year. Initial groundwater levels were 17 m from the soil surface over much of the area, however, since that time have risen steadily to be within 1.5 m of the soil surface in some regions. Groundwater salt concentrations are variable and generally low (< 2 dS/m) therefore the main problem at this time is associated with waterlogging.
Riverland	Irrigation in the region resulted in applications of water five to six times the annual rainfall. Groundwater mounds were established beneath the irrigated areas inducing saline groundwater flows to the river and river valley with subsequent detrimental salinity and environmental impacts. Irrigated plantings in the topographical depressions of the highland were generally the first areas to be affected and in some places seepage lakes formed. Waterlogging in the form of perched waterbodies was prevalent in soils with relatively impermeable subsoils. Reasons for these drainage problems are over-irrigation, inefficient irrigation methods, inefficient irrigation applications, and a general rise in the regional groundwater levels and lateral movement from adjoining irrigation areas within the district.

Table 2.
Continued

Shepparton	Clearing native vegetation and irrigation development have disrupted the natural hydrologic cycle within the Shepparton Irrigation Area and the Upper Shepparton aquifer and enclosing clay aquitards have become saturated. Groundwater levels within the region are now within 2 m of the soil surface over much of the SIA resulting in waterlogging and salinity problems.
Sunraysia	Furrow irrigation is still used by 50% of irrigators within the Sunraysia area. Under furrow and sprinkler irrigation, a perched watertable is formed over the calcareous clay subsoil. These shallow fluctuating watertables lead to waterlogging and salinisation and therefore subsurface drainage is regarded as essential to maintain productivity under current irrigation systems. In addition, hillside seepage problems occur where the deep sand of the dune crest gives way to a shallower soil further downslope.
SWIA	Within the SWIA there is a combination of waterlogging and salinity problems, with waterlogging causing major agricultural losses. Heavy winter rains cause waterlogging of soils with reduced trafficability and plant growth between June and August. Monitoring of groundwater levels suggests that there is a significant rise during winter that recedes during summer. Waterlogging as a result of irrigation is more the result of perched watertables rather than groundwater rise.

Drainage methods and design criteria

DRAINAGE METHODS AND DESIGN CRITERIA

Depending on the type of drainage problem and crop type the drainage objective will vary, as will the drainage method. The drainage objective and method for each region are outlined in Table 3

Table 3.

TABLE 3. DRAINAGE OBJECTIVE AND METHOD

Region	Drainage objective	Drainage method
Burdekin	Watertable control and subsequent prevention of soil salinisation	Vertical 30 m deep, protecting about 40 ha each
Emerald	Watertable control and subsequent prevention of soil salinisation	Cross slope interceptor pipe drains. One drain 2.5 – 4 m deep, additional drains 150– 200 m apart if required
Kerang	Salinity control	Vertical, 5–15 m deep, protecting perennial pasture and experimental horizontal drains70 m apart, also relief of deep artesian pressures
Mid Murray	Watertable control and subsequent prevention of soil salinisation	Shallow vertical with evaporation basin
	Irrigation supply and watertable control	Shallow vertical
	Irrigation supply	Deep vertical
MacAlister	Salinity control - protection of low-lying areas from salinisation,watertables less than 2 m. Partial pumping/reclamation in lowlying areas and partial interception of groundwater flows to the lowlying areas	Vertical, 5 to 15 m deep, protecting 200 to 2000 ha each
Murrumbidgee/ Coleambally	Watertable control and subsequent prevention of soil salinisation for perennial horticulture, salinity control for other crops. Deep pumping for irrigation supply	Horizontal drains or vertical spearpoints for perennial horticulture. Vertical for other crops, deep pumping for regional pressure control
Ord	Salinity control	None – probably vertical in future
Riverland	Watertable control and subsequent prevention of soil salinisation	Horizontal drainage, grid pattern, 10–30 m apart

Table 3.
Continued

Region	Description of problem	
Shepparton	Salinity control for pasture, watertable and salinity control for horticulture	Vertical 5–20 m deep protecting100–200 ha each for perennial pasture and horizontal drains or spearpoints (~25 ha each) for perennial horticulture
Sunraysia	Watertable control and subsequent prevention of soil salinisation	Horizontal drainage, interceptor drains on slopes, grid 13–40 m apart
SWIA	Watertable and salinity control	Horizontal drainage in horticulture, composite tile (40–60 m apart)+ mole (1–2 m apart) systems in perennial pasture

Depending upon the drainage objective and method, the drainage design criteria will vary, including the target watertable depth after irrigation or rainfall and drainage coefficient. These together with the actual measured long-term drainage rate are given in, Table 4.

Table 4.

TABLE 4. TARGET DESIGN CRITERIA FOR SUBSURFACE DRAINAGE SYSTEMS

Region	Drainage type	Target watertable depth	Design drainage coefficient	Actual long-term drainage rate (ML/ha/yr)
Burdekin	Vertical	3 m		1.5
Emerald	Vertical	>1.2 m (cotton rootzone)		
Kerang	Vertical		0.25–0.5 ML/ha/yr	3–4
	Horizontal	> 1.2 m < 0.1 mm/d capillary rise Also relief of artesian pressures	Experimental horizontal drains 2.5 mm/day with watertable at 0.3 m (however 0.8 mm/day may be adequate)	1–2
MacAlister	Vertical			0.5
Murray	Vertical	> 1.5–2.0 m	0.6 – 1.0 ML/ha/yr	0.3 – 0.6
Murrumbidgee/ Coleambally	Vertical		Spearpoints for horticulture 1 ML/ha/yr	3
	Horizontal	0.45 - 0.75m after 3 days for perennial horticulture	5 mm/day at 0.3 m watertable depth	0.5 - 2
Riverland	Horizontal	0.9–1.1 m one week after irrigation	2–5 mm/day	1–2 (catchment basis)
Shepparton	Vertical	None	Private - 1 ML/ha/yr over 120 days Public – 0.5 ML/ha/yr for 2 periods of 60 days	Private 3 Public 0.5
Sunraysia	Vertical	0.9–1.1 m one week after irrigation	2–5 mm/day	1–1.5
SWIA	Horizontal	Watertable < 0.3 m for less than 3 consecutive days	10 mm/day	5

These drainage practices have been developed according to local conditions and hence were appropriate for their area. Often however, the design of drainage systems particularly horizontal drainage has not changed since the original need was established in the 1920s – 1950s. Thus, the drainage criteria may need to be adapted in light of changed irrigation practices in recent times and other advances in irrigated agronomy and irrigation supply management that should result in a lower overall drainage requirement.

Drainage water salinity and disposal methods

DRAINAGE WATER SALINITY AND DISPOSAL METHODS

Drainage water salinity is affected by groundwater salinity (Table 5) and this will then affect the choice of drainage disposal method.

Table 5.

TABLE 5. GROUNDWATER AND SUBSURFACE DRAINAGE WATER SALINITY (DS/M)

Region	Groundwater		Subsurface drainage water	
	Shallow (< 30 m)	Deep (> 30 m)		
Burdekin		0.1 –21 (at 30 m)	6	
Emerald			0.6	
Kerang	30–50	1–10	20–50	
MacAlister	0.6–20		0.5–2	
Mid Murray	0.5–66	0.5–10	Public Private	23 0.5–3
Murrumbidgee/Coleambally	1–20	0.5–1	Horizontal Vertical	2 –12 5–20
Ord	0.2			
Riverland	1.6–3.9	4.7–47	1.6–47	
Shepparton	1 – 10 (and higher)	0.5–10 (and higher)	Private up to Public up to	3.5 10
Sunraysia	2 – 4	20–50	2–5	
SWIA	5 – 40	5–20	2–10	

Because there are varying drainage water quality and cropping systems, which affect reuse possibilities and various limitations on river disposal, a number of disposal options have been implemented (Table 6).

Table 6.

TABLE 6. DRAINAGE DISPOSAL METHODS

Region	Drainage disposal method
Burdekin	Reuse (mix to 1 dS/m) and river disposal (must not raise salinity by > 4%)
Emerald	Irrigation reuse and river disposal
Kerang	Very saline drainage to evaporation basins, less saline conjunctive reuse
MacAlister	Private pumps - conjunctive reuse (mix to 1 dS/m), public pumps - irrigation and drainage channels for reuse; that not reused goes to river.
Mid Murray	Mainly discharge into evaporation basins. Small amount of discharge into the irrigation supply system during the irrigation season. Discharge off-farm of groundwater from private pumps is not permitted.
Murrumbidgee	8% to river, 4% to evaporation basins, 88% to surface drainage system which is reused in Wah Wah Irrigation District.

Table 6.
Continued

Region	Drainage disposal method
Riverland	88% to floodplain basins, 11% to highland disposal basins, < 1% to river. Also reuse scheme with lucerne in Qualco district using water up to 3.5 dS/m.
Shepparton	Private pumps - conjunctive reuse (mix to 0.8 dS/m), public pumps - irrigation and drainage channels for reuse (mix to 0.5 dS/m), that not reused goes to river. Drainage water > 10 dS/m to evaporation basin.
Sunraysia	Evaporation basins
SWIA	Into open drainage network then to ocean via rivers

System costs, ownership, management and monitoring

SYSTEM COSTS, OWNERSHIP, MANAGEMENT AND MONITORING

With different drainage methods and disposal costs the overall cost of drainage will vary widely. How these costs are shared between direct and indirect beneficiaries is also important. Table 7 indicates the costs to install and operate subsurface drainage.

Table 7.

TABLE 7. SUMMARY OF INSTALLATION AND OPERATIONAL COSTS (2001)

Region	System type	Installation costs	Operating costs	
		$/ha	$/ha/yr	$/ML/yr
Burdekin	Vertical	270	52	37
Emerald	Hybrid Horizontal	4,600		
Kerang	Extended wellpoints	1,380		
	Horizontal (60 m spacing)	4,230		
	Horizontal (120 m spacing)	2,280		
	Moles	3,350		
	Deep pumps and Serial Biological Concentration	884		
	Deep pumps (winter)	680		
	Horizontal and evaporation basin	5,438		
MacAlister	Vertical	250 ($40–50K investigation/ $70–80K capital)		
Mid Murray	Shallow pumping + evaporation basin	615	7	28
	Shallow pump (250 ha)	800	10	10
	Deep pumps	$100–200,000 each		10
Murrumbidgee/ Coleambally	Horizontal (~40 m spacing)	2,800		0.90
	Horizontal + evaporation basin (10% of drained area)	3,800		25–50
Riverland	Horizontal	5,000		
Shepparton	Vertical	250 ($40–50K investigation/ $70–80K capital)		
Sunraysia	Horizontal	4,500	36	6
SWIA	Horizontal and moles	1,500	30	

Table 8 shows the ownership of subsurface drainage systems, which varies depending upon the level of government intervention in overcoming drainage problems. Depending upon ownership and government assistance the cost sharing arrangements for subsurface drainage vary markedly.

Table 8.

TABLE 8. SUBSURFACE DRAINAGE OWNERSHIP AND COST SHARING

Region	Ownership	Cost sharing	
		Capital	Operational
Burdekin	Water management agency (trial to test methods)	Water management agency (trial)	Water management agency (trial)
Emerald	Private (farmers)	Farmer 25% (by drainage levy over 10 yrs), State Government 75%	
Kerang	Water Management Agency (experimental)	Water Management Agency (experimental)	Water Management Agency(experimental)
MacAlister	Private (by farmers) if conjunctive water use to supplement surface irrigation supplies. Public (by water management agency).	Public pumps - State Government	Public Pumps - operational costs 40% by local government and 60% by local irrigators. Farmers pay $0.6/ML on all irrigation water. No charge on pumped water.
Mid Murray	Shallow vertical - Murray Irrigation Ltd (10 units) and landholders (150 units)	NSW and Federal Government for Murray Irrigation Ltd units. Subsidy up to 70% for private landholder installations	Operation and maintenance paid by farmers in all cases
Murrumbidgee/ Coleambally	Farmers (private) for horizontal.Water management agencies for vertical	All farmer (Fixed interest loan available from State)	All farmer
Riverland	Farmers (private)	On-farm by farmer. Community pipe collector main system by Irrigation Trusts	
Shepparton	Public (by water management agency). Private (by farmers) if conjunctive water use to supplement surface irrigation supplies.	Public pumps State Government. Private pumps provided with subsidy up to 65%	Public pumps -Costs shared between local beneficiary (40–50%), all irrigators (40 –80%) and Local Government (17%) Private pumps - farmers
Sunraysia	Private (farmers)	On-farm by farmer. Community pipe collector main system by government	Cost of operation and main tenance of evaporation basins met by a system of tariffs, based on a 'service' fee a 'per ha' fee and a 'per ML of irrigation use' fee.
SWIA	Private (farmers)	On-farm by farmer	Farmers pay for on-farm. State Government nominally for maintenance of open drainage network

Management and monitoring arrangements for subsurface drainage systems are highly varied (Table 9) depending upon the type of drainage system, ownership and disposal method.

Table 9.

TABLE 9. MANAGEMENT AND MONITORING

Region	Management and monitoring
Burdekin	Monitor observation bores and manually control pumping to maintain levels at 3 m. Conducted by water management agency. Other aspects to be taken up in Land and Water Management Plan.
Emerald	No management undertaken. Drainage quantity/quality by water management agency. Landholder monitored shallow observation bores.
Kerang	Mostly experimental installations.
MacAlister	Monitor over 300 shallow observation bores. Water levels are monitored monthly and groundwater salinity in selected bores quarterly. Also surface drain flow/quality and volume/quality from Public Groundwater Pumps. EM-38 surveys are being used to determine the change in soil salinity around groundwater pumps. All by water management agency. Need regular and consistent pumping.
Mid Murray	Murray Irrigation Limited (MIL) monitors 1500 shallow piezometers, the Department of Land and Water Conservation (DLWC) monitor deep groundwater observation bores. MIL manages the evaporation basin scheme and 10 other vertical pumps operated to control groundwater levels. Farmers manage the operation of private shallow and deep groundwater pumps. DLWC are responsible for monitoring volumes of groundwater extracted from licensed bores.
Murrumbidgee/ Coleambally	Horizontal - managed by farmers (sometimes turned off), vertical by DLWC. Monitoring horizontal drains surveyed every 10 years and ad hoc monitoring, vertical by DLWC - volumes/quality and drawdown. Piezometers measured bi-annually by irrigation companies.
Riverland	No on-farm management undertaken. Monitoring at end of each catchment system, not individual farms.
Shepparton	Private pumps not previously directly monitored. Implementing a groundwater plan that includes metering private pumps and monitoring pumped groundwater salinities. Public pumps by water management agency. Need regular and consistent pumping for salinity control. 2000 observation bores monitored.
Sunraysia	No management undertaken. Monitoring at end of system not individual farms.
SWIA	EM 38/31 mapping of whole farms and some transects. Groundwater monitoring on ~40 bores. Very intensive water quality (salt and nutrients) on one 16 ha site. Monthly water quality monitoring at select points in the open drainage network.

Discussion

Discussion

Practices relating to subsurface drainage design and management across irrigation areas in Australia are highly varied. It is evident, however, that in some irrigation areas of Australia drainage problems relating to both salinity and waterlogging will continue to develop until remedial measures are undertaken. Subsurface drainage has been used to good effect to overcome waterlogging and salinity along with other methods such as surface drainage, improved irrigation practices and changes in land use management practices. As these factors are interrelated, it is important to consider them in an integrated manner when aiming to develop sustainable irrigation systems.

The main crops drained are those associated with high value products such as, perennial pasture for dairying, perennial horticulture, cotton and sugarcane. Thus subsurface drainage has generally been targeted at those crops where the returns are greatest and any loss of productivity due to waterlogging and salinisation is most significant. These schemes are usually partially or completely paid for by the landholder. However, the Wakool-Tulakool subsurface drainage scheme in the Mid Murray region is significantly different. This scheme provides comprehensive drainage by groundwater pumping over many thousand hectares for a mix of crops including low value ones. Significantly, this scheme occurred with funding entirely from government.

Irrigation water use varies greatly from region to region, depending on crops grown and climate. Most regions have reported improved water use efficiency in recent times, which is vital to reduce drainage problems and make subsurface drainage implementation more affordable. The surface supply irrigation water quality is very good (<0.4 dS/m) in most regions. Thus irrigation-induced salinity is generally due to shallow saline watertables rather than the application of poor quality irrigation water. Only the South West Irrigation Area, Sunraysia and Riverland have occasional high salinity irrigation water.

Drainage problems have been reported usually as the result of over irrigation leading to shallow watertables and hence waterlogging and secondary salinisation. It is not clear for any of the regions whether improved irrigation management could have avoided the problem. Waterlogging is a significant problem in perennial horticulture and hence drainage for watertable control in most perennial horticulture has been implemented. This has also controlled soil salinisation.

Pasture, which is not sensitive to waterlogging, has also been drained for watertable control and in some cases for salinity control. In the Shepparton region pasture has not been drained to watertable criteria, rather a leaching fraction is extracted annually. In some areas such as the Burdekin and MacAlister it may be worth reconsidering whether the stated aim of watertables > 3 m and > 2 m respectively are completely necessary for those cropping systems or whether a reduced salinity and watertable control criteria may be adequate. Other regions such as Kerang and SWIA have also identified a lack of clear drainage criteria for long-term salinity control under current land use and irrigation management systems.

The drainage criteria that have been applied to perennial horticulture, especially in the Murrumbidgee, Riverland and Sunraysia areas, have been a target watertable depth developed to control very shallow watertables (<1 m). These watertables have resulted mostly after irrigation, although rain has also been a cause. This has resulted in drainage design coefficients of 2 to 5 mm/day and high drainage rates from these areas. However, most regions report declines in drainage in recent years. This may be attributed to climatic conditions but also improved irrigation efficiency. Considering the move in perennial horticulture to controlled irrigation systems and the greatly improved standards of irrigation management these design criteria need to be revisited as very shallow watertables are now less common. Design criteria developed to today's standards of irrigation design and management would be targeted more towards salinity control rather than waterlogging and should thus result in lower cost drainage systems with lower drainage discharges.

In relation to drainage design and discharge, many areas are now reviewing the management of all subsurface drainage systems. The aim of doing this is with a view to reducing drainage volumes due to disposal pressures and balance groundwater extraction for resource use against the basic aim of long-term salinity control. There is virtually no management of horizontal drainage systems. Integrating subsurface drainage management with irrigation management at a specific location still requires more research and a change in perspective.

The drainage method adopted depends upon the local hydrogeology. Usually, the surficial unconfined aquifers are pumped where the material is sufficiently permeable. Horizontal drains have been used in the less permeable materials or where drainage problems are very localised, e.g. only in small depressions, or break of slope.

The costs of these systems vary enormously. Groundwater pumping from spearpoint systems generally has a capital cost of about $250/ha protected whereas horizontal drains cost about $3000 to $5000/ha. This reflects the intensity of drainage that is required when protecting horticultural crops.

In terms of salinity, drainage water quality varies greatly across the regions. Lower salinity drainage water associated with pasture drainage is usually reused. Although some drainage from horizontal drainage systems associated with perennial horticulture is of lower salinity, it is generally not reused. Most drainage water that is not reused is disposed of to local river systems. However, this is a key constraint identified by all regions as disposal of saline drainage to creeks and river systems is becoming more restricted. Hence alternatives are being researched such as disposal to lucerne and woodlots. An alternative also mentioned by many areas is the use of evaporation basins, however, these have only been extensively implemented in the Mid Murray, Riverland, Sunraysia and Murrumbidgee irrigation areas.

Conclusions

Conclusions

1. New drainage design criteria that provide adequate protection for crops (with clear delineation of waterlogging and salinity control objectives) while minimising drain water salinity and volume are required.
2. Saline drainage water disposal is a key issue across all regions, which may severely restrict future implementation of subsurface drainage in irrigated agriculture. This may then be the greatest constraint to the sustainability of many irrigated areas.
3. Reassessment of drainage design criteria for many regions is required in light of recent changes in land use and irrigation management.
4. Management of subsurface drainage systems is being reviewed or is requiring review in many regions. Integrated subsurface drainage and irrigation management is in its infancy.
5. Subsurface drainage has been effectively designed and implemented for long periods in many irrigated regions of Australia. This has been conducted on a needs basis as problems appear. Thus, no region has a detailed plan of the subsurface drainage required to protect all areas with potential or existing drainage problems.
6. Subsurface drainage has historically been limited to perennial horticulture, which is the highest value irrigated crop. More recently subsurface drainage has been extensively applied to perennial pasture, as the dairy industry has become highly profitable. The cost:benefit of subsurface drainage for other crops is unclear.
7. Subsurface drainage is usually completely or partially funded by the landholder, thus restricting its implementation to high value crops. Subsurface drainage is still often subsidised as part of Land and Water Management Plans, by government grant or by low cost government loans. This recognition of the importance of subsurface drainage to irrigation sustainability needs to be continued.

PART 2

REGIONAL REPORTS OF SUBSURFACE DRAINAGE FOR IRRIGATED AREAS IN AUSTRALIA

Contents

PART 2: REGIONAL REPORTS OF SUBSURFACE DRAINAGE FOR IRRIGATED AREAS IN AUSTRALIA

BURDEKIN IRRIGATION AREA

BURDEKIN IRRIGATION AREA

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Introduction

INTRODUCTION

A limited amount of subsurface drainage has been undertaken in Queensland. There are two exceptions; an area in the Emerald Irrigation Area in Central Queensland, where an extensive subsurface drainage system covering 500 ha was undertaken in the late 1980s, and the Burdekin River Irrigation Area in North Queensland, where subsurface drainage using airlift dewatering has been underway for over five years.

Leichhardt Downs Dewatering Project

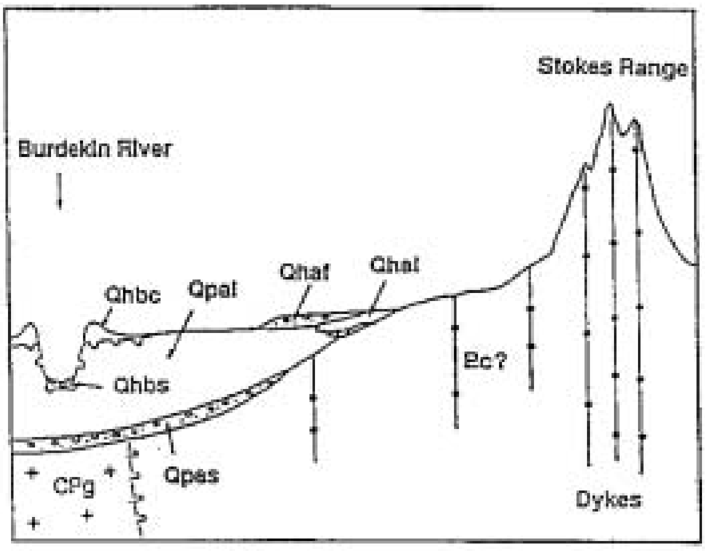
LEICHHARDT DOWNS DEWATERING PROJECT

The Burdekin River Irrigation Area (BRIA) is a relatively new irrigation area developed in North Queensland. From the early 1980s about 45,000 ha have been developed for irrigated production. Most of the land is now under irrigated cane production.

The Leichhardt Downs area is on the right bank of the irrigation area and comprises a region of 6,000 ha bounded by the Burdekin River to the west, the Stokes Range to the east and north, and the Mt Louisa system to the south. The area is geologically similar to most of the land originally targeted for irrigation development on the right bank of the scheme. It involves uplands with shallow soils developed *in situ* on a granodiorite parent material, above lower areas featuring very heavy colluvial and alluvial material of significant depth. Complicating this normal 'topo-sequence' type of formation is the widespread occurrence of dyking within the granodiorite parent material. These are on a rectangular orientation, and act as either groundwater barriers or preferential flowpaths, depending on the weathering patterns. The dyking has the effect of making the regional groundwater behave as a series of structural blocks, typically from 0.5 to 1.0 km in dimension. A representation of the geology is given in Figure 1.

Figure 1.

FIGURE 1. SCHEMATIC GEOLOGICAL CROSS-SECTION



Qhbs	current Burdekin system silts, sands and gravels.
Qhbc	current Burdekin system overbank flow deposits clay, silts etc.
Qhaf	locally derived outwash alluvial fans, sands and clays.
Qhal	locally derived clayey alluvium, thin clay soils, minor sands.
Qpal	palaeochannel infills clayey alluvium.
Qpas	palaeochannel deposits, basal sands and gravels.
CPg	Permo-Carboniferous granites major porphyry andesite dykes.
Pc	Precambrian (?) basement unconformity.

The hydrogeology of the Leichhardt Downs area and the rest of the area originally targeted for development is finely balanced. The changes induced by land clearing activities pre-development had caused salinised discharge areas upstream of dykes. Groundwater modelling had indicated that irrigation of these areas without effective groundwater control mechanisms would not be sustainable.

The Leichhardt Downs is within an area known as the Dry Tropics. Rainfall averages about 900 mm per annum, but potential evaporation is just under 2,000 mm. This feature, combined with the high salt load within the soil profile in the lower colluvial/alluvial area dictates that any drainage system must be effective at keeping the regional watertable at least 2 m below natural surface at all times. This will maintain the rootzone of the sugar cane crop above the saline groundwater, and represents a rise in the watertable of 3 to 5 m above historical levels. In reality, a 3 m target is being achieved in the pumping area and it appears necessary to accommodate the sharp response in water levels after wet season rains. An extensive surface drainage system has been provided in the area to accommodate these wet season rains; however due to the high infiltration rates (even on slopes approaching 1%) watertable responses are sharp and hence the need for subsurface drainage in this area.

The Leichhardt Downs area comprises two distinct geological environments. The western section of the area is mainly riverine alluviums, and is effectively drained by the Burdekin River Channel. Most of the irrigation development to date has taken place on this unit. The balance of the area is more poorly drained from a groundwater perspective, and irrigation there has been the subject of investigations for nearly 20 years. Limitations to irrigation development are mainly related to drainage problems associated with the topo-sequence geology, the impact of the dykes, and general low storage and transmissivity of the underlying aquifers. Solving the water management problems at Leichhardt Downs will also form the basis of future possible extensions of the irrigated area beyond Stokes Range. An area of 6,000 ha featuring similar soils and underlying hydrogeology to the Leichhardt Downs area is located at Inkerman section, 15 km further east. To adequately prove the groundwater control strategy, a long-term prototype on a manageable area was needed.

Following an investigation involving extensive drilling, long-term pumping trials, EM traverses, and the development of a detailed hydrogeological model; an area of 250 ha in the Leichhardt Downs area was selected as a prototype. A program was developed where an area would be irrigated where the modelling had predicted that the resulting accessions would make the groundwater situation unsustainable without continuous dewatering. A total area of 250 ha was selected for initial dewatering, and following a one-year-period where the dewatering system was proven; an area on the eastern side of 150 ha was leased for 10 years for irrigated cane production.

Drainage method

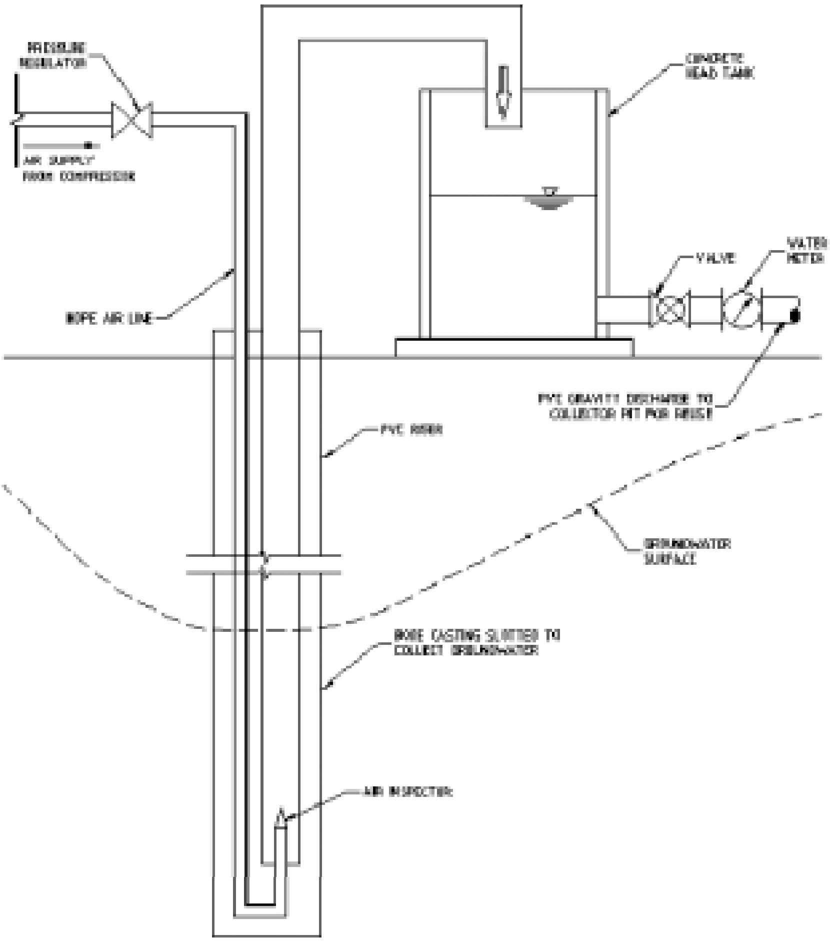
DRAINAGE METHOD

As outlined above, an area of about 250 ha in heavy clay soils with watertables approaching 2 m from the surface during wet cycles in the pre-irrigation condition was chosen for the pilot project. A study in 1994 examined a wide range of groundwater control options for the area. These included conventional tile drainage and a number of extraction methods such as submersible pumps, centrifugal pumps, solar powered submersible pumps and airlift pumps.

Airlift pumping involves moving a water column by injecting compressed air into the water at the base of the column. A schematic layout of the arrangement used for the airlifting in the BRIA is shown in Figure 2. Inherent advantages of this drainage pumping method are the low cost of the bore downhole installation, which can be of cheap slotted PVC piping, and the low cost of the energy source transmitted to the individual bores from the central compressor. Countering this is the higher, ongoing energy costs as a result of the low energy efficiency associated with converting electricity to pumped water.

Figure 2.

FIGURE 2. SCHEMATIC OF AIRLIFTING ARRANGEMENT



Based on the low transmissivity of the underlying fractured rock aquifer (typically about 10 m^2/day) and the consequent need for a number of extraction points on even the 250 ha trial area, an extraction method based on airlift pumping was recommended as the economical choice for the installation.

A total of five bores were equipped on the 250 ha area operated from a centrally located 7.5 kW, 65 cfm compressor, and the system began operating in 1995. About 150 ha of the area was leased for farming and was planted with cane early the following year. Since that time, the airlift dewatering has maintained the regional watertable about 3 m below natural surface, except for a short time in 1997 when the regional watertable rose in response to a sustained wet season, and in 1998 following a two-month shutdown of the compressor. In both cases, the dewatering array was able to lower the watertable in an acceptable time following the rise with no degradation.

Dewatering Bore, Leichhardt Downs

DEWATERING BORE, LEICHHARDT DOWNS

Drainage design

DRAINAGE DESIGN

The design of the dewatering system involved a number of steps. Firstly, the existing hydrogeological models (which were calibrated based on historical data) were used to predict the total extractions that would be necessary from the farm area to ensure stable groundwater conditions. The modelling indicated that 12 L/s total extraction would be necessary to achieve the required freeboard based on irrigation rates of 900 mm/year @ 0.3 dS/m and 900 mm/year of rainfall. Average leaching fraction has been about 0.13. The method of extraction was then determined as outlined above.

The airlift dewatering array and the associated collection, reuse and disposal systems were designed by Steve West (trading as Australian Salinity and Catchment Management) based on notional bore yields and locations.

Bores were drilled at sites which were compromises between locations predicted by the modelling as being effective and being practical from a farm layout perspective. As bores were drilled, they were pump tested and if unsatisfactory, were retained as monitoring points. In total, six pump wells and thirty nine observation holes were eventually drilled in the 250 ha area. Pump well spacing varied because of variations in soil type and geology, but on average a pump well will service 40 ha. Well depth was 30 m for the air pumps and PVC screening was used.

The arrangement for the main supply lines and effluent lines proved adequate, but the efficiency of the air injectors was improved markedly by trial and error changes to the air injector geometry after the installation was up and running. The proprietary advantage claimed by West for his configuration, covered at that time by a patent application proved illusionary because of air leakage, high maintenance costs including replacement of the compressor and need to replace injector nozzles.

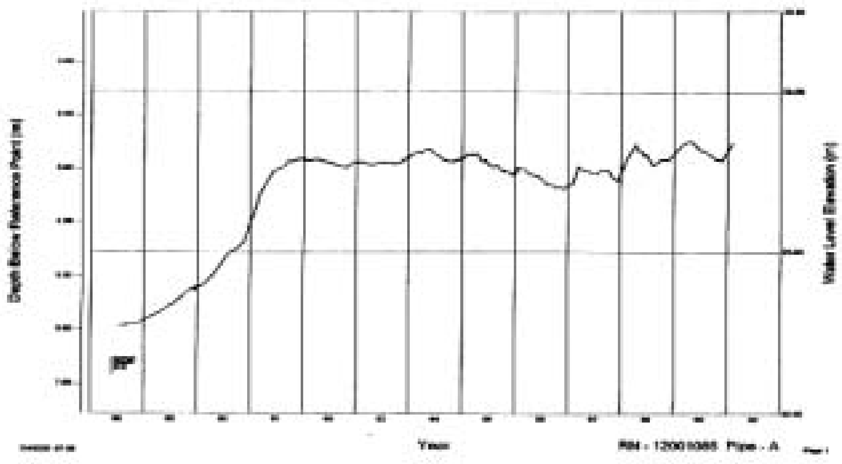
The design of the array as analysed from the surrounding monitoring points, was therefore a compromise between the generalised transmissivity values derived from the groundwater modelling, and the site-specific values derived from the bore pump tests. In general the agreement was found to be quite good, with only one of the six production bores exhibiting low transmissivity and high drawdown associated with some of the dyking features.

As the site was localised compared to the total aquifer accessible to the air pumps, the design also had to be a compromise between achieving adequate control over water levels on the farmed area, and drawing down too far and thus becoming a sump for the entire Leichhardt Downs area. When initial drawdown had been achieved, the pump flow was scaled back from its initial value of just below 20 L/s to the current value of about 12 L/s to avoid draining too large an area.

The airlift array has been successful over the longer term in maintaining water levels at the desired freeboard below the farmed areas. Figure 3 shows the water level trace for Bore 12001085 located on the eastern (highest) edge of the farmed area.

Figure 3.

FIGURE 3. WATER LEVEL TRACE FOR BORE 12001085



Figures 4 and 5.

Figures 4 and 5 give water level plots for the Leichhardt Downs area at the start of the pumping in 1995 and the current situation.

FIGURE 4. WATER LEVEL AT START OF PUMPING

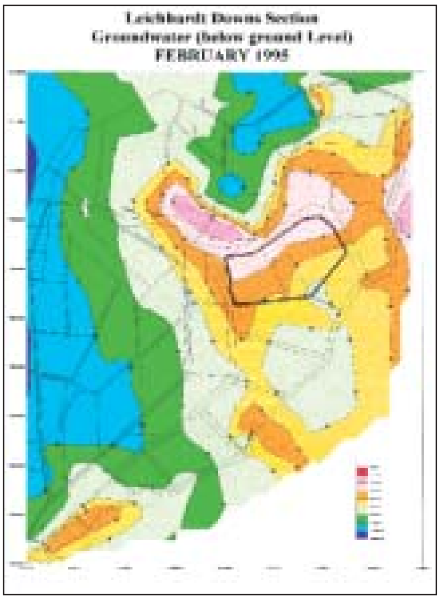
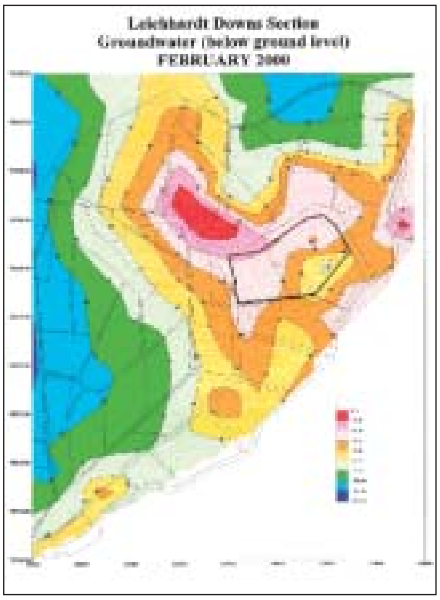


FIGURE 5. CURRENT WATER LEVEL



DRAINAGE WATER QUALITY

The quality of groundwater in Leichhardt Downs is extremely variable, both laterally and vertically. Water quality ranges from 0.11 to 21.4 dS/m, and averages 5.2 dS/m across the total area. The average water quality of the effluent from the airlift pumping in Leichhardt Downs is about 6 dS/m.

The ionic composition of groundwater shows high levels of hardness over a wide salinity range, which indicates that the groundwater is saturated or supersaturated by a wide range of carbonate minerals. The probable origin of groundwater salinity is from dissolution of minerals (mainly carbonates) through weathering, concentration through evapotranspiration, leaching from soils and precipitation of minerals.

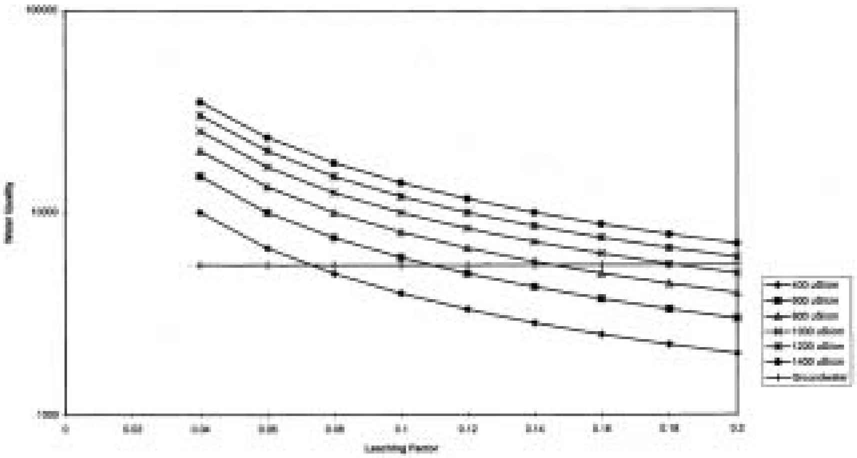
Salinity is well above the adopted limit for cane production irrigation with the expected leaching fraction, which would indicate an absolute maximum salinity of 1.5 dS/cm. The Leichhardt Downs farming area drains to the Burdekin River upstream of the major Burdekin Water Board area, which means that discharging the effluent into the adjacent Cassidy Creek is not acceptable. It has therefore been necessary to design into the airlift groundwater control system an arrangement where a proportion of the effluent is stored in a central holding reservoir for mixing with the incoming irrigation water. At each of the bore locations, a concrete cylinder is installed to provide a receptacle into which the airlift bore discharges. Sufficient head is generated in the cylinder to allow distribution of the water to this central holding reservoir.

The original intention was that 50% of the discharge from the airlifts would be mixed with the incoming water to produce an irrigation water of below 1000 mS/cm salinity. Theoretical considerations based on a rootzone salinity threshold level of 1.7 dS/m indicated an irrigation water quality of 0.7 dS/m, however, experience indicated that salinity below 1 dS/m was sustainable. Over the past five years, the proportion of water actually used back on the farm has been less than the targeted 50%. This was because of the lack of penalties for failing to reuse the water, and poor acceptance of the use of saline water for irrigation. Acceptance of saline water for irrigation is now increasing.

The theoretical relationship between leaching fractions, initial effluent quality and irrigation water quality based on a simple salt mass balance approach is shown in Figure 6. In reality, the situation is not as simple because of macro pores in the soil structure and the non-uniformity of the underlying aquifer. To date what reuse has taken place has not had any measurable detrimental effect on the soil profile. Modelling indicates that there may be some net import or export of salt to some areas, but on average salinity should be relatively constant.

Figure 6.

FIGURE 6. DEEP DRAINAGE WATER QUALITY



Plans are being developed for irrigating the remaining 500 ha section of the Leichhardt Downs Area. If this proceeds, total continuous extraction of 4.1 ML/day or 51 L/s is necessary from the area. On the basis of half of this being reused on-farm by storage and blending with the oncoming irrigation water, 2 ML per day will have to be exported. It is not practical to discharge this quantity of high salinity water directly into Cassidy Creek. It is therefore planned to pipe it to the Burdekin River via a 250 mm diameter HDPE pipeline. The impact on the water quality of the Burdekin River (under the lowest discharge regime applying to the Burdekin) will be an increase in river salinity of between 4 and 8% depending on the river salinity at the time.

System management and monitoring

SYSTEM MANAGEMENT AND MONITORING

The groundwater control system at Leichhardt Downs is a totally manual system to maintain the watertable at a minimum depth of 2 m below natural surface. The air injection rate and, therefore, the abstracted groundwater flow rate are changed manually in response to a variation in the groundwater level.

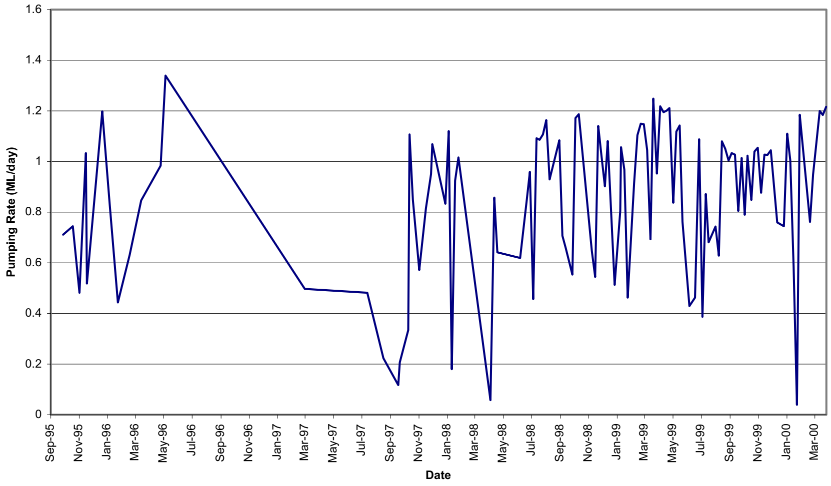
The system is managed through an informal arrangement and is monitored by and the responsibility of the Resource Management, State Water Projects, Department of Natural Resources, Ayr.

Parameters monitored at present are groundwater levels, bore flowrates, salinity and ions in the bore discharge and farm runoff. The results of the monitoring are reported on the State Groundwater Database and evaluated by State Water Projects.

The total flow extracted by the dewatering system is shown in Figure 7.

Figure 7.

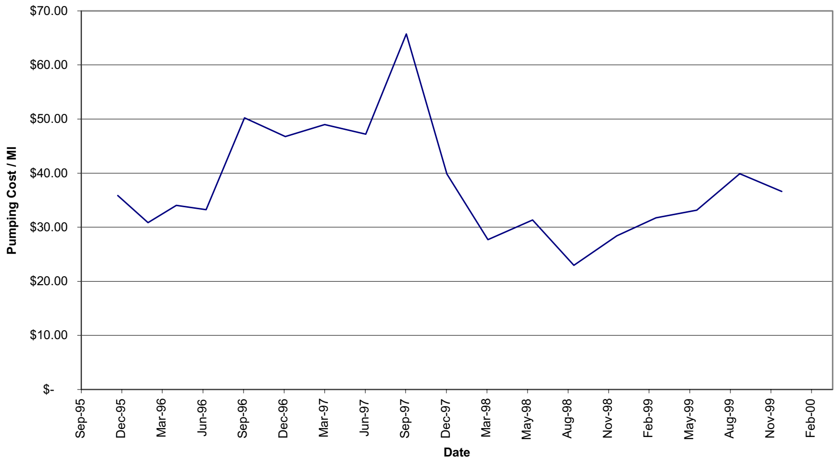
FIGURE 7. TOTAL EXTRACTIONS OF LOT 56



The dewatering system has been operating at a capacity of between 0.8 and 1 ML/day since 1995. The operating cost is shown in Figure 8. The effective cost of the system is $37 per ML over the intervening period.

Figure 8.

FIGURE 8. OPERATING COSTS OF LOT 56



Drainage funding

DRAINAGE FUNDING

This subsurface drainage project has been funded as a joint venture between State Water Projects and Regional Infrastructure Development as a trial for developing the Burdekin River Irrigation Area.

Capital cost for the works was $66,500 in 1993. Operating and maintenance costs are currently around $13,000 per annum.

Current issues and trends

CURRENT ISSUES AND TRENDS

Further development of the Burdekin River Irrigation Area is currently planned based on the success of this subsurface drainage trial. The key issues are sustainability of irrigation and disposal of abstracted groundwater.

Drip irrigation is currently being trialled by landowners in a small area on the right bank, but alternative methods of irrigation have not been considered in the Leichhardt Downs area at this time. Part of the new area proposed for development is comprised of red soils with high leaching fractions, and therefore alternative irrigation methods will be necessary to avoid unacceptable deep drainage rates to maintain the level of the watertable.

A voluntary Environmental Management Plan has been produced for expanding the area. The objective of the EMP is to ensure sustainability of the irrigation area by:

> protecting the soils of the irrigation area from salinisation and waterlogging
> preventing excessive rise in the watertable
> protecting the water quality of Cassidy Creek
> protecting the water quality of the Burdekin River.

These objectives will be achieved by:

> using water quality, watertable depth and soil salinity as environmental indicators and establishing a monitoring regime to measure the indicators at key locations
> setting acceptable limits on water quality, watertable depth and soil salinity based on the risk of environmental harm
> establishing response actions for each environmental indicator which exceeds acceptable limits
> establishing a system for reporting monitoring data, compliance status and management responses.

A summary of the monitoring regime, the performance objectives for environmental indicators and the designated response actions for non-compliance is presented in Table 1.

A Land and Water Management Plan will be required from each landholder in the Burdekin River Irrigation area and landholders not adhering to the plans will incur penalties.

Table 1.

TABLE 1. SUMMARY OF MONITORING, PERFORMANCE OBJECTIVES AND RESPONSES

Location	Parameters	Frequency	Performance objective	Response to non-compliance	Comment
Water quality					
Burdekin River (Clare River)	Electrical conductivity Total Nitrogen Total Phosphorus	Quarterly	Maintain river water to within 10 percent of maximum-recorded levels in B9.	Confirm by monthly monitoring that the source of elevated analyses is not discharge from Leichhardt 2a.	
Cassidy Creek (lower reaches)	Electrical conductivity Total Nitrogen Total Phosphorus	Quarterly	On the basis of baseline studies.	Identify the source of non-conformance.	
Cassidy Creek (downstream of Lot 59)	Electrical conductivity Total Nitrogen Total Phosphorus	Quarterly	On the basis of baseline studies.	Identify the source of non-conformance.	
Discharge pipeline (intake)	Electrical conductivity Total Nitrogen Total Phosphorus	Quarterly	Ambient river quality will not be increased by greater than 15% through discharge.	Identify source by measuring individual dewatering bores. Adjust groundwater/channel water discharge ratio.	
Burdekin River (2 km downstream of discharge)	Electrical conductivity	Quarterly	EC < 0.15 dS/m	Confirm relative contributions of salts from pipeline and upstream Burdekin River.	
Watertable					
Monitoring bore array (18 piezometers)	Water level	Monthly	> 2 m below surface	Increase dewatering rates.	Pre-existing DNR monitoring location
Salinity					
Soil salinity profiles	Soil salinity EM 38 survey and soil sampling	Annually	Maintain or reduce salinity and conductivity profiles in all soil types.	Reduce salinity of applied irrigation, apply gypsum.	
	Sodicity	Annually	No increasing trends in salinity.	Reduce salinity of applied irrigation, apply gypsum.	

National Program for
Irrigation Research and Development

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EMERALD IRRIGATION AREA

EMERALD IRRIGATION AREA

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Background

BACKGROUND

The Emerald Irrigation Area was established in 1968 to develop the agriculture potential of the Emerald region in Central Queensland.

The central feature of the scheme is Fairbairn Dam on the Nogoa River, which was constructed between 1968 and 1972. The dam operates in conjunction with the Bedford, Bingegang and Tartrus weirs on the Mackenzie River, and can supply 218,000 ML of water a year for agriculture, mining and urban uses.

Water is delivered from Fairbairn Dam to the Emerald Irrigation Area via the Selma and Weemah main channel systems. Channels are mostly of open earth construction with some short lengths of pipeline and lined channel. Most farms use a system of furrow irrigation. Water is siphoned from on-farm head ditches into downhill rows. Surface drainage systems are provided throughout the area to remove surplus irrigation and stormwater runoff from farms.

Figure 9.

FIGURE 9. EMERALD IRRIGATION AREA

Description of the drainage problem

DESCRIPTION OF THE DRAINAGE PROBLEM

Soon after irrigation began on the left bank of the Emerald Irrigation Area, high groundwater problems appeared on several farms. By 1977, ten farms had reported areas of irrigated land affected by waterlogging and associated salinity.

To identify areas with high groundwater problems, the Water Resources Commission defined 'affected areas' as those that had watertable levels within 1.2 m of the ground surface. These criteria were based on the average root depth of cotton, the primary crop of the Emerald Irrigation Area. Cotton growth was severely stunted in the affected areas.

Detailed investigations in 1978 and 1979 showed that over 100 ha of irrigable land on twenty farms could be classified as suffering from the effects of high groundwater levels. In one instance, the area affected on a farm exceeded 40 ha or over twenty percent of the farm's total irrigable area of 200 ha.

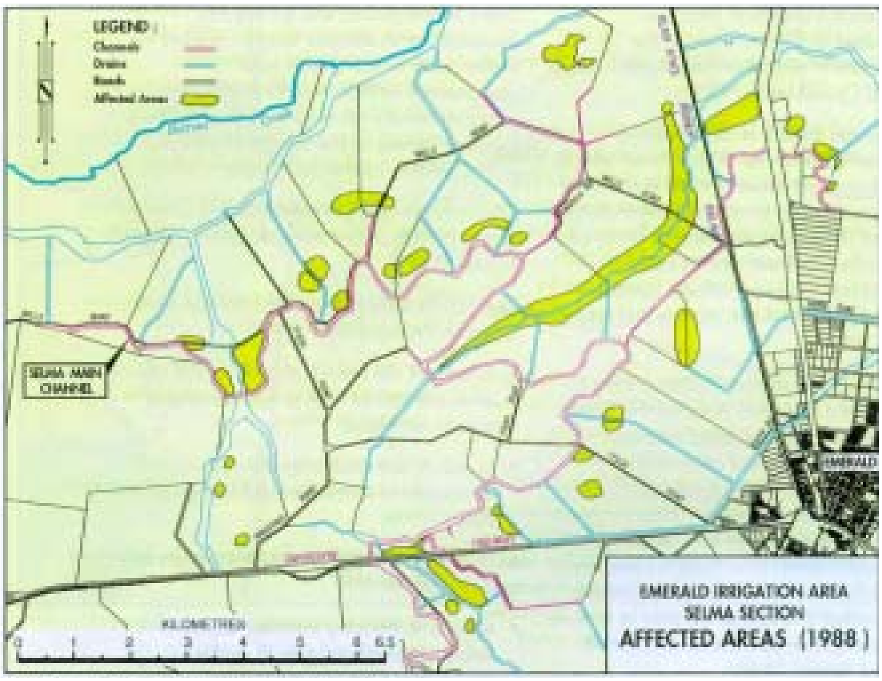
The affected areas generally occurred either in the middle or at the bottom end of an irrigated field. Their stunted vegetation cover, permanently waterlogged soil, and the appearance of salt deposits on the soil surface easily identified problem areas.

The effects of these conditions included:

> reduced seedling emergence, crop growth and final yields resulting in a decline in overall agriculture production
> problems with on-farm trafficability and possible damage to expensive farm machinery
> the use of less efficient farm management practices, such as shortening crop row lengths to avoid affected areas and modifying watering techniques to account for the presence of wet areas
> soil degradation as a result of salts concentrating and depositing within the rootzone of plants.

Figure 10.

FIGURE 10. MAP OF AREAS AFFECTED BY WATERLOGGING AND/OR SALINITY



The most important factor contributing to the problem of rising groundwater levels on farms at Emerald is a characteristic change in soil profile that occurs, generally midway down the slope. Rising water levels usually occur near the interface where shallow up-slope soils meet with deeper down-slope soils.

The shallow up-slope soils are underlain by moderately fractured and weathered basalts (hydraulic conductivity is estimated as 3.7 m/day). This provides a highly permeable aquifer through which the groundwater can flow. The deeper down-slope soils are underlain by older and completely weathered basaltic clays that are less permeable. The less permeable down-slope subsoil restricts groundwater flow and water percolates to the surface, creating waterlogged areas.

Ground slopes vary but are about 1 to 1.5% for most of the irrigated area.

Sources of water contributing to the problem were investigated and found to include; seepage from earth channels, seepage from on-farm head ditches and tail drains, and deep percolation from irrigation and rainfall.

Agricultural production was affected by rising watertables in two ways. Firstly, crop growth was directly affected by waterlogging near or at the soil surface. Waterlogging results in anaerobic conditions establishing in the rootzone, retarding vegetative development.

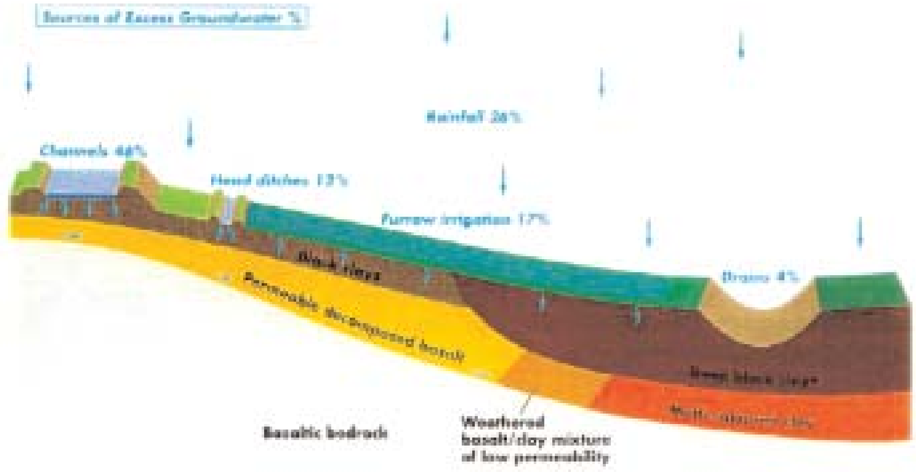
Secondly, rising groundwater was causing the upward movement of soluble salts from the subsoil. The subsequent evaporation of the groundwater caused salts to concentrate and be deposited within the rootzone of plants, severely restricting plant growth. Where groundwater levels continued to rise unchecked, salt deposits appeared at the soil surface and a barren scald formed.

The shallow up-slope soils rarely became salinised at the surface as groundwater levels rose. However, crop growth was visibly affected for a considerable distance up-slope from the soil change boundary due to waterlogging.

In contrast, the down-slope soils became saline at the surface as water levels rose, producing obvious soil degradation and poor plant growth. Down-slope of the soil boundary the watertable dropped rapidly and soil and crop effects diminished.

Figure 11.

FIGURE 11. CROSS-SECTION SHOWING SOURCES OF EXCESS GROUNDWATER AND THE MIDSLOPE SOIL PROFILE CHANGE



The Water Resources Commission initiated a number of trials involving various types of channel lining as well as subsurface drainage schemes to determine the most effective way to deal with the problem.

Exposed membrane channel lining systems were found to fail within one to four years of their installation. Although membranes buried under channel batters performed better than the exposed systems, waterlogging problems were still evident. This was due to the other sources of excess groundwater, including irrigation percolation, rainfall and seepage from drains, being left untreated.

Changing the irrigation system was also investigated, however, because of the nature of the cropping systems and the associated pest profile, underground trickle irrigation was the only alternative. However, economic evaluation eliminated this option.

Subsurface drainage was found not only to be cheaper than all tested channel lining systems, but was also the most comprehensive way of removing groundwater irrespective of its source.

A number of subsurface drainage trials were conducted in several locations within the irrigation area to assess the relative performance of various drainage systems. These trials led to the development of design rules that resulted in the successful performance of the subsurface drainage systems. Parameters optimised included:

- drainage network layout and spacing
- pipe depth
- the use of various filter and bedding materials
- minimum pipe grades.

Fundamental to the ultimate success of the Emerald Subsurface Drainage Project was the high level of community involvement and cooperation at every stage of the scheme.

Members of the farming community took an active role in the investigations, particularly in monitoring the performance of trial drainage systems. In addition, the cooperation of landholders in facilitating trials that interfered with or modified their farm management practices enabled a set of innovative design and construction rules to be developed.

Drainage method

DRAINAGE METHOD

Reclaiming waterlogged and salinised farming land can be a costly exercise, both in installation and maintenance of works. However, the solution to the problem at Emerald used a cost-effective, non-intrusive design to ensure a sustainable future for the land resources in the region.

Extensive investigations and subsurface drainage trials allowed Emerald to adopt interceptor drainage concepts that, although applied elsewhere in the world, were unique in Australia.

Lessons learnt from the Commission's investigations and drainage trials were applied in the evolution of a set of design rules customised for the Emerald problem.

Figure 12.

FIGURE 12. THE EFFECT OF HIGH GROUNDWATER

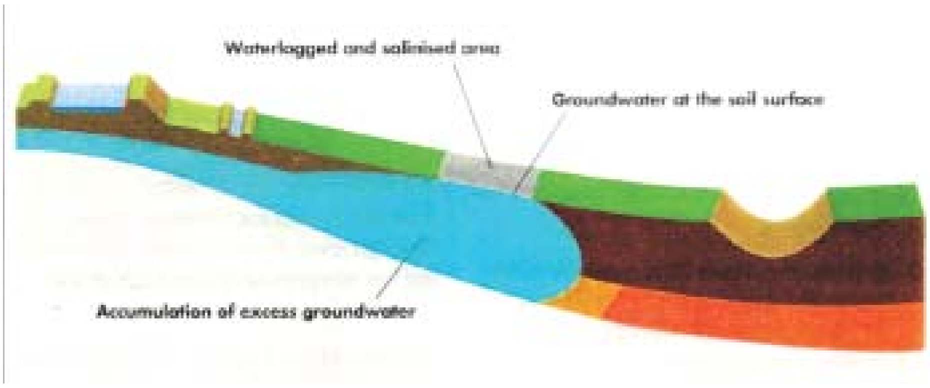
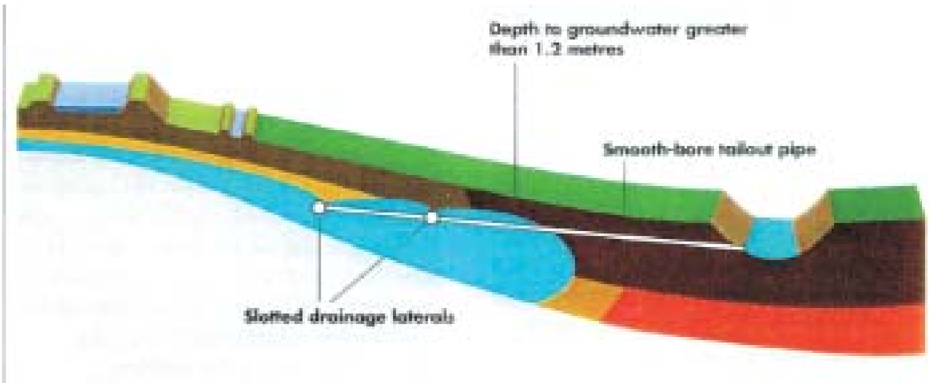


Figure 13.

FIGURE 13. THE CONTROL OF HIGH GROUNDWATER USING SUBSURFACE INTERCEPTOR DRAINS

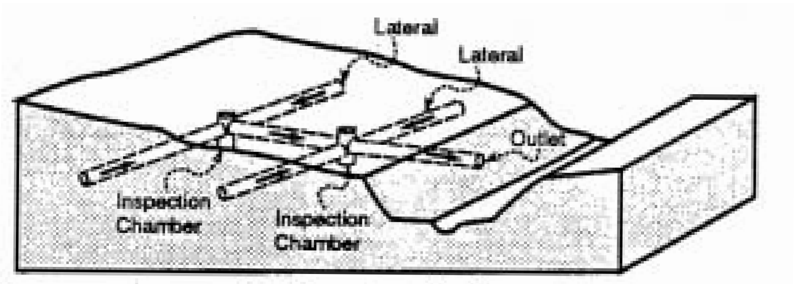


The subsurface drainage systems at Emerald consist of slotted drainage pipe laid along the slope at a depth of between 2 and 4 m below the soil surface. This depth is necessary to ensure that the drains are located within the permeable weathered basaltic subsoil. The drains operate primarily by intercepting the downslope groundwater flow rather than by simply ‘draining’ the excess groundwater. Hence, the watertable is drawn down asymmetrically about the pipe. The water level upslope of the pipe has limited response to the drain, while the effects may be evident for hundreds of metres downslope of the pipe.

The drainage pipes are run into buried concrete inspection chambers and water is disposed of via smooth-bore drainage pipe to the irrigation area’s surface drainage system.

Figure 14.

FIGURE 14. TYPICAL LAYOUT OF SUBSURFACE DRAINS



The subsurface drains have proved to effectively reclaim the affected areas. Waterlogging of the soil surface is diminished as the watertable is lowered. The continuous leaching of soluble salts from the rootzone during irrigation and rainfall decreases the salinity of affected areas. Once the problems of waterlogging and salinity are removed, the land can be restored to its original productivity.

Since the subsurface drainage schemes are designed to operate under gravity without the aid of electric or diesel powered pumps, the Emerald Subsurface Drainage Project is virtually invisible. The only features betraying its existence are the subsurface drainage system outfalls located in the bed of surface drainage systems throughout the area.

Drainage design and implementation

DRAINAGE DESIGN AND IMPLEMENTATION

The objectives of the Emerald Subsurface Drainage Project were to:

> control the spread of, and reclaim the areas affected by high groundwater and salinity problems
> ensure sustainable agricultural development in the Emerald Irrigation Area
> increase productivity in the Irrigation Area
> assist in creating a greater degree of stability and rate of growth in the economy of Central Queensland.

These objectives were in accordance with several of the organisational goals of the Water Resources Commission, in particular to:

> achieve a close liaison with the community to determine its needs and discuss water-related needs openly
> maintain, and where practicable, enhance the quality of water and the associated environment for multiple uses and values
> obtain optimum benefits for the community through flexible management and efficient use of water resources.

The design process included surveying and documenting each affected area. This involved excavating test holes in a 100 m grid to ascertain the extent of the affected area and soil profile information. Maps of the affected area were prepared and used to design the subsurface drainage layouts.

Due to the topography and layout of the farms and the location of the affected areas, individual interception drainage schemes were required.

Also, because of the complex and variable geology of the basaltic materials, hydraulic properties and accession rates were highly variable. Average figures were considered sufficient for first approximations and preliminary designs, but final designs were based on accurate field data.

A set of design rules were required to achieve "adequate" drainage, which is defined as the amount of drainage necessary for agriculture to be successfully and permanently maintained.

From the results of the subsurface trials (Claydon 1982), the following design rules were used for preliminary designs:

- Provide, in general, for interceptor subsurface drains.
- Aim to maintain the watertable at least 1.2 m below the ground surface.
- Locate the highest lateral (interceptor) no more than 40 m down-slope from the location of the highest summer 1.2 m depth to watertable line.
- Make drains as deep as the relatively harder basalt barrier as conditions permit, e.g. at typical depths of 2.5 to 4.0 m.
- Locate extra interceptors at spacings of 150 to 200 m if necessary.
- Orientate the interceptors to use available paddock slope to best advantage. Drain gradients should be no flatter than 0.15 m per 100 m.
- Provide the minimum number of outlets to the commission's drainage system.
- Use continuous pipes without perforations, slots or open joints at the bottom of slopes, and at outlets where the depth of cover is less than 2 m to stop root growth from blocking the drains.
- Use junction boxes or manholes where two or more drains join or at 200 m intervals. If the junction point is in cultivation, the top of the box should be at least 900 mm below the ground, sealed, covered with soil and its location referenced so that it can be found.
- Adopt a minimum diameter of interceptor drains of 100 mm with main carrier drains of 150 mm.

Individual drainage schemes were designed by the Water Resources Commission or by consulting engineers to commission standards.

Construction of each subsurface drainage scheme began after the landholder had approved the design and agreed to monitor a system of observation bores.

Laying pipe at depths of between 2 and 4 m required either trench benching or the use of trench shoring to provide a safe working environment.

As construction was usually in areas with waterlogged surface conditions, the average rate of installing pipe was about 80 m/day. Water in the excavated trench, large 'floating rocks' in the soil, and isolated rock bars also tended to reduce construction rates.

Water Resources Commission staff investigated, designed and constructed the Emerald Subsurface Drainage Project.

Construction began in 1987 after approval by Government in 1986. By February 1992, subsurface drainage schemes were installed on over 95% of farms affected by high groundwater.

A relatively small management, investigation, design and construction team carried out the project. On several occasions it was necessary to use two construction crews to ensure that installing subsurface drainage schemes did not conflict with farming activities or summer rains.

Drainage water

DRAINAGE WATER

The water discharged from the subsurface drainage is of good quality and subsequently reused for irrigation. Electrical conductivity of 0.6 dS/m is normal.

System management and monitoring

SYSTEM MANAGEMENT AND MONITORING

As the system relies solely on gravity flows and not pumping for subsurface drainage, it requires no ongoing management and there are no operating costs.

The Water Resources Commission regularly monitors an observation bore network throughout the Emerald Irrigation Area. Discharge from subsurface drainage outfalls is also routinely recorded. At the outset of the project landholders with on-farm works agreed to monitor water levels in observation bores on their properties.

The quality of water discharged from the subsurface drainage schemes into the surface drainage system and ultimately to the Nogoa River is monitored on an ongoing basis. The commission has undertaken a five year water quality monitoring program to quantify aspects of water quality associated with subsurface drainage outflow and the Emerald Irrigation Area in general. The program included the analysis of subsurface drainage water, tailwater, runoff and river water quality.

Losses of water from the irrigation channels have risen since installing the subsurface drainage. From the available figures, losses before construction of the drainage were 12 ML/d and recently losses calculated from a water balance are 60 to 70 ML/d. A project to measure the losses from selected sections of channel is in progress.

The design of subsurface drainage systems was based on experience gained from early trial systems to ensure minimum maintenance requirements. Design features included:

> specifying minimum pipe grades to prevent silting in the pipes
> using filter bedding gravel to prevent pipe movement or collapse
> installing slotted pipe deeper than 2 m to avoid interference from tree roots
> using inspection chambers at all network nodes to help monitor individual sections of the subsurface system if necessary.

Incorporating these features ensured that the installed subsurface drainage schemes required little or no maintenance.

Funding

FUNDING

The Queensland Government and the local landholders jointly funded the system. About 55 km of drainage pipe and associated tailouts were installed and 500 ha of formerly waterlogged and salinised land has been returned to its naturally fertile state and ensured the sustainability of agriculture in the region.

In 1992 the final forecast cost of the project was $2.33 million. The total landholder contribution to this cost was $600,000 in the form of a drainage levy over a ten-year-period with the balance funded by the Queensland Government.

The cost of installing the drainage system equated to an average of $4,644/ ha drained or $44.00/m of installed drain. Costs varied significantly between sites as a consequence of variable site conditions and construction rates. Given that small areas affect production on a larger scale and that developed land in Emerald is valued at $5000/ha, the cost:benefit is most certainly greater than one.

Financially, the increased return from the area represents a boost to the national economy of around $3.5 million a year.

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KERANG IRRIGATION AREA

KERANG IRRIGATION AREA

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Location and hydrogeology

LOCATION AND HYDROGEOLOGY

Location and climate

The Kerang Region described in this report includes the Goulburn-Murray Water Irrigation areas of Torrumbarry and Pyramid-Boort, but excludes the pumped irrigation districts (Nyah, Woorinen and Tresco) and other horticultural developments based on mallee soil types.

Kerang is in northern Victoria at latitude 38° south and longitude 144°. The climate is semiarid with an annual Class A pan evaporation of 1,390 mm and average rainfall of 365 mm. The maximum average daily temperature ranges from 31.3°C in January to 13.5°C in July. Minimum average daily temperatures range from 14.5°C in January to 3.9°C in July.

Figure 15.

FIGURE 15. LOCATION OF THE KERANG IRRIGATION DISTRICT

Geology and soils

The Shepparton Formation forms the uppermost geological strata in the Kerang Region. An alluvial fan of relict ‘prior stream’ deposits extends from the highland areas northward across the riverine plain. Well-defined levee banks mark the most recent prior stream deposits. To the north and west of the region, prior stream geomorphology gives way to a flat, featureless floodplain. In this area the upper Shepparton formation (6 – 25 m) generally comprises fluvio-lacustrine deposits, clayey sands or silty clays of moderate hydraulic conductivity (0.1 – 1 m/d), which behave as a layered, unconfined aquifer. From 25 to 50 m there is usually a clay aquitard.

Below a depth of 75 m there is a substantial regional aquifer (Calivil Sand) of coarse gravels in well-defined channels, known colloquially as ‘deep leads’. In the north of the region the Calivil Sand is present as a broad sheet aquifer, overlain in most areas by fine sand and clay deposits associated with the Parilla Sand Aquifer. Brown coal deposits (Renmark Formation) are generally found below the Calivil Sand[1]. The Parilla Sand (where present), Calivil Sand and Renmark Formation together are called ‘the deep aquifer’ in this report.

Large shallow lakes are found in the north of the region. The lakes have a clay ridge or lunette on the eastern fringe. It is thought the lunettes were formed by alternate salination and wind erosion of the lakebed[i].

The shallow groundwater is highly mineralised with an electrical conductivity from 30 to 50 dS/m while the water in the deep aquifer system has a lower electrical conductivity, generally between 1 and 10 dS/m.

The soil type is a saline-sodic cracking clay soil either red or grey in colour. The clay mineralogy is a mixture of illite and montmorillonite. The subsoil has a coarse, prismatic structure and often contains calcium carbonate concretions and gypsum crystals in distinct soil horizons.

Many of the soil and geomorphic features indicate that groundwater discharge has been an important element in shaping the landscape and soils of the region. The introduction of irrigation to the area has resulted in a shift in the hydrologic equilibrium toward increased groundwater discharge resulting in secondary salination.[ii]

Prior stream ridges are a common feature in northern Victoria. In the Kerang Region other prior stream ridges include the Calivil and Yarrowalla Ridge in the south, and the less well developed 'Reedy Creek' ridge in the northeast. The lighter texture soils in the upper part of the prior stream ridges mean these areas are highly sought after for intensive irrigation development, particularly dairying. The local recharge and discharge, called 'dry drainage' in the report, is typical in all prior stream ridges in the district. The Mead Ridge is probably atypical in that the bed of the relict 'prior stream' often has a deep surface drain constructed in the bed, which forms part of the 'Barr Creek' drainage system. The deep surface drain tends to collect regional groundwater, as well as irrigation runoff, and therefore behaves as an extensive subsurface drain.

The prior stream ridges in the Kerang Region probably account for 30 to 40% of the land area, and more than 50% of the irrigation use. The rest of the area is farflood plain equivalent of the prior stream ridges, or floodplain associated with the Loddon and Murray rivers. In general, the floodplain areas have lower irrigation intensity, a higher proportion of saline land, and are more influenced by regional groundwater discharge processes and less dependent on the local 'dry drainage' process described later.

Land use

LAND USE

The irrigated area is 183,000 ha, which is 56% of the total land area. The main land use is irrigated pasture.

Intensive dairy production is mainly found on prior stream soil types in the south and northeast of the region. In these areas the farm size is typically from 50 to100 ha and water use is from 6 to10 ML/ha.

However, over most of the region the farm size is much larger, typically from 100 to 500 ha, and water use is much lower, typically from 2 to 4 ML/ha. On these farms beef cattle or sheep are grazed on annual pastures irrigated in autumn and spring to extend the winter growing season. There are significant areas of winter and summer crops and lucerne, particularly in the south of the region where salinity is less prevalent.

In recent years there has been growing interest in horticultural development in the mallee fringe soil types to the north and west of the Kerang Region. The soil types and drainage problems in areas associated with the geomorphology of the mallee are described in the Sunraysia Regional Report.

Nature of problems and adopted solutions

NATURE OF PROBLEMS AND ADOPTED SOLUTIONS

Development of the drainage problem

Groundwater levels are thought to have been between 7 and 10 m below the land surface before irrigation. The watertable rose quickly after irrigation began in 1884. A shallow watertable was recorded at a depth of 2 m near Kerang in 1902. The increased allocation of water after 1923 intensified the problem. Currently it is estimated high watertables closer than 2 m to the surface occur over 65 to 75% of the region. Capillary rise of saline groundwater has resulted in secondary salination of 40% of the region.[iii]

The problem is further exacerbated by regional groundwater flow in the deeper aquifer system at a depth from 50 to 120 m. In the northern part of the region, artesian pressure levels occur in the deeper aquifer over most of the area. The high-pressure level in the deeper aquifer precludes natural drainage and results in a small upward flow of groundwater in areas of low elevation. It is thought that removing native vegetation in the south of the irrigation district may be the root cause of increasing pressure in the deeper aquifer, although in practice it is difficult to separate the impact of groundwater recharge in irrigation areas from hydrogeologic processes further up-basin.

Effects of waterlogging on pastures

The Institute for Sustainable Irrigated Agriculture in Tatura, Victoria, has studied the effects of waterlogging in the Kerang Region in a project running parallel to the NRMS 2137 study. The effect of complete surface inundation was investigated (as opposed to yield loss associated with a high watertable), however it is a reasonable assumption that results for inundation due to a temporary high watertable would be similar. Measurements of oxygen potential were taken during the NRMS 2137 study and at no time were oxygen potentials observed that would have indicated yield loss.

In replicated trials, surface inundation events of 18 hours and 30 hours actually yielded better than the control, where inundation was for 6 hours. Only after 54 hours surface inundation was there a yield loss in either quality or quantity of pasture. Similar research at Deniliquin and Kerang confirms these results. Work in Holland has suggested an optimum watertable depth for pasture is very high, say, 0.3 m below ground surface. Therefore, good surface irrigation, and irrigation timing in spring and autumn using continuous soil moisture measurement, and prudent stock management can reduce the yield loss associated with waterlogging without the need for subsurface drainage. This is as long as the groundwater is non-saline.

There are four distinct periods of watertable movement after irrigation when a high watertable is present. These periods are as follows:

- inundation and watertable level close to the surface
- a sudden fall in water content as the watertable level falls below the point of measurement
- slow water content decline
- rapid water content decline with substantial diurnal variation, thought to be related to active soil water extraction.

Considering these factors, as long as the period of inundation is less than 48 hours, there will be no yield loss of pasture associated with temporary high watertable levels. Presumably there is still high oxygen potential in the soil water during this period, since there is no adverse effect on plant metabolism due to the anoxic conditions. It is, however, common to see more prolonged inundation, particularly where rainfall occurs soon after irrigation.

Loss of soil structure associated with stock damage on wet soils is an important aspect that has not been studied, and should be better communicated to farmers. Waterlogging associated with crops, and more particularly horticulture, is clearly greater than for pasture. Even for pasture, there may be a penalty associated with prolonged inundation and consequent development of a shallow root system.

Solution to the problem

SOLUTION TO THE PROBLEM

Intensive irrigation areas

In intensively irrigated areas the main land use is perennial pasture, and irrigation water quality generally has an EC less than 0.4 dS/m. Studies have shown the recharge varies both temporally and spatially. In a recent study in the Cohuna District, a site high in the landscape representing the sandy loam soil type at the top of the prior stream soil association had a net leaching fraction of 29 to 50 mm/year and a mean leaching fraction of 43 mm/year. While this leaching fraction is only about 4% of the water applied, the groundwater and soil salinity is very low, despite a high fluctuating watertable.

In comparison, a site in the same district, but low in the topography, had a net groundwater discharge of 14 mm/year, with rates varying from a small leaching fraction of 2 mm/year to a groundwater discharge of 20 mm/year. The groundwater discharge at this site is consistent with high piezometric levels in the deeper aquifer system. Even though the site shows obvious signs of salinisation, productivity was estimated to be 80% of normal.

Notwithstanding the spatial differences in salinity, it is unusual to see perennial pasture in the district affected by salinity. A salt balance is achieved through lateral seepage to the surface drainage system and to adjacent lowlying areas, dryland and annual pasture. The local recharge and discharge of groundwater is described in the Maunsell report as ‘dry drainage’.[iv]

Dry drainage

The principle behind the Land and Water Management plans is that water should be used on non-saline areas employing good irrigation and drainage practices, and saline areas should be fenced and de-stocked. There are incentives for soil salinity surveys and farm plans to encourage these practices. Farm drainage and regional surface drainage are important to reduce accession to the watertable, particularly in wet winters.

The LWMPs do not consciously address the issue of dry drainage, even though from a technical viewpoint it is clear there is a balance between local recharge and discharge. ‘Dry drainage’ is not a term that would be understood or widely used by farmers, even though it is understood that poor irrigation management and ponding water will have a detrimental impact on adjacent areas.

It is accepted that periods of increased salination follow wet winters, particularly 1974–1975. Flooding is widespread and, in the absence of surface drainage, water ponds in the floodplain particularly where roads, channels and farm infrastructure obstruct natural drainage lines. A major element in all Land and Water Management plans in Victoria is provision of surface drainage to alleviate flooding and reduce the incidence of prolonged ponding. Wet winters result in an increase in substantial recharge to the deep aquifer and there is thought to be an associated increase in salination. Winter crops are likely to be impacted by waterlogging unless bed cropping has been used (rare for winter crops). Watertables are uniformly high during a wet winter, and in a flat landscape there is less likely to be local recharge and discharge because there is no gradient for groundwater flow. However, where there is undulation in the land surface, such as prior stream ridges, local recharge and discharge can occur and areas of low elevation become more saline.

Economically it is difficult to justify subsurface drainage in areas of frequently irrigated perennial pasture. There is widespread community concern over the feasibility of evaporative disposal of groundwater and the off-site environmental impact that may be associated with groundwater disposal. Water is the limiting resource in the district and studies have shown that there is adequate low salinity area in the district for use of the water resource available. However, groundwater pumping has been used in one or two places to control salinity in lowlying areas. Good surface drainage is required to ensure minimal waterlogging of the surface soil and to reduce the accession to groundwater.

Extensive mixed farming areas

Annual pasture and dryland areas are prone to salination. Areas low in the topography and close to areas of frequently irrigated pasture are likely to be most affected.

The watertable must be controlled below the critical depth to stop soil salination. Lysimeter data[v] suggest the watertable must be lowered to a depth of 1.2 m or more below the soil surface to reduce capillary rise below 0.1 mm/d during the summer months (Table 2). However, the productivity of mixed farming is low and the high cost subsurface drainage and disposal of saline groundwater effluent is difficult to justify on economic grounds.

Table 2.

TABLE 2. GROUNDWATER EVAPORATION

Depth to watertable (cm)	Groundwater evaporation (mm/day)	
	Heavy depression soil	*Kerang Clay*
100	0.01	0.1
70	0.07	0.25
50	0.1	1
40	0.13	1.5

Overall need for drainage

As drainage occurs through natural drainage processes, the question is perhaps 'what is the need for artificial subsurface drainage?' Clearly there is a need for drainage for salinity control, which could be achieved by a net leaching fraction of 60 mm/year. Given the water quality is high, this is adequate for salinity control regardless of watertable depth, provided water quality is good. This is consistent with the approach used in Shepparton, where 0.5 ML/ha is the-rule-of-thumb for salinity control. Clearly, waterlogging control is required in horticultural development, although improved irrigation practices and cultural techniques (such as hilling up) have reduced the need for drainage in horticultural areas. Subsurface drainage for cropping lies somewhere in between. Good surface drainage and bed cropping is adequate as long as salt balance is maintained. However, the Stress Day Index approach where the number of days the watertable in excess of a threshold (0.9 m, 0.6 m, 0.3 m for horticulture, crops and pasture respectively) is a sound approach. The question in Kerang remains the economic response to drainage, given the high cost of drainage and disposal of groundwater, and the generally low economic returns to farming in the region.

Description of drainage methods used

DESCRIPTION OF DRAINAGE METHODS USED

Both groundwater pumping and tile drainage are effective methods of subsurface drainage, however, economic constraints mean there are relatively few operating systems.

Groundwater pumping is less expensive to implement, and because very small drainage rates are effective in reclamation and control of salination, is generally the preferred method. The major constraint to groundwater pumping is locating suitable shallow aquifers. Aquifers from 5 to 15 m are generally effective for groundwater pumping, however, there is no surface expression of the aquifers, and the strip aquifers tend to be highly braided and discontinuous. Use of electromagnetic techniques for locating aquifers is constrained by the high salinity in the aquifer. Electroseismic techniques (EKS) have been evaluated for aquifer location and show some promise, but are yet to be widely used.[vi]

An experimental tile drainage system was installed near Kerang in 1975. Tile drain laterals were installed at a spacing of 70 m and a depth of 1.9 m. Watertable levels were effectively controlled and the area quickly reclaimed. Investigations suggested drain spacing as wide as 160 m would be adequate for salinity control. The system is still working effectively with little maintenance. The major constraint to further implementation is the expense of both the drainage system and disposal of groundwater.[vii,viii,ix]

A second tile drainage system was installed north-west of Pyramid Hill in 1993 at a drain spacing of 60 m and drain depth of 1.75 m. Corrugated HDPE plastic drain tube was used with a sand backfill. The tile drainage water disposes to a large below-ground sump, and is then pumped to an evaporation basin. Tile drains and relief wells are used to intercept seepage water from the evaporation basin. Again the major constraint to tile drainage and reclamation is the high capital cost, relatively low returns for cropping and grazing enterprises on the property, and minimal productivity response.[x,xi]

A tile drainage pilot was established by CSIRO at the Swan Hill Research Farm in the early 1970s. Drains were installed at 31 m spacing and 1.5 m depth.[xii] The area was quickly reclaimed suggesting that wider drain spacing would be effective in reclaiming and controlling salinity at the site. However, it was considered groundwater pumping would be more effective as a salinity control measure. The performance of the drainage system decreased with time due to iron ochre cementation in the drainage system. Groundwater with high iron ochre content indicates upflow from a deeper artesian/subartesian aquifer. Groundwater pumping from shallow aquifers at between 0.7 and 1.1 L/s from small unscreened bores has also been evaluated as a drainage method. Groundwater quality in the Swan Hill Flats is variable (1.6 to 8 dS/m) but low enough in the 1960s, to consider a public groundwater pumping system, with disposal to the river. Neither groundwater pumping or tile drainage have been widely adopted as a salinity control measures in the Swan Hill Flats.

In the Dingee/Calivil District, groundwater salinity is lower and aquifers more suitable for groundwater pumping.[xiii] Groundwater pumps together with conjunctive use of water are used successfully on farms and drainage practices are similar to those used in the Shepparton Region.

Drainage design and investigation

DRAINAGE DESIGN AND INVESTIGATION

The unique problems encountered in the Kerang Region require special attention to the drainage criteria. Areas that are frequently irrigated with low saline water generally do not develop a salinity problem, even though a high watertable may develop. In the experimental tile drainage system at Kerang, a drain design rate of 2.5 mm/d with a watertable 0.3 m below ground surface was used for estimating drain lateral spacing. However, these criteria relate to drain design for waterlogging control under the steady rainfall conditions of Europe. It is (and was) an inappropriate criteria for subsurface drainage for salinity control, in Australia.

The experience in the district is that very low drainage rates associated with groundwater pumping together with irrigation to leach accumulated salts is effective for salinity control. Low drainage rates will suffice if the purpose of subsurface drainage is to control a small rate of upward seepage, and allow a small leaching fraction (say 2 to 5% of the applied water). It has been suggested the drainage design should be based on the observed upward seepage rate, while maintaining the watertable at or below the critical depth. For instance, at the Kerang site design criteria of 0.8 mm/d with a watertable maintained at a depth of 1.2 m has been suggested. This would allow substantially wider drain spacings (∼160 m), and reduced costs, as well as a reduced need for groundwater disposal.

A scheme to intercept saline groundwater flowing into Pyramid Creek to improve water quality and reduce saline return flow to the Murray River[xiv] has been investigated, and a pilot project successfully implemented.

Drainage water quality, quantity and disposal

DRAINAGE WATER QUALITY, QUANTITY AND DISPOSAL

The groundwater salinity in the Kerang Region ranges from 20 to 50 dS/m. The high salinity precludes conjunctive reuse of groundwater on-farm, disposal back to the river system or to regional surface drainage systems. On-farm evaporative disposal has been evaluated in several sites in the region. Because of the high electrolyte concentration of groundwater, seepage rates from evaporation basins are relatively high (~2–6 mm/d).[xv] Plastic lining and other direct methods for seepage control are prohibitively expensive. Interception of seepage water and return of drainage effluent back to the evaporation basin is the most cost-effective method for managing seepage. This method of seepage control has the added benefit of salt concentrating through the entire depth of the aquifer, prolonging the life of the evaporation basin and delaying the need to remove salt.

However, if there is an economic return from the salt harvested, it is both desirable and economically attractive to reduce seepage and accelerate the concentration of salt in the basin(s). A company called Pyramid Salt has recently established a business in the district to harvest salt from a groundwater pumping system. The groundwater pumping and salt harvesting has resulted in significantly lower watertable levels in the areas adjacent to the salt harvesting project. Realising the potential value of saline groundwater resources for productive use will improve the prospects for subsurface drainage in the Kerang Region.[xvi]

Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

There are no specific guidelines for monitoring drainage systems as there are relatively few drainage systems operating in the Kerang Region. Disposing saline groundwater to regional surface drains is prohibited. In parts of the district there is a deep regional surface drain system and significant groundwater seepage into the drain, which acts as an extensive subsurface drainage system. In some areas shallow relief wells installed some years ago, enhance the subsurface drainage effect of the deep drain. In recent years there has been community action to reduce groundwater and surface water inflow to the drain improving the effectiveness of existing evaporation basins (Tutchewop Scheme) and ultimately improving water quality for downstream use. It is proposed to reuse brackish water on tile drained lucerne, as the waste water will be biologically concentrated before disposal.

Drainage funding

DRAINAGE FUNDING

Drainage costs

The most recent drainage costs available are for the experimental tile drainage area at Pyramid Hill in 1992. Capital cost for an area of 16 ha, 60 m spacing x 440 m long, 1.75 m drain depth are shown in Table 3.

Table 3.

TABLE 3. DRAINAGE COSTS

Item	Cost $	Cost/ha $
Install tile drains	45,000	2,813
Evaporation basin	34,000	2,125
Disposal pump	8,000	500
Total cost	87,000	5,438

Subsequent results suggest the evaporation basin (and pump/sump), which was designed on the basis of an evaporative area one tenth the area of tile drainage, could potentially serve a much larger area of the farm.

Drainage system rates

The typical soil type is a cracking clay, which has a saline-sodic character. If the surface and subsoil are saline, there is little restriction to infiltration and internal drainage rates are high. For instance, during the reclamation phase the drainage rates can be expected to be very high (2 to 5 ML/ha/year during the first two years of operation). Peak drain flow rates from 2 to 4 mm/d can be expected during this period.

After reclamation, the surface subsoil and subsoil become sodic and drainage rates are reduced. The attainable leaching fraction will be determined by the development of a throttle in the subsoil at a depth from 0.3 to 1.0 m. Drainage system rates are likely to be from 1 to 2 ML/ha/year in the post-reclamation phase, and peak drain flow 1–2 mm/d. Experiments have shown the subsoil, deeper than 1 m, retains a relatively high hydraulic conductivity (0.3 to 0.5 m/day) post-reclamation. In the post-reclamation period, drainage rates are affected by the internal drainage of the soil profile between 0.3 and 1 m rather than the dewatering performance of the drainage system. For instance, while in the reclamation phase watertable levels rise by more than one metre after irrigation, where in the post-reclamation phase, watertable levels may only rise a few centimetres after irrigation.

Base flow rates recorded at Kerang during periods without irrigation were from 0.5 to 0.8 mm/d. The base flow rate has been attributed to upward seepage from an underlying artesian aquifer, with a pressure head about one metre above ground surface. At the Pyramid Hill site the watertable level falls below the tile drain lines when the area is not irrigated and there is no consistent base flow rate.

Groundwater pumping rates depend on the transmissivity of the aquifer present. At Mincha West a pumping rate of 3.2 L/s resulted in a drawdown rate of 5 mm/d over an area of 28 ha.[xvii] This is equivalent to a mean drainage rate of about 1 mm/d over the area. At the Kerang Research Farm a groundwater pump was used to reclaim saline land. The pumping rate was 5.2 L/s. The area of influence was typically 16 ha, although this area could increase to 80 ha during dry periods.[xviii] At Sutherland's property (Cohuna) an area of 5 ha was reclaimed at a pumping rate of 3 to 7 L/s.

Outcomes - resource potential of shallow watertable

The research study 'Resource Potential of Shallow Water Table' (NRMS 2137) considered a number of drainage options. Drain 14 of the Barr Creek subcatchment was chosen as the study area for the project. This area had a good data set and contains a contrast between low salinity in areas high in the catchment, and high salinity in areas of low elevation. The study area intersects the Mead Ridge, which is a prior stream (some say ancestral river), and follows a west to east direction in the area south of Cohuna. Below is an extract from the final report,[xix] with costs and benefits quoted based on 1996 values.

Table 4.

TABLE 4. COST OF SUBSURFACE DRAINAGE OPTIONS IN SALINE AREAS

System type	Area ha	Capital cost $'000	Capital cost/ha $'000	Design discharge ML/ha	Evap. basin ha	Evap. basin $'000	Down-Stream disposal $'000	Total cost $'000	Total cost/ha $'000
Extended wellpoint	128	30.4	0.24	0.75	10.7	146.5	NA	176.9	1.38
Tile drains (60 m)	16	28.1	1.75	1.64	2.9	39.7	NA	67.8	4.23
Tile drains (120 m)	16	21	1.31	0.64	1.14	36.6	NA	22.56	2.28
Mole drains	20.3	42.6	2.095	1.3	NA	NA	25.6	68.2	3.35
Deep pumping & biological concentration	790	549	0.695	0.68	11	150	NA	699	0.884
Deep pumping winter only	790	211	0.267	0.34	NA	NA	327	538	0.68

Note 1: evaporation basin costs are based on $13,700 per hectare

Note 2: costs of biological concentration and disposal do not include buying land

Table 5.

TABLE 5. BENEFITS OF SUBSURFACE DRAINAGE OPTIONS IN SALINE AREAS (FROM NRMS 2137 FINAL REPORT)

System type	Area ha	Area improved3 ha	Increase production t/ha	Increase production $/ha	Increase farm gate $'000	Capitalised farm gate value2 $'000	Ratio of capitalised farm gate value to capital cost
Extended wellpoint	128	96	6.5	566	54.3	939	5.3
Tile drains (60 m)	16	16	7	610	9.76	168.8	2.48
Tile drains (120 m)	16	16	5.61	488	7.81	135	5.98
Mole drains	20.3	20.3	4	349	7.08	122.4	1.79
Deep pumping & biological concentration	790	395	6.5	566	224	3875	5.54
Deep pumping winter only	790	395	3	261	103	1782	3.38

Note 1: assumed to be 80% of 120 m spacing
Note 2 capitalised at 4% over 30 years
Note 3: allows for non-saline areas within the area of influence of the groundwater pump

The projected increase in production in Table 5 is estimated from modelling studies using the SWAGMAN Destiny Model. The benefit to cost ratio reported in this table depends on attaining the estimated increase in production. Notwithstanding, a summary of the various subsurface drainage options was reported as follows:

> **Extended wellpoint systems** have a high benefit relative to cost and warrant further technical evaluation. The cost depends on the expense of finding suitable strip aquifers for pumping. A low-cost technique is required to find suitable aquifer locations in a saline environment. The capital cost of disposal is six times the cost of installation. Lower drainage rates or a lower cost of evaporative disposal would make this option more attractive.

> **Tile drainage** has a high benefit relative to cost, particularly at the wider spacing of 120 m. Projects would need to generate adequate drainage rates at the spacing indicated above, to give the benefits indicated by Destiny. Much more water had to be used to attain the benefits projected by Destiny. It may be a cost-effective farm strategy to irrigate more often on the non-saline areas of the farm, using efficient irrigation practices, if the limiting resource is water.

> **Mole drains** require technical evaluation for the soil types in the area. Similar to tile drains; mole drains require a substantial increase in water use to achieve the yield increase projected by Destiny. The full operating cost and capital cost of the additional water required could outweigh benefits. The technique may be useful on farms where there is a non-saline soil and drainage effluent can be reused.

> **Deep groundwater pumping** requires further technical evaluation and more detailed costing. One of the issues will be whether the community is prepared to meet the running and renewal cost associated with a drainage project of this nature. The deep aquifer is substantial and present as a sheet across the region, therefore most locations will give adequate well yields. The main constraint is

the hydraulic resistance of the clay layers above the aquifer and the volume of groundwater that needs to be pumped to achieve the drainage rate of 60 mm/year that is required. Both local disposal and winter pumping options are worth pursuing.

Current issues and trends

CURRENT ISSUES AND TRENDS

Dry drainage and salt export

The improvement in the Kerang Irrigation Area has occurred mainly because of improved irrigation practices, and conversion of annual pasture and dryland areas to permanent pasture, which leaches salt. Most of the salt is still in the catchment, either below the rootzone, or concentrated in the areas that are not irrigated. These areas include roadside cuts and easements, as well as dryland and annual pasture areas, which tend to be very saline. However, there is substantial net export of salt through the deep surface drain in the district. The conventional wisdom is that an area of about 30 to 40% of the district will continue to be a discharge area, and therefore saline, and this will balance the accession to groundwater (Maunsell). There is a question regarding the longevity of discharge process from saline areas, as once a salt crust forms at the surface, capillary rise and 'groundwater evaporation' will reduce. A central element of Land and Water Management plans is to de-stock saline areas and maintain land cover.

Evaluation of low cost extensive drainage

A project funded by MDBC (NRMS 2137) considered the costs and benefits of various drainage options (page 52). The lowest cost options were groundwater pumping, using extended wellpoint systems in the shallow aquifer (5 to 20 m), and pumping from the deeper aquifer system to relieve upward seepage and generate a small drainage rate.

Extended wellpoint systems allow sufficient drainage rates by connecting a series of low discharge wellpoints (typically 0.1–0.5 ML/d). While each wellpoint individually would be uneconomical as a subsurface drainage method, simultaneous pumping allows adequate drainage rates to be achieved. Methods of connecting the wellpoints include discharge to a tile drain (called a 'gravity wellpoint system') or tile drainage system with 'relief wells' and connection by a common suction line or the use of airlift pumping and discharge to a common disposal pipe. The main constraint for developing this system has been finding a cost-effective way of locating suitable aquifers. Recent developments in low cost seismic survey (EKS) in saline environments may overcome this constraint.

Groundwater pumping from the deep (Calivil Sand) aquifer has been suggested as a method to reduce groundwater discharge and generate a small leaching fraction required to control salinity. Free flow from the artesian aquifer, at a pressure head ~1 m above ground surface, has been recorded at 6 L/s. At least 36 L/s is possible if the aquifer were pumped. The water is less saline than the shallow groundwater (4 to 10 dS/m) and therefore biological concentration could be used to reduce the area required for evaporative disposal. However, it is difficult to target a discrete area, and the volume of groundwater would be larger than for conventional drainage. As well the watertable drawdown rates would be much lower than conventional drainage.

Further technical evaluation of these options is warranted and pilot projects should be initiated where appropriate.

Rice development

The area being cropped for rice has been expanding over the last few years, with substantial interest in the Kerang Region. Although there is a greater risk of crop failure associated with the cooler climate in northern Victoria, the large mixed farms in the region are well suited to rice growing, and returns are generally higher than for other crops and grazing. Rice also has the potential to rapidly reclaim saline areas. However, the environmental impact on areas adjacent to rice crops is cause for concern. Subsurface drainage in conjunction with rice cropping is a possible solution to intercept lateral seepage and control secondary salination associated with rice cropping.

Drainage criteria

Further investigation of drainage criteria is warranted, in particular the response to low rates of drainage. If low rates of drainage could be used for salinity control, this would reduce the cost of drainage and the need for drainage water disposal. Technical knowledge suggests shallow fluctuating watertables may not be harmful to pasture and crop growth, as long as cultural methods are used to manage waterlogging (bed cropping and good surface drainage), and there is a small net leaching fraction (~60 mm/year) to maintain a salt balance. Reclaiming saline land may initially require higher drainage rates for two to three years.

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MACALISTER IRRIGATION AREA

Location and hydrogeology

MACALISTER IRRIGATION AREA

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LOCATION AND HYDROGEOLOGY

The MacAlister Irrigation District (MID) is located in the Sale/Maffra region of East Gippsland and covers an area of about 54,700 ha (LWSMP 1993). The irrigation water for the MID comes from both Lake Glenmaggie and the Thompson Dam. A complex network of irrigation channels distributes the water to over 500 irrigated properties in the area. Other sources of irrigation water in the area include drain and river diversion and groundwater pumping.

Geology and hydrogeology

The MID is contained within the northwestern part of the Gippsland Basin. The shallow geology in the area can be broken into the following units:

- the Haunted Hills Gravels
- prior stream deposits
- recent floodplain deposits.

The distribution of these units in the area is shown in Figure 16.

Haunted Hills Gravels

The Haunted Hills Gravels are considered to have formed as an outwash fan following uplift of the Eastern Highlands during the Late Tertiary- early Quaternary period. The formation is likely to have once covered most of the Lake Wellington Region and consists of clay, sand and gravel. Major rivers in the area have subsequently eroded the unit, with only isolated outcrops remaining. The outcropping Haunted Hills Gravels are expected to have low permeability, with limited recharge from the surface, and limited lateral groundwater flow to the Prior Stream Deposits and the Recent Floodplain Deposits.

Prior stream deposits

A lowering of sea level in the late Pleistocene (Jenkin 1976) resulted in erosion of the Haunted Hills Gravels to a depth thought to have been around 15 m below present river levels. This was followed by a rise in sea level to above the present level, and a sequence of sand, gravel, and clay was deposited over the major part of the area by the ancestral courses of the Latrobe, Thomson, MacAlister and Avon rivers. These deposits now generally form a terrace, elevated above the present floodplains of the rivers.

The Prior Stream Deposits can be roughly separated into a lower unit, which generally contains well-developed coarse grained sand and gravel beds, and an upper unit of mainly finer grained material.

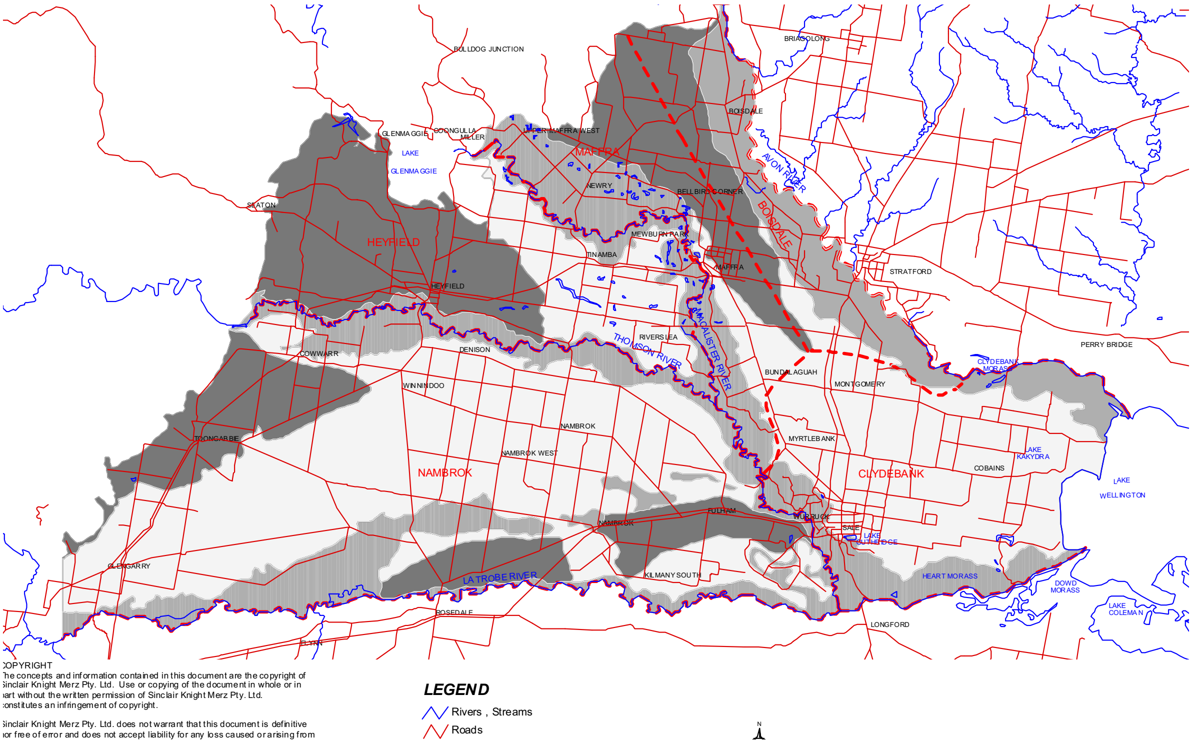
The lower unit occurs over most of the region and often contains a single gravel and sandbed to a maximum thickness of about 8 m. The lower unit has a transmissivity value of up to 1,200 m^2/day and is the main aquifer used for private irrigation bores and public groundwater pumps in the area. It is expected to be semi-confined to unconfined and have good hydraulic connection to the watertable located in the overlying finer grained sediments.

Recent Floodplain Deposits

The Recent Floodplain Deposits were formed after a further period of erosion associated with a low sea level. These deposits are associated with the present day floodplains of the MacAlister, Thompson and Latrobe rivers. The present day rivers have incised deeply into the Prior Stream Deposits. Therefore, the lateral hydraulic connection between the basal gravels of the Recent Floodplain Deposits and the Prior Stream Deposits is likely to be strong.

Figure 16.

FIGURE 16. GROUNDWATER SUB REGIONS AND SURFICIAL GEOLOGY LAND USE



Land use

Within the irrigated areas, the main land use is dairying, with smaller areas of beef and horticulture. The area is mostly flood irrigated on laser-graded paddocks with increasing use of spray irrigation, especially on the higher permeable soils. It is the second largest dairying region in Victoria with production worth more than $325 million a year. On the surrounding dryland areas, the major land use is beef, lamb, wool and dairying.

In addition to the agricultural land use, there are also large areas of environmentally significant wetlands. Most of the wetlands are located around the western fringes of Lake Wellington and the eastern end of the Latrobe River floodplains. The wetlands are either privately owned or are public land managed by Parks Victoria. Most of the wetlands in the area are listed under the international RAMSAR convention.

Nature of problems and adopted solutions

NATURE OF PROBLEMS AND ADOPTED SOLUTIONS

Since European settlement, the clearing of vegetation and the introduction of irrigation have resulted in increased recharge to the shallow groundwater systems and subsequent salinity.

Irrigation in the area began soon after the weir wall at Lake Glenmaggie was completed in 1925. Initially irrigation occurred in a small area around Boisdale but soon expanded to cover the areas around Sale and Maffra. High watertables in the area were recorded as early as the 1930s.

In 1958, the capacity of Lake Glenmaggie was increased to develop the Nambrok-Denison area as a soldier settlement. Soon after, productivity decreases were recorded. The cause was high watertables and consequent salinity problems. In the

Nambrok-Denison area, groundwater pumps were installed in the early 1960s to try to reduce the watertable level.

The Lake Wellington Salinity Management Plan (1993) reports that a survey in 1986 indicated about 10,000 ha of salinity-affected land in the broader Lake Wellington Catchment. Most of the affected land occurs in the Nambrok area and the Clydebank area west of Lake Wellington. The most evident salinity occurs in the low-lying dryland areas down-slope of the main irrigation area. An economic study by Reid Sturgess (1999) estimated that salinity is currently costing the community $9.3 million a year in lost production and infrastructure degradation.

Regional flooding can cause a short-term improvement in the land salinity in the low-lying floodprone areas due to the flushing of salts through the soil profile. However, regional flooding is also likely to cause significant episodic recharge to the already shallow watertable. The effect of episodic recharge relative to recharge from rainfall and irrigation is not well understood.

Groundwater pumping is the main salinity mitigation measure used in the area. There are currently 18 ‘Public Groundwater Pumps’ in the area, which are specifically designed to lower the watertable in strategic areas. Most of the pumps are located in areas, which are either currently salinised or showing signs of salinity when installed. More recently, groundwater pumps have been installed in areas upslope of salinity-affected areas in an attempt to intercept better quality water before discharging to lower lying areas.

Other salinity mitigation measures used in the area include encouraging more efficient irrigation practices, such as spray irrigation to replace flood irrigation. Spray irrigation is currently mainly confined to lateral systems in areas of lighter soil types. However, fixed-point spray systems are now being considered for the area mainly because of their expected improved pasture productivity compared to lateral systems. To date, there have been no local studies to compare water use and pasture productivity for the different irrigation types of flood irrigation, lateral spray irrigation and fixed point spray irrigation.

Agronomic salinity control measures have not been used widely in the area but are likely to be important in the future.

Drainage methods used

DRAINAGE METHODS USED

The main subsurface drainage method used in the MID is groundwater pumping. There are two main types of groundwater pumps in the area, which affect the shallow watertable level:

- > Private groundwater pumps installed in the shallow alluvial aquifer by farmers for irrigation and/or stock and domestic supply.
- > Groundwater pumps funded by the State Government, which are specifically designed to lower the watertable for salinity control. These groundwater pumps are commonly referred to as ‘Public Pumps’.

In recent years, private groundwater pumping has increased dramatically as a result of:

- > the increasing pressure on surface water resources
- > the cost effectiveness of pumping groundwater from shallow aquifers compared to buying surface water.

Private groundwater pumping is clustered in areas where groundwater quality is suitable for irrigation and aquifer yields are highest. Most of the private groundwater pumping occurs in the Nambrok-Denison area, where there is a high-yielding shallow aquifer of low salinity water. Typically, private bores in this area are from 10 to 15 m deep and yield between 0.5 and 4 ML/day. Private groundwater pumping from the shallow alluvial aquifer also occurs in the region around Tinamba and Boisdale.

'Public Pumps' are generally located in areas where groundwater quality is not usable by irrigators. There are currently 18 'Public Pumps' located in the MID and surrounds. Groundwater from Public Pumps is either disposed into drains or used by nearby farmers (if the water quality is suitable).

The combination of Public Groundwater Pumps and private groundwater pumping has been very successful in lowering the watertable and reducing the salinity problem. There are now only isolated pockets of salinity where there was once a regional problem. A recent Department of Natural Resources and Environment (DNRE) review of the Public Pumps program estimated that for the Public Pumps located in irrigated areas, the net agricultural benefit over 30 years is at least $1million per pump with a benefit to cost ratio of about 6. For the pumps which protect dryland areas, the economic benefits are not as great with a net agricultural benefit estimated at $200,000 over a 30-year-period with a benefit to cost ratio of about 1:2.

Drainage design and investigation

DRAINAGE DESIGN AND INVESTIGATION

The program of installing Public Groundwater Pumps in the MID and surrounds is part of the implementation of the Wellington Salinity Management Plan. The justification for a new Public Groundwater Pump is based on environmental, economic and social considerations.

The area is divided into a number of discrete hydrogeological regions (Figure 16). The boundaries between hydrogeological regions are either rivers or groundwater divides. Little groundwater flow across these boundaries is expected. The hydrogeological subregions are described in detail in Sinclair Knight Merz (1998). The need for new Public Groundwater Pumps is assessed separately for each groundwater subregion. Through computer modelling, the water balance in each subregion is determined and the need to install new groundwater pumps assessed against the vertical and horizontal recharge in the area.

The investigations involved in locating a suitable Public Pump site include the following steps:

1. Create a depth-to-watertable map for the subregion

Depth-to-watertable maps combined with subsequent ground truthing are the main criteria used to determine currently salinised areas and areas at future risk of salinity. The depth-to-watertable maps are created using the following procedure:

- A digital elevation model for the subregion is created using surveyed benchmarks, surveyed bores and river levels. The surveyed points are used in preference to digital topographic maps, as they are more accurate. However, in areas where there is a sparsity of surveyed heights, digital topographic data is used.
- A digital surface is created of the watertable elevation from shallow observation bore data. Sometimes water levels from stock and domestic bores are used in the assessment with a topographic height of the bore assumed from the digital elevation model.
- The reduced water level surface is mathematically subtracted from the topographic surface.

Areas where the watertable is within 2 m of the surface are ground truthed to determine if there are any visible signs of land salinity. Generally, the watertable map shows a good correlation with saline areas.

2. Groundwater modelling

A groundwater computer model is developed for each subregion to investigate the groundwater flow regime and water balance in the area. The modelling uses the finite element MODFLOW software and simulates flow in the watertable aquifer only. Inputs to the modelling include:

- > aquifer hydraulic characteristics as determined from pumping tests
- > recharge, which is usually determined by calibration combined with knowledge of various soil permeabilities
- > bore extractions determined from landholder surveys conducted by Southern Rural Water and metered records from Public Pumps in the area
- > river levels that form the boundary conditions of the model.

Once the groundwater model has been calibrated against observation bore data, the model is used to determine the expected depth-to-watertable in five years time assuming average rainfall and current pumping patterns. The future depth-to-watertable map represents a ‘do nothing’ scenario.

The calibration of the model provides some confidence in the predictive capacity of the modelling. However, it is acknowledged that the modelling results are indicative only. An emphasis is placed on educating the stakeholders on the limitations of the modelling and dampening stakeholder expectation. At best the modelling provides a tool for understanding how the various water balance parameters interact and the direction the system might react from a change in management practices.

3. Prioritise high watertable areas

Areas identified as having a high watertable both currently and in the future are prioritised for protection by groundwater pumping. The procedure takes into account the environmental, social and economic factors in the area.

The social implications for groundwater pumping in the area are gauged through public meetings and discussions with individual landowners. The public meetings have the dual purpose of informing the community of progress and gauging public support for groundwater pumping in the area.

A preliminary economic evaluation is conducted to determine the area of influence required from groundwater pumping to ensure that the pumping is economic (i.e. the improved production benefits are greater than the operating costs plus the annualised capital costs).

The potential impact of groundwater pumping on environmental features such as wetlands and rivers is also considered when prioritising areas for groundwater pumping. The impact may be beneficial (e.g. reduced salinity around a wetland) or detrimental (e.g. increased water salinity in receiving waters).

4. Investigation drilling program

An investigation drilling program is instigated in the areas identified as having a high priority for salinity control. The investigation bores are sited as close as possible to viable disposal points and electricity supply. Where good groundwater quality is expected, proximity to delivery point and the irrigation layout of the farm are also taken into account. The investigation bores are usually drilled with a cable tool rig and constructed with 100 mm diameter PVC. In some instances, EM-34 has been used to help site investigation bores. However, EM-34 has had mixed success in the area and is not used routinely. Downhole gamma logs are used to help identify aquifer intervals.

5. Private or Public Pumps?

In the high priority areas identified for salinity control through groundwater pumping, a decision is made on whether the areas are more suitable for private pumping or installing a Public Pump. The decision to install a Public Pump is taken only when private groundwater pumping is not viable. The viability of private pumping is determined from groundwater salinity data and the willingness of landowners to participate. Generally, private pumping is encouraged when the groundwater salinity is less than about 1.5 dS/m. The upper limiting salinity to be used for irrigation depends on soil types. Private pumping options are assessed based on local soil types, ability to shandy groundwater with fresher channel water and the general farm layout. In only exceptional circumstances are Public Pumps installed in areas where the groundwater is less than 1.5 dS/m.

If existing private pumps are located in an area that would benefit from groundwater pumping, then landowners are sometimes contracted by the Wellington Salinity Group to pump during non-irrigation periods. This obviously depends on having a suitable groundwater disposal point. Landholders must apply to Southern Rural Water for permission to discharge saline groundwater privately to the drain network. There are few examples of private disposal of saline groundwater and the disposal would only be permitted if it did not adversely affect downstream drain diverters.

6. Short-term pumping test

Short-term pumping tests of about 24 hours are conducted on investigation bores, which intersect promising aquifers. The pumping test is usually conducted with at least one nearby observation bore. The purpose of the pumping test is to determine the aquifer hydraulic characteristics that can be used to determine the likely yield from a properly constructed production bore.

7. Choice of pumping configuration

Public pumps in the MID and surrounds are either single bores installed with submersible/turbine pumps or spearpoint systems installed with centrifugal pumps. The choice of pumping configuration is determined by:

> The depth to the standing water level. Given that centrifugal pumps have a total suction limited to about 7 m depth, spearpoint systems are more suitable in situations where the standing water level is close to the surface.

> Aquifer transmissivity. Lower transmissivity aquifers are more suitable for spearpoint systems because of the spreading of the pumping bore drawdown over a larger distance.

The approximate sustainable yield is calculated for a hypothetical single bore and a spearpoint system. Generally, the higher yielding option is chosen. If the calculated yields from each of the two systems is about equal, then a single bore system is chosen to reduce maintenance costs.

8. Assess proposed pump area of influence.

The groundwater model is used to determine the likely area of influence of the proposed Public or Private Pump. The model is modified to include the aquifer hydraulic characteristics determined from the short-term pumping test and the expected sustainable yield from the proposed bore.

9. Assess disposal options

The Public Pumps generally discharge to local irrigation drains, which eventually drain into Lake Wellington either via rivers and streams or direct discharge. The impact on downstream drain diverters and the environmental impact on in-stream aquatic systems and any receiving wetlands is determined and weighed up against the economic, social and environmental benefits of the new pump. Disposal issues can limit the operation of the pump (e.g. where disposal causes unacceptable salinity for downstream drain diverters). More information on disposal is given on page 65.

Where a private pump is to be installed, investigations generally stop at this step.

Landholders are given the collected information and are expected to install the bore themselves. If the bore is located in a Groundwater Supply Protection Area, where the groundwater is fully allocated with respect to the Permissible Annual Volume (PAV), then the Salinity Group may negotiate with Southern Rural Water on behalf of the landowner to grant a bore construction and extraction licence on the grounds of watertable reduction for salinity purposes.

10. Economic assessment

An economic assessment is conducted of the proposal based on the expected capital cost, the annual operating cost and the expected increase in agricultural productivity. An economics model has been constructed for the MID area by Reid Sturgess (1999). The inputs to the model include the likely area of influence of the pump (as determined from the groundwater model), the gross margins on the land that will be rehabilitated, commodity prices, expected capital cost and operating cost.

11. Decision on Public Pump

The decision to proceed with a Public Pump proposal is based on economic, environmental and social considerations. There are instances where a Public Pump proposal cannot be justified on economic grounds, but would proceed based on environmental and/or social considerations.

12. Drilling production bore(s)

Once the decision has been made to proceed with the Public Pump, the production bore(s) is(are) drilled. For a single production bore, the hole is constructed with stainless steel screens and either ABS or PVC casing. The screen aperture is determined from a sieve analysis of the aquifer material. In the past, spearpoint bores were constructed with 100 mm diameter PVC casing and slotted PVC screens. A current spearpoint system in the design phase is proposed to have stainless steel screens to maximise the screen open area and increase bore life. Spearpoint bores are generally located about 20 m apart. All spearpoint bores and single production bores are gravel packed.

13. Production bore pumping test

A step-drawdown pumping test is conducted on the production bore(s) followed by a constant discharge rate test of between 24 to 48 hours. The purpose of the pumping tests is to determine the sustainable bore yield and an appropriate pump design. The drawdown response is plotted during the test and the test is stopped only when any initial delayed yield effects have been overcome. The sustainable bore yield is determined from a combination of results from the step drawdown test and aquifer hydraulic characteristics calculated from the constant discharge test.

14. Pump design and installation

The pump design is based on the sustainable bore yield and the type of production bore. Spearpoint systems are designed with a buried header line connected to an above-ground centrifugal pump. All centrifugal pumps are electrically driven which often requires power to be brought to the site. Gas extraction systems are now being considered for spearpoint systems that have problems with air in the header line but have no obvious air leaks. In these situations, gas is assumed to be coming out of solution and affecting the operation of the centrifugal pump. Gas extraction systems are considered the most efficient way of addressing these problems.

More recent single bore submersible systems are designed with the pump below the screen to maximise the available drawdown. This requires a shroud to be fitted to the outside of the pump for cooling. Water level sensors are installed in the bore and cut off levels set to stop the drawdown in the pumping bore reaching the top of the screen.

Drainage water quality, quantity and disposal

DRAINAGE WATER QUALITY, QUANTITY AND DISPOSAL

Volume and salinity of pumped water

There are currently 18 Public Groundwater Pumps in the area. The pumping rate ranges from 0.5 to 4.5 ML/d. The increase in private pumping over recent years has reduced the need to operate the Public Groundwater Pumps continuously. The Public Pumps are now scheduled to take into account the volumes of groundwater pumped privately and the rainfall patterns.

Over the last three years of unusually dry weather, many of the pumps have had a reduced output. However, during wet years, the output from the pumps will increase to counterbalance the decreased private pumping and the increased recharge. Currently, operating rules for the Public Pumps are being determined. These rules are linked to groundwater levels in nearby observation bores. To date the emphasis has been on reducing the watertable level to below 2 m from the surface for the entire year. The system used in Tatura, where reducing of watertable levels to below 2 m from the surface is only considered necessary for part of the year, has not been contemplated.

Full watertable control for the entire year has been the goal, mainly because of the lack of constraints on disposal or exploitation of the groundwater resource. However, as disposal options become more limited and with increased stresses on the groundwater resource, full watertable control for the whole year may become an expendable luxury.

The salinity of the pumped groundwater from the Public Groundwater Pumps varies between 0.65 to 20 dS/m.

Disposal of pumped water

The disposal of pumped groundwater is one of the biggest hurdles in installing new Public Pumps. The Public Pumps generally discharge to local irrigation drains, which eventually drain into Lake Wellington either via rivers and streams or direct discharge. Lake Wellington is at the western end of the Gippsland Lakes system, which opens to the sea at Lakes Entrance. Given the large volumes of water in the lake and the high salinity of the lake water, the impact of groundwater disposal to the lake is minimal.

The impact of disposing saline groundwater into drains and rivers is assessed taking into account the following:

- > the impact of disposal on the salinity of the drain/river water and the consequent environmental impact (including satisfying EPA SEPP requirements)
- > the impact of the changed water quality on downstream drain diverters and the potential for new drain diversion
- > the impact on any receiving wetlands.

Two factors limiting future disposal options are as follows:

- > the increasing volume of saline groundwater being discharged to the drains and rivers
- > an increased awareness of the need to encourage drain diversion to reduce nutrient loads to the lake system.

However, disposing saline groundwater to Lake Wellington is generally far less restrictive than equivalent schemes in the Murray Darling Basin.

Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

The Wellington Salinity Group, which is an implementation committee of the West Gippsland Catchment Management Association (CMA), controls the investigation and management for the Public Pumps program. A Technical Working Group consisting of representatives from the West Gippsland CMA, DNRE, Southern Rural Water and consultants Sinclair Knight Merz (contracted to DNRE), advises the

Wellington Salinity Group. The Technical Working Group uses a multi-disciplinary team approach to tackle the complex technical, economic, social, environmental and political issues associated with the groundwater pumping program.

The monitoring used to determine the impacts of the groundwater pumping program involves groundwater monitoring through a network of over 300 shallow observation bores in the region. Water levels in the bores are monitored monthly and the groundwater salinity in selected bores is monitored quarterly. Other monitoring includes drain water flow and quality and pumped volumes and quality from Public Groundwater Pumps. EM-38 surveys are used to determine the change in soil salinity around groundwater pumps.

Southern Rural Water is responsible for the operation of the groundwater pumps. As previously mentioned, the operation of the Public Pumps is increasingly taking into account the need for groundwater resource management and the needs of downstream drain diverters. Consequently, there is now a stronger focus on scheduling Public Pump operation based on water level and seasonal considerations.

Drainage funding

DRAINAGE FUNDING

Funding for investigating and installing Public Groundwater Pumps in the area is provided by the Department of Natural Resources and Environment through the Government Services Contract. Typical investigation costs for each pump are from $40,000 to $50,000 and average installation costs are from $70,000 to $80,000. Sinclair Knight Merz, subcontracted to the DNRE, currently manages the investigation. Southern Rural Water is responsible for installing new Public Pumps.

The operational costs of Public Pumps are shared 35% to 40% by local government and 60% to 65% by local irrigators. The local government contribution is based on the principle that the pumps are protecting infrastructure such as roads and buildings from degradation by salinity. Therefore local government indirectly benefits through a more sustainable irrigation sector. The irrigators' contribution is funded through the 'Salinity Mitigation Rate' charged on irrigation water used from channels, drains, rivers and deep groundwater bores. Where use is not metered, the rate is charged on the annual licenced volumes. The rate is not charged on use from shallow groundwater bores, recognising the salinity benefits of shallow groundwater pumping. Currently, the Salinity Mitigation Levy is set at $0.60/ML of water used. However, the charge per megalitre is continually reviewed in line with changing operating costs.

The charging of all irrigators in the area is a policy decision made by the Wellington Salinity Group recognising that all irrigators contribute to a high watertable in the area and will benefit from watertable control. However, they also recognise that some irrigators benefit from the pumps more than others. This funding policy is contrary to that of the Shepparton Area where the direct beneficiaries pay for a proportion of the pump operation. However, identifying the precise cone of influence and local beneficiaries is expensive and ignores the longer term down-gradient beneficiaries.

Current issues and trends

CURRENT ISSUES AND TRENDS

Groundwater resource management

With the rapid increase in private groundwater pumping in the area, there is now a need to balance the needs for watertable control for salinity purposes with sustainable groundwater resource management. There are now Groundwater Management Areas (GMAs) over much of the shallow groundwater system in the MID. Each GMA has an assigned Permissible Annual Volume (PAV), which defines the approximate sustainable yield. Once the groundwater allocation reaches 70% of the PAV, a Groundwater Supply Protection Area (GSPA) is proclaimed under the *Water Act* (1989). Each GSPA requires a committee of management to be set up and a groundwater management plan to be developed. The Denison GMA, which covers the shallow aquifer system in the Nambrok-Denison area, has recently been proclaimed a GSPA. The groundwater allocations in this area now exceed the calculated PAV and no new licences are being issued. This has implications for the management of the five Public Pumps in the area and any new Public Pumps to be located in the area. In this situation, the role of the Public Pumps can be thought of as 'taking up the slack' in the portion of the PAV not used by private irrigators. Hence in wet years when private groundwater pumping is likely to be reduced, Public Pumps should have a greater output than in dry years when private pumping is likely to increase. Also, there is a need to define the 'natural level of the aquifer' and determine if 'mining' the aquifer for a number of years may be desirable from a salinity perspective. These issues are currently being debated and are likely to be of increasing importance in future.

Conflicts and synergies with nutrient management

Recent algal blooms in the Gippsland Lakes have focused attention on the source of nutrient loads to the lakes. Runoff from irrigated pastures is likely to be a significant source of these nutrients. There is now a strong focus on reducing nutrient export from farms to meet the target, set by the EPA, of a 40% reduction in nutrient loads from the MID.

There are both synergies and conflicts between salinity and nutrient objectives. The synergies lie in the need to increase irrigation efficiency thus reducing runoff (nutrient benefit) and groundwater recharge (salinity benefit). The main potential conflict is the discharge of saline water to drains from groundwater pumping, which has the potential to discourage drain diversion. Increased drain diversion is an essential element of the Nutrient Management Plan for the area. There is now a strong need to ensure that salinity and nutrient issues are not tackled in isolation but rather seen as part of a whole of catchment approach.

Land subsidence

There are currently large volumes of groundwater, oil and gas being extracted from the deeper Latrobe Group Aquifer in the Gippsland region from the following operations:

- off-shore oil and gas extraction
- coal mine dewatering in the Latrobe Valley
- irrigation development, mainly in the Yarram area.

The volumes being extracted are far higher than the total recharge volumes in the aquifer, resulting in sustained groundwater level decline. The dewatering of the aquifer has the potential to cause land subsidence as the overlying clays compact because of the reduced groundwater pressure in the underlying aquifer. Subsidence of 2 m has been recorded in a localised area around the Hazelwood area. However, the actual or potential subsidence in the rest of Gippsland is not known. A complex monitoring program instigated by DNRE will provide more information on the magnitude and spread of land subsidence in the area.

If land subsidence does occur in the Lake Wellington area, then there is a potential for the salinity problem to worsen as the land subsides to meet the already elevated watertable. The risk and magnitude of this occurring is not known and there is a need for the salinity program to be kept informed on new monitoring and technical information. If there is significant subsidence in the area, then groundwater pumping will need to increase to maintain the appropriate watertable level for salinity control.

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MID MURRAY IRRIGATION AREA

MID MURRAY IRRIGATION AREA

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Background

BACKGROUND

The mid Murray region of NSW is the geographic area located in the Murray Valley, extending from Mulwala in the east to Moulamein in the west, a distance of about 300 km. The Murray River in the south and the Billabong Creek and Edward Rivers border the region to the north, with Deniliquin the main urban centre.

The region includes both irrigated agriculture and dryland agriculture and unimproved pastoral areas. The irrigation areas include West Corurgan, the Murray Irrigation Ltd area of operations, Moira and Cadell irrigation districts and individual and small group irrigation schemes along the Murray, Edward and Wakool rivers. The Murray Irrigation Ltd area accounts for about 80% of the irrigation water use. This area includes four districts, Wakool in the west, Deniboota/Cadell and Denimein centred near Deniliquin, and Berriquin to the east.

About 50% of the irrigation water is used for rice production, 20% for dairy production and the remaining 30% for irrigating annual crops and pastures. Less than 5% of irrigation water is used for horticultural and vegetable production. Dryland agriculture involves production of winter crops and production of sheep and beef industries.

Groundwater pressure levels within the Murray Irrigation Ltd area of operations have been monitored regularly since the mid 1980s. In the 1970s about 32,000 ha of land in the Wakool district was subject to a high watertable. The Wakool Tullakool Subsurface Drainage Scheme was designed in the late 1970s and built in two stages between 1980 and 1988. The area of high watertable in the Wakool area was reduced to less than 12,000 ha by 1999 as a result of the operation of Wakool Tullakool Subsurface Drainage System (WTSSDS).

The eastern area of the region had less than 15,000 ha with a high watertable in 1980. This expanded to over 90,000 ha in the early 1990s, but then reduced to less than 40,000 ha in 1999 a result of improved farm management and a period of below average annual rainfall.

During the early 1990s the landholder community, together with the NSW Government, developed the Murray Land and Water Management plans for the Murray Irrigation Ltd area of operations.

The principle focus of these plans was to manage rising groundwater pressure levels. An integrated strategy was developed to minimise further groundwater accessions and to manage areas of high watertable to minimise degradation resulting from soil salinisation and waterlogging. Subsurface drainage is an integral component of this integrated strategy and any future requirements for subsurface drainage and its management have and will continue to be considered in the context of the Land and Water Management plans.

Regional and local hydrology

REGIONAL AND LOCAL HYDROLOGY

Regional hydrology

The mid Murray region of NSW, including the Murray Irrigation Districts, is located in the eastern and central part of the Murray Geological Basin. The Murray Basin is a saucer-shaped depression underlain by bedrock; it resulted from the tectonic uplift associated with the formation of the eastern highlands. A sequence of sedimentation began in the Eocene period, and the basin gradually filled with fluvial and marine sediments. The Murray Basin can be divided into two distinct regions. The western part of the Basin is known as the Mallee Region and is the result of past marine inundation. The eastern part is known as the Riverine Plain and is the result of past river systems associated with various climatic periods. The closed nature of the Basin inhibits the release of excess groundwater. There are also physical barriers to deep groundwater flow from a basement ridge west of Wakool and impermeable clay barrier (Geera clay) further west.

The basin was filled by a sequence of sediments, which started in the early Tertiary geological period. There are three main hydrogeological units in the region. They are the Olney Formation (part of the Renmark Group), the Calivil Formation and the Shepparton Formation.

The Olney Formation overlies the basement rock at a depth of about 140 to 350 m below the ground surface. Sedimentation began 60 million years ago and consists of sand and gravel layers up to 40 m thick, which are interbedded with clay and silt layers which are carbonaceous. There can be three layers of aquifers in this formation known as Upper, Middle and Lower Renmark aquifers. The sand layers have favourable aquifer properties providing high yields (up to 50 L/s). In the Berriquin and Denimein Irrigation districts, irrigators pump water from Upper and Middle aquifers to a depth of about 300 m. The high salinity of groundwater imposes restrictions for domestic or irrigation use, varying from 0.7 to 39 dS/m. In the western irrigation districts of Wakool and Deniboota, the use of Olney aquifers is less due to the higher salinity levels.

The Calivil Formation (Pliocene sands) is about 10 million years old and consists of sand and gravel layers interbedded with clay layers and overlies the Olney Formation. It occupies from about 70 to 140 m from the surface. The thickness of the formation is reduced to the east. This formation contains an important groundwater resource within the Murray Region. High yields of low salinity water are possible from sand/gravel aquifers with transmissivities ranging from 500 to 3500 m^2/d and salinity levels ranging up to 3 dS/m in the eastern part of the basin. Groundwater salinity in the Calivil Formation under the Wakool area ranges from 0.78 to 40.2 dS/m. Most of the irrigation bores tap the Calivil aquifers because they are shallower than Olney aquifers. In the Denimein Irrigation District, the available bores suggest that the Calivil aquifers are not productive, but in all other irrigation districts they are productive to varying degrees. In some cases irrigators obtain water from both the Olney and Calivil aquifers (mixed water) to increase the yield of the bore.

The Shepparton Formation represents the most recent major phase of fluvial sedimentation. The Shepparton Formation overlies the Calivil Formation (up to a depth of about 70 m), which consists of clay and silts interbedded with minor sand layers. The aquifers in this formation are grouped into two major categories, upper and lower, based on the depth of aquifers. Transmissivities of aquifers in prior stream deposits range from 260 to 900 m^2/d, averaging 500 m^2/d. Groundwater salinities are higher than that of deep aquifers and range from 0.5 up to 66 dS/m.

Prior stream aquifers can be used to pump groundwater as a general measure to control watertables. Public pumpsites and private spearpoints are located either on the main prior streams or on shoestring aquifers connected to the main prior stream. Because of their shoestring nature, the aquifers have a highly variable thickness, depth and texture. These aquifers and their hydrogeological characteristics are quite complex.

The aquifers in the Renmark and Calivil formations are recharged at the Basin margins, basal leakage from the Murray River and its anabranches and drainage from the formation(s) above. They flow westerly toward the lowest point within the basin, which is located in South Australia. The aquifers of the Shepparton Formation also flow in a westerly direction, however, they are recharged by rainfall and irrigation leakage from the entire Riverine Plain.

The westerly flow of groundwater is uneven because of the closed nature of the basin and the configuration of the aquifers, bedrock and clay barriers. Large areas with an upward component of groundwater flowing from the deeper aquifers contribute to the shallow aquifers and the problem of surface salinisation.

Saline surface flows and groundwater draining directly into the river increases the salinity of the river system. This drainage, together with evapotranspiration, constitutes the only way for groundwater to leave the basin.

The western (Wakool) part of the region is partially located within a regional groundwater discharge area, where under pre-European agriculture conditions there was potential for upward leakage of water from the deeper aquifers and subsequent discharge to the rivers.

The recharge of leakage from deep to shallow aquifers depends on the pressure level difference between two aquifer systems. At present some parts of the Wakool area have upward leakage and others leak downward. The Wakool area has a net recharge from shallow to deep aquifers at present.

Within the eastern area of the region, deep drainage from the Shepparton to the Calivil occurs as a result of the difference in hydraulic head between the two aquifers. As water leaks into the Calivil, hydraulic head increases reducing the downward leakage. This effect should lead to a situation where the deep drainage to the Calivil will become zero within 20 years. In the past four to five years, however, the level of groundwater extraction from the Calivil and Renmark formation has resulted in a decline in pressure levels.

Irrigation within the region

IRRIGATION WITHIN THE REGION

The mid Murray irrigation region covers about 1 million ha stretching from Berrigan in the east to Moulamein in the west. Irrigation was introduced into the region in the 1930s to 1950s. Over 3,600 km of channel system convey up to 1,500 GL of water from the Murray River system to 2,400 landholdings within Murray Irrigation Ltd's area alone.

Most of the irrigation is flood irrigation using border check and contour bay irrigation. Within the Murray Irrigation Ltd Area, around 46% of the landscape has been developed for irrigation of which over 55% of the irrigation layouts were laser landformed. Variation in the area developed for irrigation varies from around 30 to 40% in the Mathoura-Bunnaloo area to about 70% east of Deniliquin and the Wakool areas. A small proportion of water is delivered via overhead irrigation systems and micro-irrigation systems.

The region's irrigated areas support three main farming systems:

> Rice-based farming systems, producing rice, annual winter crops and pastures.
> Winter cropping and annual pastures in areas with lighter soils. These farms may also grow lucerne or other summer crops.
> Dairy farming systems, which are located on the lighter soils, mainly in the eastern part of the region.

Groundwater pumping for irrigation purposes is common on dairy farms and less so on the winter cropping/grazing farming systems. The rice-based farming systems, produced on the heavier soil types, generally have limited access to good quality groundwater.

Groundwater pumping for salinity control is generally undertaken in the western areas where more saline groundwater and heavier saline, sodic soils exist. These soils are commonly used for rice-based farming systems.

The annual use of irrigation water in the Murray Irrigation Ltd area is detailed in Table 6 and land use is summarised in Table 7. In recent years the amount of water used for annual pasture production has decreased and the area of rice grown increased.

Table 6.

TABLE 6. CROP WATER USE (ML) FROM 1992/93 TO 1998/99

Year	Rice	Annual Pasture	Perennial pasture	Winter crops	Other	Stock & domestic	Total
1992/93	521,356	357,082	97,273	21,359	16,394	6,468	**1,019,932**
1993/94	614,327	409,382	145,390	16,522	61,452	9,978	**1,257,051**
1994/95	622,888	378,541	171,092	54,179	63,105	8,710	**1,298,515**
1995/96	714,499	320,527	151,741	39,481	52,580	12,353	**1,291,181**
1996/97	786,792	335,924	192,126	80,622	60,696	15,750	**1,471,910**
1997/98	561,259	212,758	150,739	58,208	47,799	14,895	**1,045,658**
1998/99	626,157	264,168	157,088	51,030	52,291	16,411	**1,167,775**
Ten-year-average*							**1,293,763**

* Ten-year-average from 1986/87 – 1995/96

Table 7.

TABLE 7. LAND USE IN MURRAY IRRIGATION REGION, INCLUDING EAST CADELL

Land use	Proportion of total area (%)			
	1995/96	**1996/97**	**1997/98**	**1998/99**
Dryland pasture	26	31	34	34
Winter irrigated pasture	24	20	20	18
Winter crops	19	18	21	26
Rice	5	10	6	6
Rice stubble/fallow	7	6	4	2
Lucerne/summer pasture	6	4	2	7
Other crops	1	2	2	1
Trees	3	5	3	4
Infrastructure/other	9	4	7	5

Source: 1999 landholder survey that involved 318 landholders covering an area of 96,473 ha, or about 11% of the region.

NOTE: Comparisons of recordings between years for the minor land uses should be made with caution, as the sample of landholders was not the same for the four years. The total may not be 100% because of rounding errors.

Groundwater levels

GROUNDWATER LEVELS

As the Shepparton Formation fills with water, more and more land within Berriquin becomes affected by high watertables. In 1980, Berriquin had 15,000 ha of land with watertables less than two metres from the soil surface. In 1992, ninety one thousand hectares were affected by high watertables.

In 1944, eight years after irrigation began, the average depth to the watertable was 8 m in the Wakool District, the average increase in watertable height was eight centimetres per year from 1945 to 1981, bringing the average depth to around five metres. In 1981, thirty two thousand and three hundred hectares had watertables within 1.5 m of the ground surface in the Wakool District. At this depth, capillary action and evaporation leave salt deposits within the rootzone of plants. Because of increased soil salinisation more than 2,000 ha of land could not be used for agricultural production and crop yield had declined by 50% or more, in the remaining rice growing areas.

Minor, shallow watertable problems (less than 2 m below the surface) were first recorded in the early 1950s. By 1960, Wakool had seven thousand and two hundred hectares with watertables less than 2 m. This figure had increased to twenty four thousand and five hundred hectares by 1970.

In 1981, thirty thousand and nine hundred hectares within Wakool had shallow watertables, but by July 1999 this was reduced by the operation of the WTSSDS to twelve thousand and three hundred hectares.

A total of 1,501 piezometers are monitored within the Murray Irrigation Area during late February/early March and late July/early August each year. The piezometers are read in August before filling the supply system. The results of the regional watertable monitoring are presented in tables 8 and 9.

Table 8.

TABLE 8. DEPTH OF WATERTABLE FOR THE MURRAY IRRIGATION LIMITED AREA OF OPERATIONS FEBRUARY/MARCH 1995 – 1999

Year		Depth to watertable (m)			Total
	0 – 2	2 – 3	3–4	4+	area
1995	100,550	162,890	123,960	326104	713504
1997	110,636	189,728	147,267	301,571	749,202
1998	32,576	202,748	165,492	348,386	749,202
1999	69,988	197,324	141,400	340,490	749,202

Table 9.

TABLE 9. DEPTH OF WATERTABLE FOR THE MURRAY IRRIGATION LIMITED AREA OF OPERATIONS JULY/AUGUST 1993 – 1999

Year		Depth to watertable (m)			Total
	0 – 2	2 – 3	3–4	4+	area
1993	121,690	146,574	123,043	322,197	713,504
1994	114,300	163,500	129,900	305,804	713,504
1995	113,130	163,530	120,200	316,644	713,504
1996	87,837	189,728	131,110	304,829	713,504
1997	84,252	193,488	154,912	316,550	749,202
1998	55,728	194,736	160,032	338,706	749,202
1999	63,604	193,244	144,436	357,918	749,202

Between 1993 and 1998 there was an overall decline in the area of land subject to a watertable level of within 2 m of the soil surface. The area of land with a watertable within 4 m was the lowest since 1993. This reflects the low rainfall received during the six-year-period and the improvement in water management, both at a district and farm level.

From 1991 to 1995 the Murray Land and Water Management plans were developed to determine the major source of groundwater accessions and the strategies required to minimise future watertable rise.

These LWMPs highlighted the difficulty in quantifying with accuracy the level of groundwater recharge and the source. It was concluded that the major sources of accessions included; rootzone drainage from irrigated agriculture, soil profile wetting from rainfall and seepage from district irrigation infrastructure. An integrated strategy was developed to address all three sources.

The groundwater accession minimisation strategies included educating landholders, adopting better farm practices, surface drainage to minimise rainfall induced recharge and sealing areas of significant channel seepage. The specific strategies and water balances calculated are detailed in the Murray LWMPs. To complement the plans, Murray Irrigation refined a policy to restrict rice growing to low permeability soils and introduced a Total Farm Water Balance Policy to restrict irrigation intensity on-farm to minimise the level of groundwater recharge.

There is considered to be a small regional movement of deep groundwater within the Calivil and Renmark Formations from east to west. This was estimated to be between 6 and 12,000 ML/year in 1995 for the Berriquin Irrigation District.

A major surface drainage scheme has been developed for the region. The purpose of this scheme is to remove stormwater (mainly during winter) from the landscape to minimise groundwater accessions. Watertable rise has been most pronounced in the years of above average rainfall. Further studies are being conducted to determine the seasonal climatic effect on watertable rise.

Subsurface drainage

SUBSURFACE DRAINAGE

The region has three main forms of groundwater extraction – shallow groundwater pumping, deep groundwater pumping, and the Wakool Tullakool Subsurface Drainage Scheme.

Shallow groundwater pumping

There are about 175 licensed shallow groundwater pumps operated by landholders each year to extract groundwater suitable for irrigating crops and pastures. The depth of extraction is typically from 4 to 7 m and pumping rates range between 1 and 4 ML/day. There are no accurate records of the volumes pumped each year. These pump systems are mainly located in areas of major prior streams or significant shoestring aquifers. A level of watertable control and reduced waterlogging is achieved from these pumps. These bores are licensed and have unlimited access to the groundwater resource if less than 12 m. The unlimited access previously applied to bores of depth less than 20 m. The policy is designed to encourage the ‘recycling’ of groundwater recharge as much as possible.

The main aim of this shallow groundwater pumping has been to provide a water resource, however, the benefits of watertable and waterlogging control have been recognised by many landholders.

Deep groundwater pumping

There are about 120 deep groundwater pumps operated by landholders each year. Pumping depths are from 100 to 180 m and flow rates vary typically between 5 and 15 ML/day. This groundwater is used for irrigating crops and pastures despite a generally high level of sodicity in many bores. A regular bore monitoring program began in 1999-2000 to record volumes of water pumped. These bores are licensed and extraction allocations are determined for each individual bore.

The main purpose of the pumping has been to provide a water resource.

Wakool Tullakool Subsurface Drainage Scheme

From about 1960, some landholders had been trying to combat the rising groundwater by pumping and disposing of the water off-farm. However, this was of limited effectiveness, pumpsites were scattered and the only means of disposal was via surface drains and eventually into rivers. This method was only safe to the downstream environment in periods of high river flow, which provided adequate dilution.

Investigations in the Wakool area between 1960 and 1980 indicated that extensive sandy substrata existed, from which pumping would be possible and effective. Investigations also showed the feasibility and economics of a regional pumping scheme, with the disposal of the saline effluent into evaporation ponds.

Construction of the Wakool Tullakool Subsurface Drainage Scheme (WTSSDS) started in 1978. Stage I was commissioned in 1984. Stage II of the scheme began operating in 1985 and was commissioned in 1988. Extra pumps were added in 1992. The total capital cost was around $32 million and the annual operation costs are about $350,000.

The WTSSDS pumps saline groundwater from 54 strategically situated tube well pumpsites to evaporation basins for disposal. The scheme consists of two independent and self-contained stages, each comprising a system of tube wells, pumps, pipelines and evaporation areas. The area of influence of the two stages overlaps forming a cohesive, integrated drainage pattern influencing about 52,000 ha of land. The evaporation basins cover an area of 2,100 ha. As well as the direct effect on farmland, it is recognised that the scheme provides salt interception value to the Murray River system.

Since inception, the WTSSDS has greatly reduced the watertable to, or stabilized it at, 2 m from the surface over an area of 23,000 ha and it has also stopped watertable levels reaching a hazardous level beneath a further 29,000 ha of land. The scheme now maintains the groundwater at a safe level beneath a total of 52,000 ha of agricultural land, enabling it to remain fully productive. This is the long-term aim of the scheme. Because of the salinity level of the groundwater it is not reused for agriculture purposes.

Stage I and II operation

Since 1986-87, an average of 14,600 ML of groundwater with an average saline reading of 26.6 dS/m has been pumped each year into the evaporation basins. Successive dry years and reduced irrigation allocations in the late 1990s have resulted in a total of 11,206 ML being delivered to the evaporation basins for the twelve months ending 30 June 1999. This figure does not include small volumes of water returned to the basins via the four peripheral drain sump pumps or seepage intercepted and returned via the airlift system, comprising five compressors delivering compressed air injection to forty four individual tube wells.

Details of the scheme

The collection system comprises 54 pumps extracting saline groundwater from over one hundred tube wells, mainly of slotted Poly Vinyl Chloride (PVC) pipe installed to depths averaging 12 m. The three main types of pumps are centrifugal, self priming (44) and submersibles (10), and they are mostly situated below ground on a concrete slab. The average pump is capable of delivering up to 1.25 ML a day.

The tube wells penetrate coarse sandy strata that mark the course of ancient river channels and prior streams, long buried beneath millions of years of sediments.

As water is removed from the sands, groundwater from surrounding clayey deposits percolates slowly towards the tube well and is also removed.

Most of the pumps are connected via a spurline to one of the two main discharge pipelines. The two main pipelines are each about 26 km long; and the whole scheme contains about 115 km of pipeline. The main pipeline ranges in diameter from 200 to 900 mm. Pipes used in the scheme are either Reinforced Concrete (RC), Fibre Cement (FC), Unplastisised Poly Vinyl Chloride (UPVC), Poly Vinyl Chloride (PVC), High Density Polyethylene (HDPE) and Acrylonitrile Butadiene Styrene (ABS).

Originally all pumps could be operated by an analogue time clock. As time progressed, most of these time clocks malfunctioned and were not replaced. As a result of successive dry years and pumping there has been a considerable reduction in watertables recently in individual pumps and their respective areas of influence. The aim is to greatly reduce energy costs by installing digital time clocks.

Other areas of reduced system efficiency that will require further detailed investigation are that of Bio-Fouling and trapped air in both main and spurlines, particularly in the Stage I lines. The first area relates mainly to iron-oxide bacteria developing in a number of aquifers ultimately completely fouling some tube wells and pumping units. The approach was to inject Nitric Acid or Chlorine, which has had limited success. At present, MIL is investigating developing a self-producing bulk chlorine injection system. This concept will have to be carefully weighed against the cost:benefit of simply relocating the tube well. The efficiency problems surrounding air being trapped in the delivery lines originate from an underestimation of the effect of minor variations in the hydraulic grade line. Simply put, air is trapped at points were the grade of the pipe changes and this results in additional pressure that the pumps must push against, leading to pump inefficiencies and increased operating costs.

Operation

Murray Irrigation Ltd is responsible for managing the scheme. Crucial to management is the use of external contractors. The maintenance contract covers all facets of operation, maintenance, reporting and monitoring of the scheme.

Murray Irrigation Ltd also liaises with a Wakool/Tullakool Advisory Committee; a committee, which is a delegation elected from the Wakool Landholders Association, to deal with all facets of operating and maintaining the scheme and, in particular, any landholder issues that may arise.

Evaporation basins

There are two evaporation basins—Stage I of 770 ha and Stage II of 1,330 ha, a total of 2,100 ha. Each of the basins are laid out in rectangular concentrating bays ranging in size from 25 to 48 ha with water depths up to 1.2 m, and contain crystallising ponds for salt production and a works area. Evaporation occurs naturally, powered by the energy of the sun and wind.

At present about 32% of the total evaporative capacity is used, with an estimated volume of 6,208 ML being stored.

Table 11.

TABLE 11. AREA AND USE OF THE WAKOOL TULLAKOOL SUBSURFACE DRAINAGE SCHEME

Areas & capacities (as @ 25 October 1999)	Stage I	Stage II	Total
Total evaporative area (ha)	770	1,330	2,100 ha
Current area utilised (ha)	690	324	1,014 ha (48%)
Estimated volume - at present	3,264 ML	2,944 ML	6,208 ML
Percentage of total capacity	79%	20%	32%

A peripheral drain that is up to 3 m deep surrounds the entire area of the basins. This drain traps any seepage from either the basins or the surrounding land. Four vertical lift pumps, two on each stage, are located around the drains enabling water to be pumped back in to the evaporation ponds. A number of airlift pumps surround the basins intercepting any water seeping from the drain and returns the water back into the ponds.

Because it is very windy in the area of the basins, wind erosion and wave erosion of the banks dividing the bays (which are access tracks as well) are major problems. Bank protection trials on a small scale are under way with the use of granite spalls, redgum timbers, grout matt (concrete-filled mattress) and shotcreting (concrete sprayed onto the ground surface). At the moment granite spalls and shotcreting seems to be the most economically viable and effective method of erosion control.

Construction of earth banks

The earth banks were built with a 1-in-7 batter on the water side(s). They were built from clay without mechanical protection against erosion. The top of bank is 500 mm above the maximum design water level and banks are generally 3 m wide at the top. The Stage I evaporation basin was built in 1978 and Stage II in the early 1980s. Since that time there has been little maintenance of the earth banks. Bank erosion has reduced the crest width to less than 2 m in some locations.

Area of influence

A total of 130 piezometer hydrographs (from 1980 to 1995) in the WTSSDS area were analysed to assess water level changes during the period and also to assess the extent of the direct influence of pumpsites. Out of the 130 hydrographs analysed, eighty were within the radius of 1 km from a pumpsite and fifty were between 1 and 1.5 km away from pumpsites. These piezometers were not evenly distributed around pumpsites. The hydrograph analysis suggested that the area of influence of WTSSDS pumpsites, in general, be taken as areas within a 1.5 km radius of pumpsites. It is understood that, depending on the lateral extents of shallow aquifers and confining clay layers, the area of direct influence of pumps can be greater or less than 1.5 km, but in absence of a numerical model, the qualitative hydrograph analysis indicated that the best average area would be 1.5 km. Regardless of individual pumping rates, the whole system of pumps can be regarded as one big spearpoint system pumping from 12,000 to15,000 ML/year of groundwater. Hydrograph analysis suggested that some areas between pumpsites, though they do not lie in 1.5 km radius, have to be included as influence areas of pumpsites.

When determining the area under influence, “influence” was defined as the areas, which effectively control shallow watertables by a pumpsite. To proceed, a cut off depth of watertable value had to be defined. Assessing hydrographs and watertable maps of 1981 and 1995 indicated that the best watertable depth would be 1.5 m. In summary, the areas with depth to watertable deeper or equal to 1.5 m (in February 1995) and within 1.5 km radius of a pumpsite were judged as areas that are effectively controlled by pumpsites. There were some areas within 1.5 m circles that had watertable depths deeper than 1.5 m before the operation of WTSSDS (February 1981). With the rising trend of watertables, these areas would have had shallow watertables (shallower than 1.5 m) if the WTSSDS wasn’t operating. Moreover, watertables in most of these areas are kept deeper than 2 m by the WTSSDS at present.

Assumptions and limitations

There are a number of assumptions and limitations in this study. In the absence of a numerical model that would take into account climatic conditions, irrigation regime, land use, aquifer transmissivity, vertical leakage/discharge from/to shallow aquifer etc., in addition to the data used in the present assessment, the important assumptions and limitations of the study are detailed below.

1. Depth-to-watertable maps were prepared based on the existing piezometer network. These piezometers were installed for different reasons and projects with varying density. Therefore, the piezometers were not evenly distributed over the area. Hence, the reliability levels of watertable contours can vary from place to place.
2. One qualitative criterion determining the influencing area was comparing 1981 and 1995 watertable maps. The number and the geographical distribution of piezometers used to prepare watertable maps for those two years are significantly different.
3. It is indirectly assumed that the shallow aquifer within 1.5 km radius of a pumpsite is isotropic and evenly distributed.
4. Fifty one pumpsites were used in the assessment. However, operation details (pumping rates, pumping duration etc.) of pumpsites were disregarded. In

other words, it was assumed that during and before February 1995 (when the piezometers were monitored) all these pumps were operating and pumping rates were similar for all pumpsites.

5. Aquifer parameters over the whole area are assumed to be uniform. Regardless of the actual pumping rates, the area of influence of every pumpsite was considered as a 1.5 km radius. Use of a numerical model could have nullified this assumption.
6. Climatic conditions, irrigation regime and the land use pattern over the whole area were assumed to be similar.
7. After the qualitative assessments of hydrographs and watertable maps, certain criteria to measure influence areas were adopted. The ‘influence’ by the pump was defined as the ability to keep the water level deeper than 1.5 m in a designated area of 1.5 km radius around the pumps.
8. The areas were measured from AUTOCAD drawings available at Department of Land and Water Conservation. As these maps were not digitised from survey plans, there can be some unknown error in the measured values.

The volume of groundwater pumped from the network of 54 bores and discharged into the WTSSDS evaporation basins is summarised in Table 11. The average salinity level of the groundwater discharged into the WTSSDS evaporation basins was about 26 dS/m.

Table 11.

TABLE 11. VOLUME OF GROUNDWATER DISCHARGED INTO THE WTSSDS BASINS 1995 – 1999

Basin			Groundwater discharge (ML)		
	1994/95	1995/96	1996/97	1997/98	1998/99**
Stage I	*7,335	5,686	6,984	4,766	4,575
Stage II	*6,505	4,838	6,466	8,846	6,631
Total	**13,840**	**10,524**	**13,450**	**13,612**	**11,206**

* Approximate split between Stage 1 and Stage II.

** For the period August 1998 – July 1999

The level of groundwater extraction has remained relatively constant over the 5-year period. The pumps were significantly refurbished in 1995-96, resulting in the lower level of extraction. Given the moderately dry conditions over the winter period the decline in watertables up to August 1998 indicated the volumes pumped exceeded the extractions necessary to stabilise the watertable at a depth slightly below 2 m. A significant buffer has been created in the event of a major wet period. Since the commissioning of the WTSSDS more than 160,000 ML and 3.07 million tonnes of salt have been discharged into the evaporation basins.

The conclusion of the study conducted by Kulatunga (1996) was that 52,000 ha were directly influenced by the WTSSDS. This included a direct drawdown of the watertable over 20,000 ha and a stabilisation of pressure levels in the adjoining 32,000 ha. The change in watertable levels for the area influenced by the WTSSDS is summarised in tables 12 and 13. These results show a rise in the watertable level within the area influenced by the groundwater pumping scheme in 1998-99. However, the watertable level in 1998-99 was still lower than that recorded in all previous years since the pumps were installed.

There was 5,332 ha or seven percent (excluding the evaporation basins) of the 75,500 ha area that had a watertable within two metres of the soil surface in August 1999 (Table 13). This compared with 1,475 ha in August 1998. The change in watertable depth in the WTSSDS area indicates that the watertable has been lowered by between 0.5 and 2 m over most of the area since 1980. During the same period, land next to the area of influence has been subject to a rising watertable. This adjoining area is being investigated to determine future groundwater pumping requirements.

No discharges have been made from the evaporation basins since 1994-95. This would suggest that the evaporation basins are big enough to protect the 50 to 60,000 ha at risk of high watertables, particularly given the soil storage 'buffer' that has been created from the 10 to 15 years of pumping. This was not the case in the early 1990s when the watertable levels were higher and a series of above average winter rainfall occurred. A discharge from the basins was then required to create enough storage.

Table 12.

TABLE 12. DEPTH-TO-WATERTABLE FOR WAKOOL TULLAKOOL SUBSURFACE DRAINAGE SCHEME REGION FEBRUARY 1981 – 1999

	1981	1991	1992	1993	1994	1995	1997	1998	1999
0–0.5 m	300	100	100	1,200	550	350	0	0	0
0.5–1.0 m	4,700	1,000	1,200	5,100	3,600	1,850	*2,168	2168*	2,192*
1.0–1.5 m	12,700	6,500	5,000	17,400	10,700	7,050	2,124	0	956
1.5–2.0 m	13,200	15,100	13,700	18,000	20,400	13,600	14,743	244	9,124
2.0–2.5 m	11,300	16,100	15,500	12,200	15,300	16,600	20,664	16,816	18,938
2.5–3.0 m	9,400	11,300	13,200	8,300	10,300	14,200	15,622	25,604	16,526
> 3.0 m	21,800	21,800	24,700	13,500	14,600	21,850	20,179	30,668	27,764
0–2.0 m	30,900	22,700	20,000	41,700	35,250	22,850	19,034	2,412	12,272*
> 2.0 m	42,500	49,200	53,400	34,000	40,200	52,650	56,466	73,088	63,228
Total	**73,400**	**72,100**	**73,400**	**75,700**	**75,450**	**75,500**	**75,500**	**75,500**	**75,500**

* This includes the area of the evaporation basins (2168 ha).

Table 13.

TABLE 13. DEPTH-TO-WATERTABLE FOR WAKOOL TULLAKOOL SUBSURFACE DRAINAGE SCHEME REGION JULY/AUGUST 1981 – 1999

	1981	1991	1992	1993	1994	1995	1996	1997	1998	1999
0–0.5 m	1,900	200	50	400	500	450	273	3	0	0
0.5–1.0 m	8,200	2,500	1,500	1,200	1,050	2,600	1,051	*2,221	2,168*	2,178*
1.0–1.5 m	9,100	8,100	4,900	7,500	5,900	7,050	2,911	297	93	254
1.5–2.0 m	11,800	12,700	14,800	17,100	17,850	13,200	12,194	7,974	1,382	5,068
2.0–2.5 m	12,400	15,800	15,000	17,900	18,100	15,900	21,534	21,270	21,351	15,864
2.5–3.0 m	9,400	14,200	14,500	12,500	13,550	14,950	15,332	19,058	23,067	19,354
> 3.0 m	20,700	20,600	22,600	19,000	18,550	21,350	22,205	24,677	27,439	32,782
0–2.0 m	31,000	23,500	21,250	26,200	25,300	23,300	16,429	10,495	3,643	7,500*
> 2.0 m	42,500	50,600	52,100	49,400	50,200	52,200	59,071	65,005	71,857	68,000
Total	**73,500**	**74,100**	**73,350**	**75,600**	**75,500**	**75,500**	**75,500**	**75,500**	**75,500**	**75,500**

* This includes 2168 ha covered by the WTSSDS evaporation basins.

Drainage design

DRAINAGE DESIGN

Shallow groundwater pumping

The aim of shallow groundwater pumping in the Murray Region is to restrict the watertable level to a depth at or below 2 m of the soil surface. The zone of capillary rise in the clay soils can extend up to 1 m. The rootzone for the commonly grown crops and pastures is about 50 to 70 cm. A watertable depth of 2 m provides a precaution against salinisation of the rootzone, and provides a buffer against a sharp rise in watertable levels as a result of above average rainfall.

Shallow groundwater pumps are generally installed into the first pumpable aquifer, generally at a depth of around 4 to 7 m. The pump capacity is around 1.5 to 5 ML/day and the pumping system used has either a single tube well or a spearpoint. The main aim of these systems is to extract good quality water for irrigation use or to provide watertable control benefits, including reduced waterlogging, or both.

Site investigations for isolated pump systems, generally used for irrigation supply, involve electromagnetic surveying. Historically EM34 but more recently EM31 equipment has been used to identify the presence of shallow aquifers. Test pumping of the aquifer is undertaken to determine likely pumping rates and water quality.

In areas subject to high saline groundwater, shallow groundwater pumps are installed as either isolated single units or as a network of pump sites. The rule-of-thumb applied for determining landscape protection is 1 ML/ha/yr within the more intensively irrigated areas and discharge areas located in the western (Cadell, Wakool) part of the region.

Site investigations for installing a network of groundwater pumps for subsurface drainage purposes involve more detailed mapping of watertable conditions, presence and connectivity of aquifers and the transmissivity of the aquifers. The key elements to the investigations are electromagnetic surveying, combined with test drilling and transmissivity assessment.

The aquifer potential for subsurface drainage involves determining aquifer transmissivity using available stratigraphic data (subsurface profiles) and pumping test information. Aquifer transmissivities higher than 200 m^2/d are considered as having moderate potential for groundwater pumping and transmissivities between 100 and 200 m^2/d are considered as having limited potential. Along with prior streams these potential areas provide a guide for subsurface drainage.

EM34 and drilling data assessment in areas of Wakool with high watertables (with either moderate or low aquifer potential for groundwater pumping) indicated that pumping rates of an average of 0.9 ML/day per pumpsite can be sustained (270 days of pumping per year to meet the drainage requirement of 0.6 ML/ha/yr) and would drain an area of 250 ha. An alternative to single site pumps is to install 6 to 10 shallow bores (up to 20 m deep with 200 to 300m spacing) and connect them to one pumpsite, e.g. airlift pumping.

The airlift system consists of an air compressor with a capacity ranging from 12 to 44 cfm free air. The air flows through a small airline (16 to 25 mm polyethylene pipe), which connects to the air pump located at the bottom of the eductor pipe. A single airline can service a multi-wellpoint system spread over a few kilometres. This system provides benefits in areas of high salinity groundwater as there are no components that can be corroded by salt. Also, very small quantities of groundwater can be pumped from low transmissive aquifers. At present there are four airlift pump systems operating in Wakool, serving as peripheral pumps for WTSSDS evaporation basins.

The 54 pumps operating in the Wakool area have had a direct watertable drawdown effect over about 20,000 ha. Given that the pumps extract 13,000 ML each year, an average of 220 ML/pump is extracted. This indicates the average direct drawdown protection zone for each pump is about 320 ha, using the rule-of-thumb of 0.6 ML/ha/yr.

Deep groundwater pumping

Deep groundwater pumps are generally installed to depths of 100 to 180 m and may have either single or multiple screens, depending on the water quality and capacity of the aquifers intercepted during the drilling. Pumping allocations are determined by the DLWC based on estimations of aquifer yield and the number of pumps extracting from the aquifer.

Pump allocation is also related to the Total Farm Irrigation Water Use limits that apply to the landholding. Each landholding is limited to the amount of irrigation water (from all sources) that can be applied, to try to achieve a farm water balance and hence reduced groundwater accessions.

Drainage water quality

DRAINAGE WATER QUALITY

Shallow groundwater

In August 1997, water samples were taken from the piezometers used to measure groundwater pressure levels within Murray Irrigation Ltd's area. The water was analysed for salinity and sodicity levels. The results were detailed in the Murray Irrigation Ltd 1997-98 *Annual Environment Report*.

The results of the salinity level of the groundwater show that a large proportion of the district is underlain by groundwater too saline for agricultural use. Only 23% of the region had groundwater of less than 3 dS/m. The average salinity level of the water discharged into the evaporation basins is about 23 dS/m.

The sodicity of groundwater is a key determinant of the suitability of water for use as irrigation water. Sodicity refers to the amount of exchangeable sodium action in the soil or water.

The results of the sodicity analysis of the region's groundwater showed a similar trend to the electrical conductivity with regard to the similarities between Berriquin and Denimein and between Deniboota and Wakool. Over the entire Murray Irrigation Ltd area of operations, only 8% had groundwater with an SAR of below 5, with 6% in the Berriquin and Denimein area and 2% in the Wakool and Deniboota area.

Of the water samples analysed for both salinity and sodicity only 30% had salinity levels less than 5 dS/m and sodicity levels less than SAR of 5. Over 60% of this area was within the Berriquin District.

The results highlight that there are very few areas in the region with groundwater of a quality suitable for long-term use for agriculture purposes. This information reinforces the need to continually implement strategies to reduce groundwater recharge.

At present, most of the shallow groundwater pumping for irrigation is from aquifers at depths of up to 7 m. The unconfined aquifers are usually located above the major aquifer system located from 7 to 12 m deep and have more suitable groundwater quality for irrigation. The piezometers are located within this deeper major aquifer system.

Deep groundwater

A study was done in 1997 to assess the quality of deep bores within the region. Irrigation bores obtaining water from Calivil and Olney Formations, stock and domestic deep bores located in areas where deep irrigation bores were sparsely distributed, and the DLWC deep investigation bores within the irrigation districts were sampled. A summary of the results is shown in Table 14.

Table 14.

TABLE 14. SUMMARY STATISTICS OF DEEP GROUNDWATER QUALITY PARAMETERS

Parameter	Minimum	10% ile	Median	Mean	90% ile	Maximum
pH	6.36	7.06	7.47	7.48	8.05	8.45
EC dS/m	0.13	0.73	1.96	4.64	9.14	51.50
Hco3 mg/L	1.83	109.00	179.00	197.70	318.00	448.00
Na mg/L	0.10	78.50	200.00	531.00	1220.00	5650.00
K mg/L	0.10	0.10	3.60	15.06	42.80	186.00
Ca mg/L	0.10	3.70	20.40	62.70	132.00	1110.00
Mg mg/L	0.20	14.50	48.50	148.60	301.00	2440.00
B mg/L	0.10	0.10	0.10	0.12	0.10	0.90
SAR	0.00	3.70	5.75	7.82	14.50	25.20
S mg/L	0.00	0.50	9.80	36.00	84.50	687.00
NO3 mg/L	0.10	0.10	0.10	0.15	0.17	2.67
TH mg/L	0.90	68.50	249.55	774.00	1713.00	12840.00

pH

Optimum pH levels should be in the range of 7.5 to 8.5. In this range, there will be minimal corrosion of pipes and fittings. In the study, pH values were in the range of 3.36 to 8.45, with an average of 7.48. pH levels above 8.5 indicate that water will have high sodium levels. No bore results exceeded this 8.5 limit.

Electrical Conductivity (EC)

The deep groundwater salinity in the Murray Irrigation District range from 0.13 to 51.5 dS/m with a mean value of 4.64 dS/m. Higher values are found in groundwaters towards the west. When the EC is greater than 2.25 dS/m, the water is not suitable for soils with restricted drainage. Even with adequate drainage, special management of salinity control may be required and the salt tolerance of the plant must be considered.

Sodium Absorption Ration (SAR)

The Sodium Absorption Ration (SAR) was determined to assess the degree of sodium hazard from deep groundwater. A low SAR (0–10) indicates low danger from sodium. A high SAR (11–26) indicates a hazard of strong sodium replacement of absorbed Ca and Mg in the soil. SAR above 18 is not suitable for irrigation unless drainage and leaching characteristics are excellent, and the soil is high in organic matter.

Increasing permeability problems are expected where the SAR of irrigation water exceeds 6. Nineteen bore samples exceeded an SAR value of 10. SAR ranges from 0 to 25.2 with an average of 7.8. High SAR associated with very high salinity indicates that those deep groundwater samples in the Murray Irrigation District are a hazard for irrigation.

Bicarbonates (HCO3)

Levels of bicarbonates in the deep groundwater range from 1.83 to 448 mg/L, with an average level of 197.7 mg/L.

There are no quantitative guidelines for bicarbonates on irrigation water because the potential hazard is influenced by other soil and water characteristics. For example, bicarbonate hazard can be high in low salinity water applied to sandy and silty loamy soils.

Sodium

Generally the higher the salinity, the higher the concentration of most other anions and cations and Sodium Absorption Ration (SAR), but the lower the pH.

High exchangeable sodium levels in groundwater indicate reduced soil hydraulic conductivity and soil stability compared to the use of surface water.

As shown in Table 14 deep groundwater sodium level ranges from 0.1 to 5650 mg/L with a mean value of 531 mg/L.

Too much sodium in irrigation water compared with calcium and magnesium levels can adversely affect soil structure and reduce the rate at which water moves into and through soil, as well as reduce soil aeration.

Potassium (K)

From the study it was revealed that potassium levels in the deep groundwater range from 0.10 mg/L to 186 mg/L with an average of 15.06 mg/L.

Calcium (Ca)

From a corrosion perspective, calcium levels are important. (High levels of calcium result in rapid corrosion of metal parts.) From Table 14 it can be seen that calcium levels are in the range of 0.10 to 1110.0 mg/L with an average of 62.7 mg/L.

Magnesium (Mg)

Magnesium levels range from 0.20 to 2440 mg/L with a mean value of 148.6 mg/L.

Boron (B)

Boron is essential to plant growth, but too much is highly toxic. If present above 1 mg/L, Boron will reduce yield. Levels above 2 mg/L are not considered suitable for irrigation. The study reveals that all results were well under these limits, ranging from 0.10 to 0.90 mg/L with an average of 0.12 mg/L. The maximum limit for sensitive crops is 0.5 mg/L.

Sulphur (S)

Sulphur levels in the samples were found to range between 0.0 and 687.0 mg/L, averaging 36.0 mg/L.

Nitrates (NO3)

The level of nitrates in deep groundwater in the study area ranges from 0.10 to 2.67 mg/L with an average of 0.15 mg/L. Higher nitrate levels lead to the formation of algal blooms. The concentrations found in the analysed samples are low enough not to cause any problems.

Total Hardness (TH)

Total Hardness levels are expressed in mg/L and in the study area deep groundwater hardness lies between 0.90 and 12,840 mg/L, with a mean level of 774 mg/L.

Groundwater use

GROUNDWATER USE

The Murray LWMPs developed guidelines for the use of groundwater for irrigation. The salinity guidelines were set at 3 dS/m for shallow groundwater and 2.3 dS/m for deep groundwater. This was based on research conducted by Slavich *et.al.* NSW Agriculture, however there is concern that continued irrigation with high application rates of groundwater of salinity levels exceeding 2.3 dS/m may be unsustainable.

Given that the SAR of water relative to its EC level has ramifications for both infiltration and the long-term stability of the soil structure, sodicity guidelines are required. In general, there is a risk of both reduced infiltration and declining soil structure problems if the water has moderate to high SAR but low ECw.

NSW Agriculture developed interim guidelines for sodicity levels, however, these generic guidelines require refinement for local soil types. The interim guidelines are detailed in Table 15.

Excess levels of some elements sometimes found in groundwater restrict the growth of plants. Crop and pasture plants vary in their sensitivity. Of those elements commonly found in Murray Valley groundwater, there is a risk of damage to most plants if exposed to high levels. Guidelines for selected ions are detailed in Table 15.

Table 15.

TABLE 15. WATER QUALITY CHECK GUIDELINES FOR SURFACE IRRIGATION

		Risk of potential problems		
Potential problem	**Units**	**None**	**Moderate**	**High**
Problem for soils				
Sodicity				
SAR 0–2 when ECw is	dS/m	> 0.8	0.8–0.3	< 0.3
SAR 2–4 when ECw is	dS/m	> 1.3	1.3–0.4	< 0.4
SAR 4–8 when ECw is	dS/m	> 1.6	1.6–0.7	< 0.7
SAR 8–12 when ECw is	dS/m	3.0–2.0	2.0–1.0	< 1.0
SAR 12–20 when ECw is	dS/m	Not rec.	3.0–1.5	< 1.5
Problem for plants				
Salinity *	dS/m	0.8	0.8–2.5	> 2.5
Specific ion toxicity and other				
Sodium	SAR	< 2.0	2.0–6.0	> 6.0
Chloride	Me/L	< 4.0	4.0–10	> 10
Boron	Mg/L	< 0.7	0.7–3.0	> 3.0
Bicarbonates	Me/L	< 1.5	1.5–5.5	> 5.5
Nitrates	Mg/L	< 5.0	5.0-30	> 30

Source: Dr Harnam Gill, NSW Agriculture (1997)

Note that the figures given are for light, well-drained soils—lower limits apply with some pasture species and crops grown in the heavy, very slow draining soils

Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

Groundwater licensing

Groundwater licensing is the responsibility of the NSW Department of Land and Water Conservation. All groundwater pumps require licensing, however, bores less than 12 m deep are given unrestricted access to the groundwater resource. Licence conditions regarding the location, use and monitoring of shallow groundwater pumps are detailed below.

> Shallow groundwater pumps are not to be located within:
  - 200 m from any boundary of the property, unless written permission is obtained from adjoining neighbours before issue of this licence
  - 400 m from any irrigation bore on an adjoining property
  - 100 m from any Murray Irrigation Ltd channel
  - 50 m from the high bank of any watercourse.

> If the salinity of water from the bore/spearpoint exceeds 1.6 dS/m (or the salinity limit determined by the LWMP), water may not be used for irrigation without department approval of the arrangements proposed by the licensee to deal with salinity. If deemed necessary by the department, the licensee must stop

pumping when directed by the departments regional director and cannot resume pumping until that officer gives approval.

> In July each year the licensee will give the department (on a form which is provided) a return showing the meter reading of the hours pumped, the extraction rate from each month during the previous twelve months, the area of each crop type irrigated and how the water was applied, regardless of the number of times these areas were actually watered.

> In any year starting 1 January, water abstracted by means of the licensed work/s will not be used for irrigating rice unless, for each year in which irrigation of rice is intended, permission to do so has been given by the Department of Land and Water Conservation. Application for permission must be in writing and lodged with the department before 30 May in the relevant year. Any permission granted by the department is in writing. If the department's approval of an application to irrigate rice includes any limitation or restriction as to location then such limitation or restriction is a condition of this licence.

> The works authorised by this licence must not exceed a depth of 12 m.

An embargo commenced in 1998 for deep bore licences. A Groundwater Management Committee is being formed for the region. This committee will advise government of future licensing and groundwater management practices.

Groundwater monitoring

GROUNDWATER MONITORING

Monitoring groundwater pumping is a responsibility of DLWC, the licensor. The first coordinated monitoring of deep bores began in September 1999. There has been regular annual monitoring of shallow groundwater pumping systems in recent years.

Wakool Tullakool Subsurface Drainage Scheme

Murray Irrigation Ltd operates the WTSSDS. Water extraction was regularly monitored in the initial years of the scheme, however, because of metering equipment failure and pump replacements, individual pumps were not monitored regularly in the early to mid 1990s. Murray Irrigation Ltd refurbished the metering devices and the annual water volumes extracted are recorded.

Groundwater disposal

GROUNDWATER DISPOSAL

Landholders using groundwater for irrigation purposes are not permitted to drain irrigation tailwater or excess groundwater into district drainage channels. All tailwater runoff must be retained on-farm and reused for subsequent irrigation. Runoff resulting from rainfall following irrigation with groundwater is permitted to be drained from the landholding except where the salinity level of the water exceeds 1.5 dS/m.

Groundwater discharged into evaporation basins is not permitted to be subsequently discharged into a waterway unless approved by the NSW DLWC. Any approved discharges must be compliant with the Murray Darling Basin Salinity and Drainage Strategy.

Groundwater is also not to be disposed into district irrigation supply channels unless approved by the irrigation supply authority. An approval will only be granted if it is considered there will be no deleterious effect on the downstream landholdings or environment.

Reporting

The volume of groundwater extracted by the WTSSDS and the groundwater pressure levels are reported in the Murray Irrigation Ltd *Annual Environment Report*. Data from 1,500 piezometers located within the Shepparton Formation are monitored biannually and recorded on a GIS. Groundwater levels and trends are reported annually. Deep groundwater pressure levels are monitored annually by DLWC.

Drainage funding

DRAINAGE FUNDING

The funding arrangements for subsurface drainage depend on the purpose of the works.

Shallow groundwater pumping installed by landholders

An incentive has been available through the Murray Land and Water Management Plans for installing groundwater pumps in areas where the piezometric pressure is within 4 m of the soil surface. In all other areas the landholder pays the full cost of installing privately operated bores.

Shallow groundwater pumping installed by an authority

In areas where a groundwater pump(s) is installed by Murray Irrigation Ltd for the control of saline groundwater as part of an approved LWMP groundwater control project, the costs are shared between the Government and the landholder community as part of the respective Land and Water Management Plan.

Deep groundwater pumping

An embargo is currently in place for the installation of deep groundwater pumping systems. Before this embargo, funding of deep groundwater pumping was the responsibility of the landholder.

Operation and maintenance

On-farm systems

The landholder who owns the groundwater pump is responsible for its operation and maintenance costs. An incentive has been made available by the LWMPs where the pump is located in a high watertable area and groundwater pressure levels continue to rise. The regional piezometer network is used to determine the zones eligible for an incentive.

Public groundwater systems

The groundwater pumps installed and owned by Murray Irrigation Ltd have the operation and maintenance costs paid by the company. These costs are then passed back to the members of the company in the areas serviced by the pumps (as primary beneficiaries) via annual water charges. All members of Murray Irrigation Ltd recognising the broader regional benefits also meet a small proportion of these costs.

Current issues and trends

CURRENT ISSUES AND TRENDS

Shallow groundwater use

The below average seasonal rainfall experienced within the Murray Region and the associated reduced irrigation water availability resulted in an increased level of shallow groundwater use, both from existing pumps and installing new pumps.

There is, however, no information available to quantify the volume of water extracted, the quality of the water, or on what land use the groundwater was applied.

Implementing the Murray Darling Basin Cap on river extractions will continue to provide an incentive to landholders to increase the quantity of both shallow and deep groundwater extracted from either new or existing bores.

The main constraints to the further expansion of shallow groundwater pumping is poor water quality and low yielding aquifers. A significant proportion of the groundwater has elevated salinity and sodicity levels that restrict the use for irrigation.

Deep groundwater use

The embargo imposed in 1998 has meant no new licences will be issued. However, there are a number of licences that were issued in the previous five years that can still be activated. A number of deep bores are currently being installed.

The level of monitoring of deep bores was increased within the region in 1999-2000, however, because of limited historic records, no trends can be determined regarding the change in deep groundwater extraction levels. Anecdotal evidence suggests that extracted volumes have increased significantly in the past three to five years due to both reduced irrigation availability and the implementation of the Murray Darling Basin Cap on river extractions.

The main constraint to the further use of deep groundwater for irrigation relates to the water quality. High sodicity levels and marginal salinity levels restrict the use of the water without mixing with surface irrigation water.

Managing of saline groundwater

The Murray LWMPs have identified the need for further groundwater extraction and disposal to control watertable levels where they are within 2 m of the soil surface and the salinity level exceeds 3 dS/m. This will involve constructing evaporation basins and the associated network of pumps. Existing evaporation basins will be used where possible.

The major effort being employed to minimise groundwater accessions will reduce but not replace the need for managing saline groundwater. Rainfall will provide enough leaching to maintain rootzone salinity at acceptable levels where there is a downward hydraulic gradient. In some locations groundwater accessions have already led to areas of highly saline groundwater. The regional flow of groundwater to 'natural discharge' zones in the landscape will also create further need for groundwater management. Added to this is the variable nature of rainfall, where during periods of high rainfall and overland flooding significant groundwater recharge will occur.

Detailed locality investigations will determine the size and scale of the pumping systems and disposal areas, e.g. farm level systems *versus* larger subdistrict systems. Complementary activities and the attitude of the local community are also being considered. The complementary activities include applying less saline water to appropriate salt-tolerant enterprises and the use of saline water in evaporation basins for marine aquaculture or other uses.

The community preference is to minimise groundwater accessions to avoid the need for establishing new evaporation basins. There has been no indication of community preference for small or large evaporation basins at this stage. This matter will be considered on a case-by-case basis and will be influenced by the hydrogeology studies and the likely area of influence.

The Murray Region requires that groundwater is not discharged off-farm into district drainage channels or into natural watercourses. There is also a community expectation that evaporation basins will not adversely affect (via leakage) adjoining lands. In the case of the WTSSDS, additional groundwater pumps were installed to protect the adjoining land. Other impacts, including wildlife damage to crops, visual amenities and odour are all issues that need to be considered.

The major constraint to further developing saline groundwater drainage systems is economic viability. The high capital costs associated with constructing the drainage systems indicate the economic viability of such systems is marginal. This is compounded by the difficulty in accurately quantifying the agricultural, environmental and social benefits of groundwater control.

Research requirements

The major research requirements relate to the following areas:

- guidelines for the sustainable use of saline, sodic groundwater
- better predictive capability of watertable rise and to what extent this watertable rise can be addressed by non-extractive means
- the impacts of applying saline sodic water to the region's soils as part of an integrated disposal system.

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MURRUMBIDGEE AND COLEAMBALLY IRRIGATION AREAS

MURRUMBIDGEE AND COLEAMBALLY IRRIGATION AREAS

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Hydrogeology and soils

HYDROGEOLOGY AND SOILS

The Murrumbidgee Irrigation Area (MIA) and Coleambally Irrigation Area (CIA) both lie on the riverine plain of the Murray Basin. The eastern boundary of the plain is formed by outcropping bedrock, which forms the foothills of the eastern highlands. The Murrumbidgee alluvial fan forms a large part of the lower Murrumbidgee region. The apex of this fan is situated near Narrandera and sediments become thicker in a westerly direction from the eastern flank of the basin.

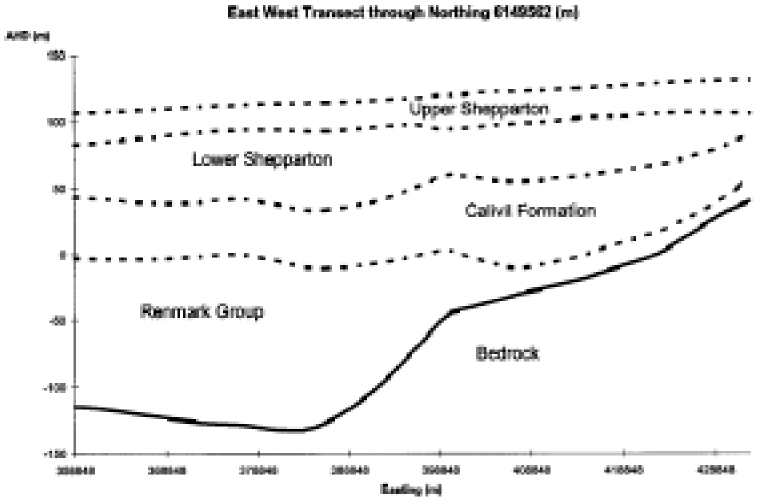
The geological units are the Renmark Group, the Calivil Formation and the Shepparton Formation (Woolley *et al.* 1978). The total thickness of materials varies from about 50 m in the north to about 230 m in the Coleambally area. In the latter area the Renmark Formation may be found at a depth of about 120 m, the Calivil Formation varies from about 45 to 120 m. To the north of the MIA the formations are shallower, for instance at Bilbul, lignites and brown coal (typical Renmark Formation materials) may be found at a depth of 60 m. The Calivil Formation has a high transmissivity to the south - up to 3000 to 6000 m^2/day (Lawson 1992). Prathapar *et al.*, (1997), prepared cross-section diagrams of the Formations. Figure 17 shows an east - west section, which demonstrates that bedrock is also coming closer to the surface east of Coleambally. The Shepparton Formation consists of variegated sands and clays, within 45 m of the surface, deposited in an alluvial plain. Buried sands of prior streams have permeability from 5 to 25 m a day. Intermediate clays pose restrictions, both horizontally and vertically, except where the stream deposits cross.

Pels (Pels *et al.*, 1977), described the hydrogeology of the Coleambally Irrigation Area, and Stannard (Pels *et al.*, 1977) described the physiography. Van der Lely wrote a report, *Landscapes in Coleambally, Past, Present and Future* (Van der Lely 1998). The MIA and districts Land and Water Management Plan (1998) and Van der Lely (1995a) are examples of a summary of the conditions.

The general landscape of clay plains and prior streams is bounded in the north by Devonian era outcrops, along which there is a strip of colluvial materials. A layer of aeolian "parna"(windblown clay) blankets the whole landscape. The structure of soils derived from this material may be more porous and permeable than suggested from the texture where the deeper profile exhibits better drainage as a result of sub-plasticity (Butler & Hutton 1956, Van Dijk 1958). Along old prior stream courses aeolian sand hills can be found, the material of which was derived from the prior streams (Butler & Hutton 1956).

Figure 17.

FIGURE 17. EAST-WEST TRANSECT AT COLEAMBALLY (PRATHAPAR ET AL. 1997)



Watertables were about 20 m from the surface before irrigation. In these areas the average land gradient is roughly 1:2000. Where clay soils dominate and lateral dissipation gradients are limited, the accessions are usually greater than the lateral dissipation and leakage to deeper aquifers (if positive). This means groundwater levels rise until they get close to the surface. Salts already present in the soil profile become dissolved and start moving with the groundwater.

The nature of the clay soils varies from very low permeability of 0.001 to 0.005 m/day in the subsoil of the plains, to over 0.5 m a day in some of the colluvial soils mentioned. Soil permeability affects the choice of crop on each landscape, and also influences the drainability of the profile once waterlogging problems develop. The locations and depth of sandy deposits of prior streams have a major influence on rates of accessions, leakage to deeper layers, lateral dissipation of groundwater mounds, the feasibility of vertical subsurface drainage systems, and suitability of land for evaporation disposal.

Investigation of the geomorphology of the area and review of the soil surveys by Van Dijk (1958), Stannard (1970), Taylor and Hooper (1938) and Van Dijk (1961), revealed that although there were at least 94 different soil types mapped within the CIA and MIA, the soils could be grouped together based on morphological similarity and recurrent patterns of associations. Hornbuckle and Christen (1999) distinguished five groups: clays, red brown earths, transitional red-brown earths, sands over clay and deep sands.

Crops

CROPS

In the MIA there are about 18,000 ha of horticulture, mostly grapes and citrus. The large area farmlands (about 180,000 ha) in the MIA grow about 35,000 ha of rice, rotated with winter wheat, canola, barley and pasture. The areas of winter pastures used to be significant but are now declining. The area of summer crops other than rice is small. There are about 6,000 ha of vegetables (Murrumbidgee Irrigation 1999).

In Coleambally, the 80,000 ha of irrigation area comprise about 24,000 ha of rice and a mixture of other summer crops including maize and soybeans. However, winter wheat and canola are still the most common in the rice rotation. Annual pasture areas are declining (Coleambally Irrigation Corporation 1999).

In both areas most land is laid out to a lasered contour system. Water management has improved on many farms in recent years. Recycling systems are common in

Benerembah, and becoming more popular in the MIA and Coleambally, because of increasing water scarcity and the need to contain herbicide and pesticide contaminated drainage on-farm.

On horticultural farms most land is irrigated by furrow methods supplied from piped supplies and risers. Of the 600-odd commercial-sized farms, about a hundred have converted to drip systems, particularly grape enterprises in the newer developments.

Of particular interest is the conversion of large area farmland into horticulture. About 6,000 ha have been converted over the last six years. The new farm units are larger than the older existing farms, which are typically from 10 to 20 ha. The new farm areas range from 50 to 600 ha in size and tend to be sited on heavier soils than previously associated with horticulture.

Nature of problem

NATURE OF PROBLEM

High value crops that are sensitive to waterlogging and salinity, such as citrus, stonefruit and grapevines, have been the focus of drainage problems in the past. Other crops grown in the area such as rice, pastures and cereals are less susceptible to waterlogging and have a lower value and therefore have tended not to be drained.

Waterlogging in horticultural crops was caused by over-irrigation combined with rainfall in wet winters. In 1923, 1939 and 1956 waterlogging of horticulture in the area resulted in a tree loss of fifty percent. Watertable surveys were then carried out to understand the nature of the problem (Van der Lely 1972). Tile drainage was introduced and extensively researched (see below). By September 1959, two hundred and eighty of 600 horticultural farms were tile drained and by 1980 about eighty percent had tile drainage installations. Similar wet winters of 1963, 1973, 1989, and 1996 did not result in massive yield losses (Van de Lely 1978a). Soil salinity, which had developed on many farms with watertable problems, was also remedied by drainage.

Many channels leaked badly as a result of aging infrastructure. This also created additional waterlogging and salinity in many horticultural farms. Similar processes have occurred in Large Area Farms (LAF) with Rice Based Farming Systems (RBFS). Accessions from rice and other crops have been estimated for the LWMPs (MIA and Districts Land and Water Management Plan 1998; Coleambally Land and Water Management Plan 1996). In the MIA, total accessions are about 95,000 ML/year and in Coleambally about 70,000 ML/year (1994). Rice is the main contributor. Channel seepage is significant at 12,000 ML/year in both the MIA (MIA and Districts Land and Water Management Plan 1998) and the CIA (Coleambally Land and Water Management Plan, 1996), but of a lesser proportion than for instance in the Berriquin District, where it is estimated to be more than 50% of all accessions (Berriquin Land and Water Management Plan 1995).

Rice growing usually results in significant accessions (from 50 to100 mm/season in high watertable areas), which create a groundwater mound in the high watertable area and dissipation into adjacent areas. Net groundwater movement is towards less intensively irrigated land and topographically depressed areas, which therefore are at the most risk of salting over a period. The land used for rice growing is involved in an occasional leaching regime, but this applies to a much lesser extent to the less intensively irrigated lands, reserves and depressions. This means that the potential problem with salinity, does not apply to all the land in which high watertables occur.

Additional factors in the salt balance of fields are the salts introduced by irrigation water and deep leakage. Where lateral dissipation to adjacent areas, or leakage to deep aquifers is very small, salts in the irrigation water will add to the problem of salt accumulation over a period of 100 years and more.

During September up to eighty percent of the MIA has watertable levels within 2 m of the surface; this variation caused by the highest rainfall month since March, the Calivil Pressure depth, and a carryover effect from the previous year. Analysis has shown that in the MIA there is a probability that since 1983 average groundwater levels have dropped from 0.5 to 1.0 cm/year because of improved irrigation practices and better surface drainage (Van der Lely, 2000).

Soil salinity surveys are carried out every three years to determine trends. At present about 20% of the MIA landscape is affected by topsoil salinity above 2 dS/m, but in some areas it is close to 50% (Van der Lely, 1998a). The latter areas have very limited downward leakage to deeper aquifers and these areas have had high watertables for about 50 years. In Coleambally, the extent of salinity is much less and is most serious in southern Coleambally; where up to 28% of the land may have soil salinity above 2 dS/m, increasing slowly. The average for Coleambally during 1998 is about 10% (Van der Lely, 1999).

The 2 dS/m area is an indicator and not necessarily the proportion of land where problems are experienced. Most crops grown have some tolerance in the 2 to 4 dS/m category; for instance, rice and wheat are not affected at these lower levels of soil salinity.

In Coleambally, the areas with high watertables have stabilised at about 30% of the landscape during a series of recent dry years. Despite the alarming rates of watertable rise in this area during the 1970s and early 1980s, not a lot of attention was given to remedial measures, such as rice farming controls. In the longer term, it is expected that about 50% will be affected by high groundwater and about 15% will be salt affected with a LWMP (LWMP, 1996).

In sandhill farms of the Murrumbidgee and Coleambally Irrigation areas where horticulture and vegetables are grown, groundwater level problems occurred in the lower slopes, because the permeable sandhill deposits are usually located on an impermeable layer at just below the average plain level. The waterlogging caused severe yield reductions in the horticultural crops and vegetables grown (Van der Lely 1971a). Other problems related to vehicle movement in the areas and mosquitoes.

The areas between rice fields have watertable levels varying between 0.6 and 2.0 m in normal years, with an average of about 1.2 to1.5 m, increasing towards the end of the rice season, and dropping during the subsequent autumn and winter, except in higher rainfall years (Van der Lely 2000). The high groundwater condition at many locations precludes growing high watertable sensitive crops. A rotation of rice with other crops is essential to manage the salt balance of fields, and it is believed that without subsurface drainage the areas not used for rice growing would be at risk of degradation through salting.

In summary, drainage needs of horticultural farms are mostly watertable control, but in large area farms the problem is one of salinity control. No large salt reclamation schemes have been implemented in either the MIA or the CIA.

Methods used

METHODS USED

Horizontal drainage for horticulture

In the past, high watertables have been effectively controlled in the MIA on horticultural developments by ‘tile’ drainage installed from 1.8 to 2.0 m deep. Traditional deep subsurface ‘tile’ drainage systems were designed to protect the plant rootzone from waterlogging and salinisation by maintaining a deep watertable. These drains were installed at a depth of around 1.8 m and from 20 to 50 m apart, depending on the soil permeability, and were designed to flow freely with no management of drainage effluent.

These early horizontal subsurface drainage systems in the MIA were built solely with cylindrical unglazed earthenware tiles 0.3 m long. Tiles were generally 0.15 m in diameter for main lines and 0.1 m for laterals, (CSIRO 1965). Trenches were built mainly with a Barber-Greene trenching machine, with a vertical boom and bucket line or a Wal Allen trenching machine, which consisted of an inclined boom and bucket.

These machines had a maximum depth of cut of 2.5 m, which was the limiting factor for drain depth, (Polkinghorne 1992). Envelope material in horticultural developments was usually considered unnecessary because of the subplastic (Butler 1976) nature of the subsoil material, which remains highly permeable and hence head loss is minimal, (Smith, undated; Talsma & Haskew 1959).

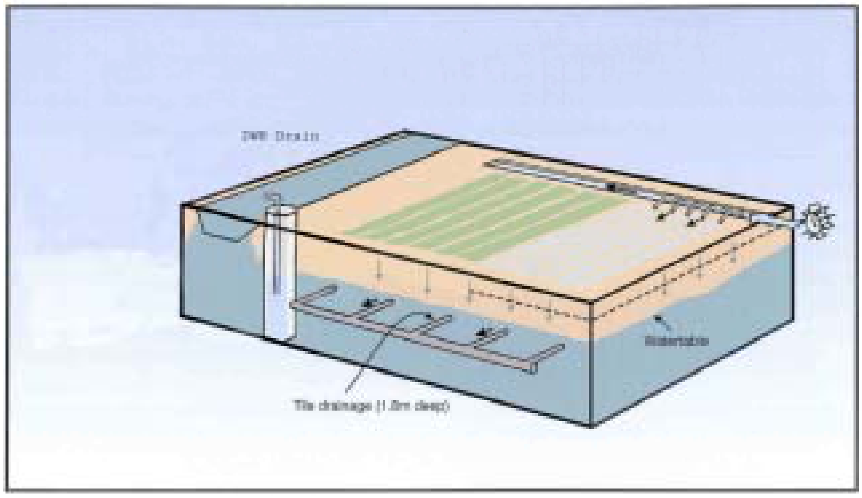
Recently, drainage materials have become more technologically advanced and systems tend to use plastic agricultural drainage (perforated plastic) pipe rather than traditional tiles. Pipe sizes are 100 mm for laterals and 150 mm for mains. Some mains have recently been laid in 150 mm smooth bore sealed pipe. Trenching machinery has also improved dramatically and trench depths to 3.5 m can easily be constructed.

With its flat topography, horticultural plantings in the MIA tend to be regular in nature and a square plan drainage system is generally used. Within the MIA, gravity drainage outlets are rarely used and typically a pumped sump is used to dispose of the drainage effluent, either into a nearby surface drain or into an evaporation basin for disposal (Polkinghorne 1992).

Inspection pits were built at each junction and at 100 m intervals along long drains. The pits also function in a secondary capacity as a silt trap and are constructed from 0.65 m diameter concrete with a lid and base. The inspection pits are installed from 300 mm above ground level to 300 mm below the drainage line (Polkinghorne 1992).

Figure 18.

FIGURE 18. SCHEMATIC OF A STANDARD SUBSURFACE DRAINAGE (SSD) SYSTEM COMMONLY FOUND IN THE MIA



The lessons of the past are that the design criteria adopted were appropriate, considering the spatial variation in factors such as hydraulic conductivity (Van der Lely 1978a). Based on climatic data alone there may be a degree of over-drainage and this is the case in most of the fields drained. However, the variation in hydraulic conductivity, which has a standard deviation of over 100%, and the fact that many farmers fail to adopt Best Management Practices (BMPs) to do with surface drainage management, means that the safety factor applied through the criteria adopted is justified.

In recent times there has been a disposal issue associated with such drainage designs, as these systems remove large amounts of salt in the drainage water. This drainage is then exported downstream, having negative effects on downstream irrigators and the environment.

Current research (Christen & Skehan 2000) is focusing on developing an integrated irrigation/shallower drainage system, which aims to minimise drainage volumes, thereby reducing salt loads exported while maintaining crop protection. These systems involve the use of bi-level drainage systems, which allow a greater degree of management, and also shallower (0.75 m) mole drainage systems (Christen & Skehan

1999). The main focus of these systems has been to minimise salt. Traditional tile drainage systems often are influenced by regional groundwater inflows in addition to irrigation drainage. The regional groundwater flows are often highly saline compared with irrigation drainage flows. Therefore, research investigating shallower drainage systems that leach less salt from the soil profile and do not intercept regional groundwater flows, are being developed. Currently only a very limited number of horticultural farms within the MIA have adopted this approach, due largely to a lack of knowledge about shallower drainage systems and also the suitability of mole systems in permanent plantings.

While mole drainage can result in less drainage and less salt discharge, this method (Christen 1994) has not been widely adopted by farmers, who generally adopt a policy of keeping their watertables as deep as possible for their permanent plantings. This may be partially caused by a remnant fear for severe events such as have happened in the past. The 1942 Irrigation Research and Extension Committee (IREC) survey on the yield of canning peaches following the 1939 wet year showed a positive correlation between yield and the depth to the watertable up to 2 m. This supports studies such as reported by Van de Goor (1972).

Area of horticulture now drained

The area of tile drains installed within the MIA in 1992 is shown in Table 25. The Mirrool Area of the MIA has always had a larger proportion of tile drainage installed compared to the Yanco Area mainly because a large proportion of the Yanco Area is underlined by deep sandbeds and rock making them unsuitable for trenching, (Polkinghorne 1992).

Table 16.

TABLE 16. GROWTH OF TILE DRAINAGE IN THE MIA (POLKINGHORNE, 1992)

	Mirrool Area		Yanco Area		
Year	Total Farms	Total Area (ha)	Total Farms	Total Area (ha)	
Prior to	1955	13	83	12	76
1956	53	339	13	83	
1960	286	2192	33	237	
1964	343	2620	35	250	
1973	524	4411	48	335	
1987	826	7269	70	581	
1992	886	7985	79	680	

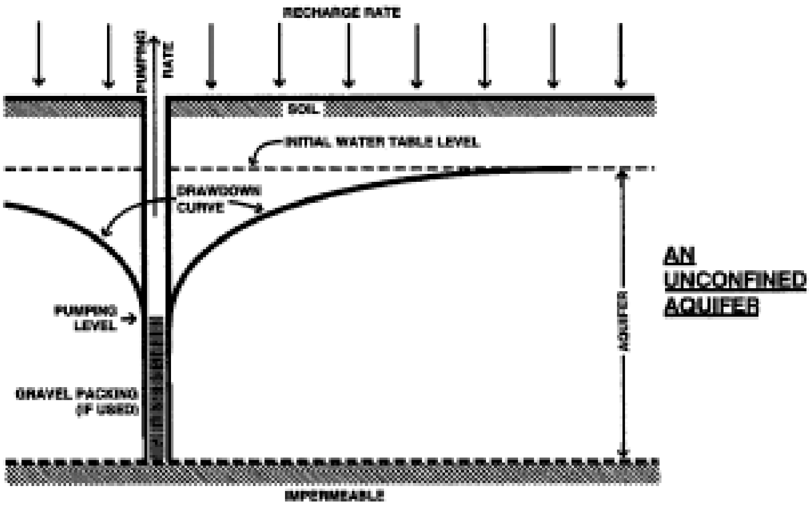
Vertical drainage for horticulture

Vertical drainage has been applied to about 2,000 ha of horticultural land in the MIA, particularly in the Yanco/Leeton area. This method requires aquifers of sufficient transmissivity. Where these occur, sites are selected from piezometer bore logs, a screen lowered in a casing sunk by drilling and baling, followed by pump testing. A single stage drawdown test is carried out initially. This is followed by a long-term (3 week) pump test using a diesel-driven pump if the site proves to be suitable. Water levels in piezometers are checked for assessing the area of drawdown. The pump capacity is determined, electricity connected and the bore equipped (Turnell 1988).

Figure 19 shows schematically the effect of vertical drainage pumping (from Haskew 1996).

Figure 19.

FIGURE 19. TUBE WELL DRAINAGE IN AN UNCONFINED AQUIFER (HASKEW 1996)



A typical vertical drainage bore sunk to a depth of about 12 m, would consist of a 30 cm casing and a 20 cm screen, and would pump from 10 to 20 L/s.

Pump tests to determine aquifer transmissivity and storativity can be done using methods compiled by Kruseman and Ridder (1990). This type of analysis has been carried out for large area farmlands in the MIA. However, variation of transmissivity within the aquifer is high and wedge and boundary effects influence the long-term achievable pumping rates. Consequently, assessing the transmissivity and storativity has not commonly been used for designing pump dimensions. A multi-stage drawdown test (Roreabough 1953) has occasionally been used to determine head losses by the screen.

Vertical drainage for large area farms

In large area farms of the Murrumbidgee and Coleambally Irrigation Areas there has been little development of subsurface drainage. It was initially popular for experimental purposes, but because of the cost of effluent disposal, the economics of such projects became questionable. To protect farmers downstream who use the drainage from the MIA, a moratorium was declared on the disposal of the subsurface drainage flows into surface drains in 1984.

Experimental bores during the 1960s and 1970s were constructed very much the same as for horticultural farms. Typical pumping rates were 1 L/s for every fifteen hectares of land protected, which converts to about 2 to 3 ML/ha per year, which is much more than the leaching requirement. When salt disposal became an issue, methods to reduce the volume of effluent were used.These consisted of:

> assessing the soil salinity status (visual inspections)
> identifying where rice was to be grown during the forthcoming season
> formulating a pumping strategy, targeting certain pumps for use in the next season, and leaving the rest unused.

This strategy worked very well, but after a number of years, at the insistence of downstream water users, and policies of the LWMP Working Group, all experimental large area pumps were permanently switched off.

For the Coleambally LWMP, subsurface drainage potential using vertical pumping (Bosch 1995) and discharge of the effluent into the nearest supply channel was investigated. While the outcomes were partially effective, after the experimental two-year phase, the pumps were switched off because of a lack of interest by the local landholders.

Experience with subsurface drainage for large area farms

As mentioned, in the MIA vertical drainage in large area farms was believed to result in too much effluent for the area being protected. This area was determined from piezometer mapping to identify where the drawdown was about 20 cm and more. Obviously, the area of influence is larger than the 20 cm contour, but it was perceived that drainage volumes were too high. It was decided to start experiments with horizontal drainage, including the use of evaporation areas, the idea being that discharge volumes from a targeted area could be better controlled.

The experiments were carried out on three rice farms, draining from 5 to10 ha each. Wide drain spacings from 40 to 100 m apart were used, consistent with a drainage discharge rate of from 0.5 to 1 mm/day. The drained areas were located in depressed, saline areas, and groundwater flows to the site had the effect that up to 1.5 ML/ha was being drained, with tiles at about 1.8 m depth (Smith *et al.* undated).

It was concluded from these experiments that applying subsurface drainage in the lower parts of the landscape can protect large areas, but it probably should not be attempted to fully reclaim the depressed areas themselves. As the depressed areas occupy from 5 to 10% of the landscape, they may have to be sacrificed, at the same time creating an opportunity to remove groundwater from the average plain level areas at the rate of the leaching requirement. This is less than about 0.2 ML/ha/year for the MIA.

At one of the sites in a RBFS the soil hydraulic conductivity turned out to be so low, that the discharge from the horizontal drains was only a trickle, despite the watertable (pressure level in aquifer) being at about 1 m. This system was converted to spearpoints at four locations connected by a T piece between the vertical pipe and the horizontal drain and drained by gravity at a satisfactory rate. Hybrid systems consisting of both vertical and horizontal subsurface drainage could be designed like this, based on pumping tests at a number of sites within the same locality. This system offers very effective opportunities to control the flow in any of the spearpoints used.

Mole drainage systems were also trialled by Muirhead *et al.* (1995) and Christen (1994) on large area farms for waterlogging protection of irrigated vegetable crops on raised beds. Moles were constructed at a 0.6 m depth and 1.8 m spacing during a series of trials to evaluate the efficiency of these systems. Hybrid systems using mole drains and Gypsum Enrich Slots (GES) (Jayawardane *et al.* 1994) were also trialled along with conventional installed tile drainage systems. Results from the study indicated that mole and mole/GES systems provided the most consistent protection from waterlogging, however, the costs associated with a mole/GES system were prohibitive and around double the cost of a mole drainage system without the GES.

Comparison of the shallow mole and mole/GES drainage systems with a traditional tile drainage system installed at 1.65 m depth and 9.1 m apart showed that the shallower drainage systems had an average salt load of 2 t/ha compared with 12 t/ha for the traditional tile drainage system and were much more effective in preventing waterlogging in the rootzone. The costs of mole drains were roughly a quarter of the cost of a conventional tile drainage system. For an expanded analysis of the economics of these drainage systems see Moll (1995).

Deep groundwater pumping for drainage

Deep leakage to the Calivil Formation from 45 to 120 m has resulted in investigations as to whether pumping from this formation can achieve viable salinity control. There is leakage from the Shepparton Formation aquifers to the deeper Calivil Formation aquifers at a rate of about 20 mm/year per 10 m head difference, which is about the same as the rootzone leaching requirement. A pump test was carried out at

Coleambally, with discharges of about 20 ML/day over about 20 months. The salinity of the discharge was 0.6 dS/m. The data proved difficult to analyse because the drawdown in the most shallow watertable aquifer was very small. It was concluded from analysis of the data that the leakage effect may only be about 7 mm/year for every 10 m head difference between the aquifers (Lawson 1992). This is less than values from alternative assessments, which range from 10 to 50 mm/year/10 m for Coleambally (Enever 1998, Van der Lely *et al.* 1987).

The most significant effect exists in North Coleambally, where watertable levels are still 4 m deep, despite significant accessions from rice areas due to private groundwater supply development creating a head difference and hence leakage into the Calivil Formation. The main conclusion from the experiment was that a subsurface drainage scheme based on this concept could only be partially successful, because the pumped volumes are derived from a much wider area than the area targeted for watertable control. As such these schemes should be considered water supply schemes, rather than drainage schemes.

Site investigations and design

SITE INVESTIGATIONS AND DESIGN

Horticulture tile drainage

Design equations

The earliest method of investigation to determine the optimal drain depth and spacing at which subsurface drains should be installed was undertaken using open trenches and observing the flow of water to the open drains. This method proved unsatisfactory because of the impractical nature of such an approach and the fact that depths and spacings could not be established for particular soil types due to the large variation in hydraulic properties within classified soil groups (CSIRO 1965).

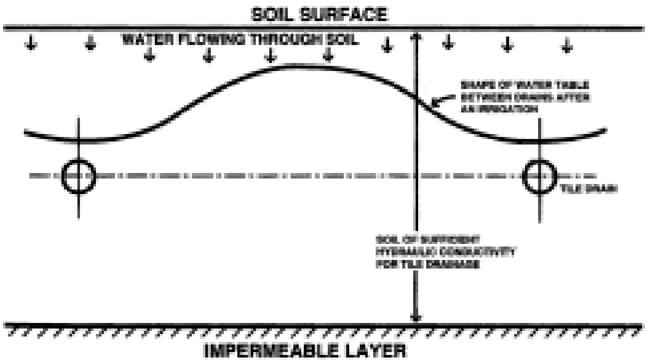
Previously, in Victorian irrigation regions, the use of soil type designations gave consistent results in selecting soils that could be tile drained successfully. It was found that in the MIA however, that such a method gave inconsistent results when used for soil types found in the region (Haskew 1996).

The MIA is unique in many respects in that the design of subsurface drainage layout is based almost entirely on drainage theory. Figure 20 shows a diagram for a simplified condition, where a homogeneous soil occurs above an impermeable layer at depth (D) below the level of the tile drains. The calculation of drain spacing (S) was based on the Hooghoudt formula (Maasland & Haskew 1956). Assuming a steady state condition of recharge (q) to the watertable, a soil hydraulic conductivity (k), and a height of the watertable (m) between the tile drains, (S) may be calculated by:

$$S^2 = \frac{4km}{q}(2d + m)$$

Figure 20.

FIGURE 20. WATERTABLE SHAPE AT EQUILIBRIUM FOLLOWING TILE DRAIN INSTALLATION TAKEN FROM HASKEW (1996)



Essentially, this equation assumes the Dupuit-Forchheimer conditions of horizontal flow between the point where the water enters the watertable and the location of the tile drains. Because the groundwater flow lines are curved, the flow path is actually a little longer than assumed. In addition, near the horizontal (tile) drains the flow lines will exhibit radial flow as they come together, and this creates an extra resistance to flow. Hooghoudt (1940) accounted for these extra factors by using an equivalent depth to the impermeable layer "d" rather than "D", "d" being smaller. It follows that "d" is a function of the flow geometry, including D, S, and m. These relationships were compiled in nomographs.

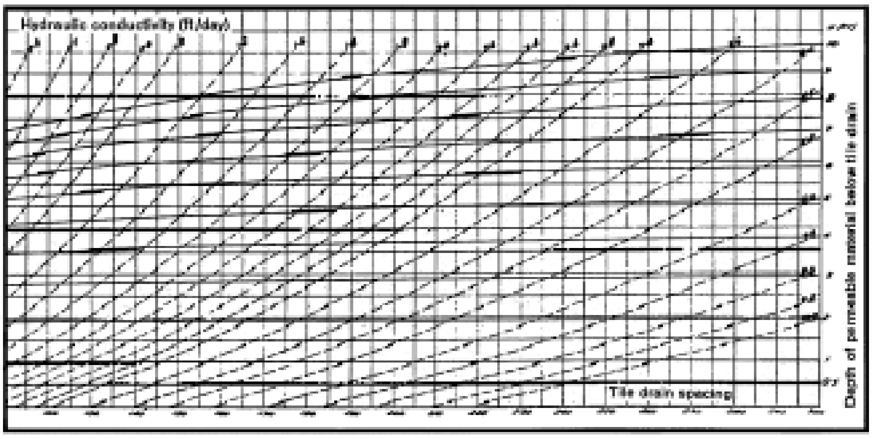
As mentioned, the flow of groundwater from the watertable to the tile drains occurs through the whole of the saturated zone above the impermeable layer. The latter is considered to occur if its hydraulic conductivity is less than 10% of the upper layer.

The capillary fringe above the watertable may contribute significantly to the groundwater flow (Talsma 1963), but this is usually ignored.

Most conditions in the MIA where tile drainage is used, involve an impermeable layer at some depth. If there is a more permeable aquifer, subsurface drainage is often achieved by vertical tube well drainage. However, it also often occurs that the hydraulic conductivity of the layer above tile drain level is higher than that of the layer below, or vice versa. These situations may be assessed by using other approaches as described by the International Institute for Land Reclamation and Improvement (IILRI) manuals (1978), however the use of the nomographs of Figure 21, which is based on the above equation, was usually enough.

Figure 21.

FIGURE 21. NOMOGRAPH USED FOR ASSESSING DRAIN SPACINGS BASED ON THE HOOGHOUDT FORMULAE IN THE MIA



Determining hydraulic conductivity

The hydraulic conductivity of the soil layers in the MIA is determined from an auger hole test, where a hole is drilled to below the watertable, left overnight to allow equilibration, and then bailed and the rate of recovery monitored over a period. The hydraulic conductivity is a function of the rate of recovery and the flow geometry relative to the dimensions of the hole. Nomograms were developed and used to assess hydraulic conductivity from the observations made (Maasland & Haskew 1958).

Design criterion

The effect of high watertables on growth of plantings is still subject to continued research. Early studies by Penman (1938) found that citrus trees remained healthy for the first 8 to 10 years in watertable conditions within 1.2 m of the soil surface, however, after this age a deeper watertable depth was required to maintain tree health.

Minessy *et al.* (1971), studied the effects of high watertables on citrus in the Middle

East. They found a positive linear relationship between watertable depth and yield, with watertable depths down to 1.75 m.

In a survey of factors relating to the yield of canned peaches in the MIA by Balaam and Corbin (1962) it was found that soil type and watertable depth each contributed from 25 to 30% of total variation, with management practices accounting for a further 25%. During September a positive relationship between watertable depth and yield was also found and continued to a depth-to-watertable of 2.1 m. In reviewing these studies it was noted by Van der Lely (1978a) that the experiments involved a number of dependant and independent variables, which are difficult to separate and salinity effects may be confused with the effects of high watertables.

The design criterion depends on the tolerance to waterlogging conditions of the crop to be protected. In the MIA these crops were mainly peaches, citrus and grapes. Peaches proved the most sensitive and on that basis the aim has been to develop a criterion, which would provide its protection. Citrus and grapes would automatically be protected if standards adopted for peaches were sufficient.

The design criterion proposed by Maasland and Haskew (1958) has been widely adopted for subsurface drainage in the MIA to protect against waterlogging on a 1 in 100 year basis (CSIRO 1965). This is equivalent to about 5 mm/day when considering the March 1956 average monthly rainfall. Drainage design in the MIA is based on the assumption that the watertable midway between the tile lines should be lowered from a level of 0.45 to 0.75 m below the soil surface in a period of three days. For economic and technical reasons, connected with trenching machinery and the necessity to guard against salt damage, the depth of drains was standardised at around 1.8 m, although in some cases reduced due to the presence of a shallow impermeable layer (CSIRO 1965). With the depth of drains decided, the design of subsurface drainage depended only on determining two key soil parameters, the hydraulic conductivity of the soil and the depth to the impermeable layer, as discussed above.

The watertable response compared with theory was studied by Talsma and Haskew (1959) who found that the design criterion discharge rate occurred when watertables were at 0.45 m below the surface, and the soil drainable porosity about 8%, which applied for the lighter textured soils. However, in heavier soils with a lower drainable porosity of about 4% the reduction in watertable target would be achieved if the discharge coefficient were as little 2.5 mm/day (Talsma and Flint, 1958, Van der Lely, 1978a). The lower design criterion was adopted for heavier soils with lower drainable porosity, assuming that infiltration rates would be less and half the excess rainfall would be removed by effective surface drainage management. Drainage coefficients under improved irrigation management practices, as seen in recent years, have at this stage not been investigated; with all drainage coefficients still based on research in the 1950s and 1960s under poor irrigation management practices.

Non-steady state equations of drainage discharge involve variable rates of recharge to the watertable and a fluctuating watertable. This is the actual situation in the field. These equations could also be used for drainage design, but they are less simple in their practical application. Field observations of daily watertable behavior and day-to-day simulation based on non-steady equations found this not to be necessary. The steady state approach to drainage design provides a satisfactory degree of watertable control in all but the most extreme conditions (Van der Lely, 1978a).

Site investigations

The installation of tile drains within the MIA was largely under the authority of the Tile Drainage Committee, initially consisting of farmers and representatives of the Water Conservation and Irrigation Commission (WC&IC), CSIRO, and the Rural Bank. The farmers' first contact was with the Secretary of the Committee who passed the application on to the Water Conservation and Irrigation Commission. Site investigations for installing tile drains involved measuring two key soil parameters; the depth to the impermeable layer and the hydraulic conductivity of the soil.

In the process the farmer would drill the holes, marked at 2.5/ha on an aerial photograph. WC&IC personnel would measure the water level recovery in baled 2.1m deep holes using a stopwatch and water depth sounding equipment, calculate the hydraulic conductivity, determine the depth to the impermeable layer, provide a recommendation, and after consulting the farmer, produce a design layout. This plan was on a scale of 1:1500, and showed the location of all laterals, mains, inspection sites, and depth of drains. The gradients of the tile drains were designed so that silting and scouring were avoided as much as possible – 1:420 for the laterals and 1:720 for the mains. Recently, with the advent of laser control, minimum gradients have been 1:1000.

After approval by the Manager of the water authority to discharge the effluent subject to conditions, the Secretary organised the installation of the works with the farmer and contractors. Finance was made available to farmers during the 1960s to 1980s, mainly in the form of low interest loans.

Copies of all drainage installation plans have been kept by the tile drain committee and the WC&IC and its successors (Murrumbidgee Irrigation). In this way a record of the areas drained, designs and disposal points are available.

Tubewell drainage

Horticultural farms

Generally, with vertical drainage there are no criteria regarding the volumes to be pumped. Rather, the area of influence is determined as where the drawdown is greater than 0.3 m, and compared to where the protection is required. This usually results in about 3 ML/ha being pumped. This figure of course is influenced strongly by the permeability of the surface horizons, the transmissivity of the aquifer and the rate of recharge from the irrigated crops. If irrigation efficiencies are improved, the drawdown in the bore will increase to where the pump level may need to be lowered to the maximum possible depth,[1] and the area of influence will increase. If the transmissivity is greater, the area will be larger. The surface layers may be restrictive in permeability; this will also increase the area of influence.

For results on a study into the variation of hydraulic conductivity, see Van der Lely, 1974. The standard deviation of values over short distances, at about 100% of the mean is high.

Design objectives in horticulture are for waterlogging control, similar to the criterion for horizontal drainage. However, continuous pumping tends to create a buffer unsaturated zone, which during high rainfall events provides some protection, and the average rate of pumping over the area influenced may only be about 1 mm/day (over the whole year).

Salinity has been an issue on many farms. The criteria for salinity control involve a much lesser discharge rate.

The South Hanwood Pump (Van der Lely, 1978b) has been subjected to close analysis, including pump test analysis and performance. It was found that it protected only a limited area effectively. This was due to the limited extent of the aquifer at this locality.

The procedure for locating suitable sites is as follows (Van der Lely, 1978a).

1. ***Bore to establish stratigraphy and extent of the aquifer***. This may be preceded by electrical resistivity or EM34 surveys but results of such surveys often are difficult to interpret. Shallow clay layers saturated with relatively salty groundwater have very low resistivity. High salinity of groundwater in the aquifer obscures the sands in this method. However, it is not uncommon for a major

underground stream to contain less salty groundwater, allowing it to be recognised by the resistivity or EM techniques.

2. *Pump testing of pilot bores.* A relatively short, small diameter screen is lowered to the bottom of the aquifer and pumped at the maximum rate for a brief period. The screen is then lifted over its length and the procedure repeated. The pumping rates achieved by experience indicate the suitability of the site and the layer within the aquifer with the highest permeability is found. The salinity of groundwater from the various layers is measured.

3. *Availability of disposal facilities*. The site needs to be close to a drainage channel or other disposal facility. Pumping into irrigation supply channels has not been practiced, but has been used on an experimental basis in the Berriquin Irrigation District where groundwater salinity is less than 3 dS/m.

4. *Availability of power, single phase or three phase*. The amount of power available limits the size of the bore and selection of pumping equipment. Diesel pumps have not been used for long-term pumping.

5. *Access to the site for service etc*. Items, 3, 4 and 5 need consideration at an early stage to avoid escalating costs.

6. *Selecting site and pump testing.* An appropriate screen is installed at the site selected and a more elaborate pump test done to determine the required pump capacity, to predict the lateral extent of the cone of pressure reduction and to evaluate the tramsmissivity (T), the storativity (S) and the well loss factor (C). Observation wells are installed near the pumping site to provide the data required in the analysis. This testing may continue for several months. The range of values T and S found in NSW irrigation areas and districts are shown in Table 17. The alternative of installing a number of tube wells close together is sometimes considered, especially with very shallow aquifers where insufficient drawdown can be achieved. These tube wells are joined to one pumping unit, as with spearpoint systems.

7. *Selecting pumps*. Three types of pumps have been used: vertical turbine, submersible and centrifugal. The latter type is only suitable for moderate drawdowns. The cost of pumping effluent is similar for all pump types. Pumping rates from existing tubewells vary from between 9 to 30 L/s.

8. *Area of pressure relief*. About six to nine months of operation for units discharging about 20 L/s are needed before equilibrium of the cone of depression is obtained. A network of observation wells from which watertables are read allows plotting of groundwater contour maps to evaluate the effectiveness of the pump. The cost of these investigations is relatively high.

Table 17.

TABLE 17. RANGE OF TRANSMISSIVITY AND STORATIVITY FOUND FOR PUMP TEST SITES IN NSW IRRIGATION AREAS (*1)

Type of Aquifer	Transmissivity m2/day	Storativity (%)	Number of sites
Ancestral river	1000–4600	0.17–4.0	2
Prior stream	500–2000	0.4–4.0	6
Minor prior stream	100–401	0.02	1
Floodplain aquifer	80–1000	0.02–0.81	7

N.B. A tubewell is usually not installed at sites with T less than about 200 m2/day
(*1) After Haskew (1996)

Large area farms
Initially on large area farms there was little concern about the volumes (and therefore the salt loads) discharged. This changed in the early 1980s, see page 103, Volumes and quality of drainage. Salt management and safeguarding downstream users became a major focus as a result of disposal concerns, overriding the desire to protect all land in the MIA. Preliminary schemes were considered (Van der Lely, 1984). This was further considered for the MIA LWMP (MIA and Districts Land and Water Management Plan, 1998), however no scheme has been found to be economically viable at this stage. A key aspect for design is the drainage rate required to maintain productivity in most of the landscape. Some initial values were considered (Van der Lely, 1984).

Another study involved the analysis of the flow from rice fields to adjacent areas considering gradients, clay permeability and aquifer transmissivity. Analytical models were used and compared with field data from piezometers in a 5,000 ha area. Van der Lely (1989), based on earlier work (Van der Lely, 1984) found that the groundwater flow from rice fields to adjacent areas each year is about 0.5 ML/ha/year when about 35% of the landscape is grown to rice. This would be the potential maximum required to be intercepted for salinity control. A proportion of this flow is to depressions and lowlying areas, which may require protection. However, much of the total flow from rice to adjacent areas each year will not result in harmful effects, because the flow will be reversed when rice is grown on the adjacent areas next year or the year after in a rotational management system. It is likely therefore that, only about 0.2 ML/ha/year needs to be pumped to protect the landscape.

The upper limit of about 0.5 ML/ha/year could apply if and when it is decided to grow rice permanently in designated areas and use the rest of the landscape for other crops, allowing investments in improved soil management for those areas.

The 0.2 ML/ha/year contrasts with commonly used values, e.g. 0.7 ML/ha/year for the Pipeline to the Sea report (MDBC, 1990), and experience in Victoria, which suggests 0.5 ML/ha/year (Jolly *et al.* 2000). However, the leaching requirement with water use of about 7 ML/ha/year would not be more than from 1 to 2% or about 0.1 ML/ha/year. When it is considered that the downward leakage from shallow aquifers to deeper aquifers may be in about that order, it is realised that the overall pumping rates required are very small, provided the process of groundwater movement between fields can be controlled. This control at present is in the form of a rotational management.

The main problem is the practical implementation of such small pumping rates, which have to include some sort of inefficiency factor. The concept for developing a tubewell drainage scheme of a 10,000 ha area of the Murrami region in the MIA was to carefully target the pumps in depressed areas, then let the natural gradients in the landscape move groundwater to these locations. This would be assisted by the pump drawdown of the vertical drainage bores. But there would be no effort to induce an observable drawdown over the whole landscape (Van der Lely and Tiwari, 1995). The pump discharge over time would not be more than the requirement, and managed by switching pumps on and off. There may be some fine-tuning of pumping periods every few years based on the outcome of soil salinity surveys.

There would be no attempt to protect all depressed areas. It would be accepted that these would become salt-affected, despite the pumping. This has undesirable consequences for the remnant vegetation, but to protect these the pumping rate may have to be more than 0.5 ML/ha/year overall, becoming an unrealistic target.

A scheme such as this would need to operate before the problem of salinity becomes too severe. Once the problem develops too far, a reclamation effort is required involving larger volumes of discharge, such as occurred with the Wakool/Tullakool subsurface drainage scheme (Department of Water Resources, 1987).

The above principles for design were developed based on data for the South Hanwood area, which is fairly typical for the MIA. However, there could be local variation in the key factors transmissivity, permeability of clays, and gradients, which could require adopting different design rules. For instance, in the Benerembah and Yenda areas there are no suitable aquifer systems to pump from, so it would be necessary to implement tile drainage schemes. One such scheme was considered for the Benerembah area, using the same 0.2 ML/ha/year criterion, (Van der Lely and Tiwari, 1995). Actually achieving such low discharge rates for tile drainage schemes is an aspect still requiring further consideration, but it will involve selective operation of tile drains in different fields, even being selective about individual laterals, depending on when and where rice is grown.

Using the above concept the discharge rates are minimised, pipeline sizes are minimised, and the size of the evaporation area is also minimal. These are the conditions under which the most economic scheme may operate.

Despite the minimisation of sizes and costs it was found that subsurface drainage in RBFS is not an economic proposition (DLWC, 1995). In the MIA and Coleambally the average productivity is from $600 to $700/ha/year. The economics analysis of the tubewell drainage scheme at Murrami and Benerembah showed a BCR of from 0.5 to 0.6 (DLWC, 1995).

The Land and Water Management plans for Wakool, Berriquin, Denimein, and Cadell indicate productivity of only $150 to $300/ha overall. In these areas rice growing creates groundwater mounds, which dissipate to less intensively irrigated areas, depressions and dryland. The productivity of dryland areas is less than average. The irrigated areas themselves are being protected by the lateral groundwater flow, except where channel seepage aggravates the problem. Therefore, regional schemes in these districts are likely to be even less viable.

The lack of economic merit in RBFS has three consequences:

> RBFS may not be sustainable in the long run, because Best Management Practices alone are insufficient to counter the trends in the landscape (Van der Lely, 1995a).
> Subsurface drainage can only be justified and implemented on those fields where higher productivity can be achieved.
> Research into lower cost subsurface drainage is necessary until economic viability is no longer a major constraint.

Volumes and quality of drainage

VOLUMES AND QUALITY OF DRAINAGE

Horticulture

Although the aim of installing subsurface tile drainage in the MIA is to protect against waterlogging, it does also have the effect of removing salt from the soil.

Studies undertaken by Van der Lely (1978a) indicate that on average sixteen percent of irrigation or rainfall is discharged through subsurface tile drainage systems, with much of it attributed to base flow after temporary storage as groundwater. No relationship between discharge, rainfall or irrigation and salinity was found but it did appear to the investigators that the highest salinities were related to the fall of the watertable, rather than the height of the watertable.

Van der Lely and Ellis (1974) showed that with a sixteen percent drainage value the effluent concentration would be about six times the salinity of the irrigation water, if there was no leaching of other salts. This value would be reached an estimated 25 years after drainage installation. From data recorded during this investigation it was found that the average drainage pump in a typical horticultural farm discharges about one tonne of salt per week. The ratio of salt removed from the soil profile to salt applied through irrigation water ranging from 5:1 to 25:1 depending upon the age of the system.

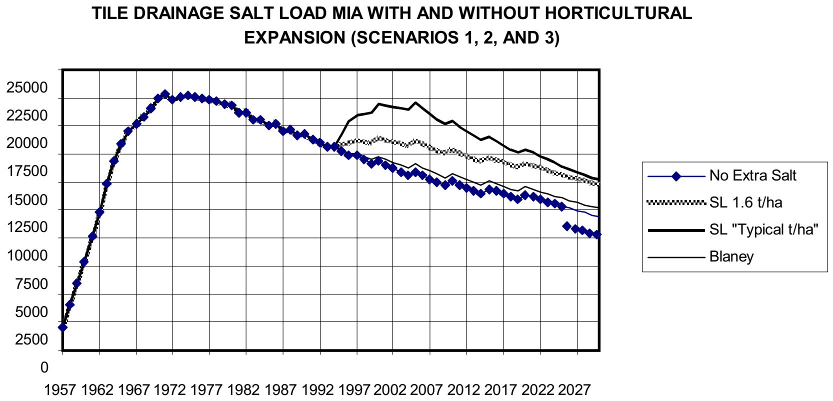
It is clear that for many years after installation the salt discharge is much higher than the salt applied through irrigation water, and there is effective mining of salts previously stored in the deeper soil profile. In some instances salinity does not decrease as expected, which may be due to seepage from surrounding areas.

The Hassall Associates consultancy report (1995) contains references to salinity in tile drainage, the salt loads generated, and the effect on downstream users. Salt loads are declining only slowly. Surveys on salt loads have been carried out regularly, e.g. 1970, 1980, 1990 and one in progress 1999. Van der Lely and Tiwari (1995) contain the key discussion on salt load decline from horticulture. It increased until about 1975, then peaked at about 23,000 t and was about 18,000 t in 1990. Since then there have been a few measures causing more rapid improvement, e.g., tile drainage pumps were handed over to the farmers, giving them an incentive to better manage discharge volumes. There have been on-farm improvements in irrigation practices and techniques. The current salt load would be from 12 to 15,000 t/year, and the average discharge salinity about 2.5 dS/m.

Figure 22 shows the current estimated trend for salt load discharge from horticulture in the MIA based on trends until about 1990 (Van der Lely, 1996). The increases for several options after 1997 are hypothetical if new irrigation of horticultural land would be allowed to discharge their salt load to the drainage system as well. After this analysis it was decided that future discharges would not be allowed and that these new enterprises had to use evaporation basins for disposing their salt loads.

Figure 22.

FIGURE 22. PAST, CURRENT AND PREDICTED TRENDS IN SALT LOAD DISCHARGES FROM THE MIA, INCLUDING ALTERNATIVE PREDICTIONS FOR SCENARIOS WITH “EXTRA” HORTICULTURE.



While the trend shown in Figure 22 is favourable in the absence of discharges from horticultural expansion areas, the Land and Water Management Plan for the MIA aims to lower salt loads to downstream areas. The target is to lower salt loads by from 20 to 30% compared to the 1995 baseline (MIA and Districts Land and Water Management Plan, 1998). This should be easy to achieve with more adoption of improved irrigation techniques such as a shift to drip irrigation in grapes and citrus, combined with better practices in terms of pump management (e.g. times of pumping, float switch controls).

A reduction in tile drainage volumes potentially increases their salinity levels, if the irrigation water salt content is the main source of salts. This is likely where an equilibrium salinity level has developed, however, in most situations there is still mining of pre-existing salts in the profile, hence, salinity levels in the discharge are not expected to increase. It may decrease more slowly, but the volume reductions would provide the overall desired effect on salt loads.

All subsurface drainage in the MIA is reused, except for a small proportion in the

Yanco Irrigation Area, which drains back to the Murrumbidgee River. It is mixed with other surface drainage flows, totalling about 240 GL/year (MIA and Districts Land and Water Management Plan, 1998). This results in an average drainage water quality from 0.3 to 0.4 dS/m at the end of the drainage system during summer, rising from 1 to 2 dS/m during winter, when less dilution occurs.

The Hassall report (Hassall Associates, 1995) discusses the effect of salinity on productivity in the Wah Wah District, including economic analysis. Subsequent economic analysis by Stanton (1996) confirmed the results, with some refinements.

The main deficiency of the current system is that there is no viable proposal for long-term salt management in the MIA. None of the proposals has been proven sufficiently attractive from an economics point-of-view. This includes deep well injection, discharge to agro-forestry proposals, serial biological concentration, and community evaporation areas to the west of Griffith. The productive potential of the landscape where RBFS are used is declining slowly. Only where higher value crops are adopted can subsurface drainage costs be justified, including the costs of evaporation disposal to on-farm or local community basins (Christen *et al.* 2000).

Considering the disposal issues present in the Murrumbidgee and Coleambally Irrigation areas research into management of tile drain systems has been undertaken by Christen and Skehan (1999) to reduce drainage flows from existing tile systems and new shallower drainage systems. The project aimed to develop management criteria for existing subsurface drainage systems, which minimised salt discharges from these systems. Management of the drains involved preventing drainage during irrigating to reduce preferential trench flow to the drains and targeting a watertable control depth of 1.2 m. Monitoring watertable depth and switching the tile drainage pump on and off when needed achieved this regime. The investigation showed that managed tile drainage systems had a 33% reduction in drainage volume and a 36.5 % reduction in the salt exported compared to an unmanaged system. (See figures 23 and 24). Shallow drainage systems constructed with mole drains were also investigated in the trial and found to be superior to tile drainage and tile drainage with management.

Figure 23.

FIGURE 23. MEASURED DRAINAGE VOLUMES FOR THE THREE DRAINAGE TREATMENTS OVER TWO IRRIGATION SEASONS

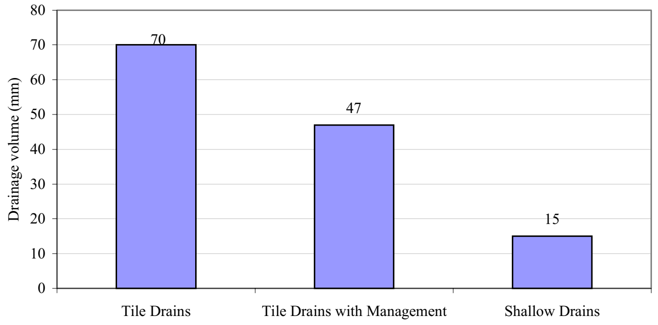
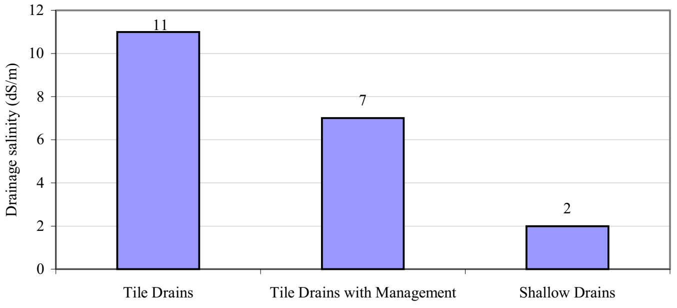


Figure 24.

FIGURE 24. AVERAGE DRAINAGE SALINITY FOR EACH TREATMENT FOR AN IRRIGATION SEASON



From the results of the investigation a series of guidelines have been developed to improve drain water quality from new and existing systems through improved design and management of subsurface drainage systems.

Guidelines for subsurface drainage design and management to improve drain water quality

Aim of the guidelines

AIM OF THE GUIDELINES

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

Background

BACKGROUND

Research in the riverine plain has shown that in general:

Deep drains (traditional tile or pipe systems about 2 m deep and 20 to 40 m apart):

- have high drainage volumes with high drainage salinity
- unnecessarily extract large quantities of salt from the soil below the rootzone
- drain large volumes of water from sources outside the farm itself.

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.

By managing deep drains it is possible to:

- reduce drainage volume and drainage salinity
- control waterlogging and rootzone salinity.

GUIDELINES

New drainage systems should consider the potential for mobilising salt:

- avoid sites where large volumes of drainage could occur from intercepted regional groundwater
- install drains as shallow as possible
- design drainage systems into management units
- install drainage control structures to manipulate watertables
- main drains and sumps installed at depth should be sealed to stop saline water entering them directly.

Existing drainage systems should:

- have water control structures installed to manage drainage
- be divided into management units with control structures aligned with irrigation units.

To manage drainage systems:

- do not discharge during irrigation
- control to maintain watertables safely below the rootzone and don't leave drains uncontrolled where watertables may fall much deeper than required
- normally keep closed or turned off and then turn on as needed rather than running all the time without considering whether or not the drainage is really necessary.

Disposal of drainage water by evaporation basins

On-farm evaporation basins have been used in the MIA since 1988. They were adopted as part of the MIA Land and Water Management Plan (LWMP) in an effort to reduce the salt load leaving the area. This was brought about by pressure from downstream users of the drainage water. The salt balance for the MIA shows that 40% of the salt load leaving the area is from the horticultural farms, which have subsurface pipe drainage. These horticultural farms however, only constitute about 15% of the area (Van der Lely 1996). In addition, the area of horticulture has steadily expanded since the late 1980s to a peak of about 500 ha annually between 1995-97. So that these new developments do not further increase the salinity of the MIA drainage by discharging their subsurface drainage water, a moratorium on off-farm discharge was introduced forcing growers to build on-farm evaporation basins.

Since 1989, about 15 on-farm basins have been built with a total area of about 60 ha. These basins are used to store the drainage water from subsurface pipe (tile) drains installed about two metres deep, spaced from 20 to 40 m apart. The salinity content of water from these drains varies from 3 to 20 dS/m. A summary of the basin conditions in the MIA as of October 1997 is presented Table 18.

Table 18.

TABLE 18. SUMMARY DATA FOR ON-FARM EVAPORATION BASINS IN THE MIA (OCTOBER 1997)

	Average	Minimum	Maximum
Basin area (ha)	4.3	0.6	14.0
% of drained area	4.1	1.1	7.4
Drainage water salinity (dS/m)	10	3	20
Basin water EC (dS/m)	20	8	45
Concentration factor Basin EC/Drainage EC	2.2	1.2	4.8

The design and management of these basins and the associated subsurface drainage system vary widely as a result of a lack of clear guidelines. Some basins are very small compared with the drained area and are thus nearly always full. Poor irrigation and drainage management and variable rainfall has led to overflowing basins in some years creating demands to allow basin releases to the surface drainage system.

Conversely, during some years of low rainfall, basins have dried out, resulting in claims that basin areas are too large. At the time of the survey fifty percent of the basin area was dry. This is in part due to the drainage pumps being turned off (farmers deciding there is no need to drain) and in part due to relatively high basin leakage rates. The lack of salt concentration in the basin water is evidence of high leakage rates. Thus there are a lot of on-farm basins that have highly variable physical attributes. The design and siting of these basins have also led to problems of saline leakage to surface drains.

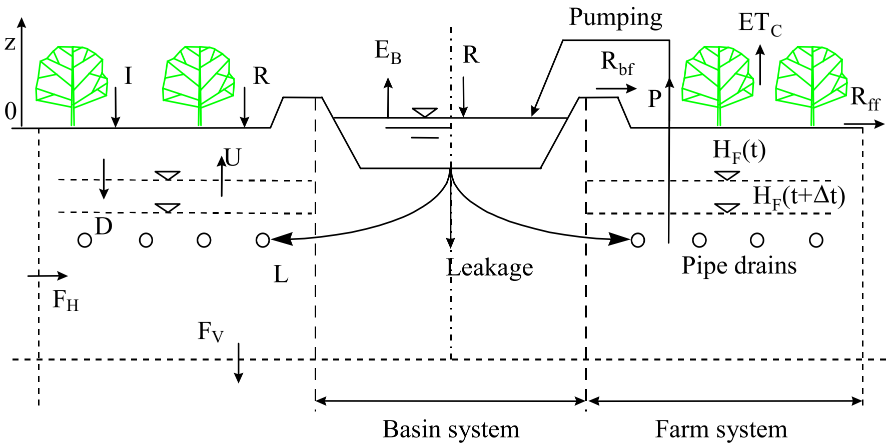
Basin design guidelines have been “best bet” with no follow-up work to determine if the basins were functioning adequately. However, recently a CSIRO Land and Water/ CRC for Catchment Hydrology project ‘*Managing disposal basins for salt storage in irrigation areas*’, has been monitoring these on-farm basins. This included intensive monitoring of a newly commissioned basin.

The results of this monitoring indicate that basin leakage rates are initially high and then stabilise at around 3 to 5 mm/day. The leakage from these basins was reported to have penetrated up to 5 m below the basins and up to 20 m away from the basin in the shallow groundwater, (Leaney and Christen 2000a). They also reported evidence of shallow lateral leakage entering nearby surface drains. Other contaminants concentrating in these waters are of concern; Christen and Gray (2000) report that elevated levels of some heavy metals and pesticides were found in these basin waters and the basin sediments.

Along with this monitoring, a model has been developed for investigating the interaction of the farm and basin to improve design and management, (Wu *et al.* 1999). A schematic of this model is shown in Figure 25.

Figure 25.

FIGURE 25. SCHEMATIC OF BASINMAN MODEL



Other work within the project *Managing disposal basins for salt storage in irrigation areas*, has resulted in the development of principles for the use of evaporation basins, Christen *et al.* (2000a) and guidelines for the implementation of basins, Christen *et al.* (2000b). These are developed for use in the riverine plain of southeastern Australia.

Pesticides

Studies relating to pesticide levels in tile drainage waters have been very limited within the MIA and CIA. Bowmer *et al.* (1998), reported on work in 1992 and 1994, which analysed tile drainage effluent for bromacil, diuron and atrazine using GC/MS and also ELISA immunoassay kits.

Tile drainage effluent was monitored on 49 horticultural farms during January, May and August of 1992 with May being the most extensively monitored period. Eight samples were collected from each of the farms over a 14-day period and analysed for bromacil (> 0.05 mg/L) and diuron (> 0.05 mg/L). Of the farms monitored, about 28% were found to have detectable levels of both bromacil and diuron. Maximum concentrations of bromacil and diuron were found to be 11 and 28 mg/L respectively. Investigation of management practices showed that those farms controlling weeds with herbicides were more likely to have detectable levels of these compounds in their subsurface drainage effluent.

During the Murrumbidgee Irrigation Area Tile Drainage Monitoring Project 1998-99 pesticide data was also collected from 36 sampling sites within the MIA (McCaffery, 1999). There were eight detections of screening chemicals in September of 1998 and ten detections of these chemicals in February 1999. Of the detection's during this study, notification levels were not exceeded (8 mg/L for diuron and 750 mg/L for bromacil). Although the study was limited in that grower participation was low and data quality in some cases was questionable, it was highlighted that of the farms where detection occurred, only one participating grower recorded any pesticide use.

System management and monitoring

SYSTEM MANAGEMENT AND MONITORING

Before 1991, tile drainage pumps throughout the MIA were owned and operated by the Department of Water Resources, which has become the Department of Land and Water Conservation. In 1991 individual farmers within the MIA were given the responsibility for operating and maintaining of their own tile drainage pumps.

Fully privatised companies subject to two main licences, manage the

Murrumbidgee and Coleambally Irrigation areas. The DLWC Water Management Works Licence and the Environmental Protection Licence of the EPA. Each farmer has a contract with the private company, which includes conditions regarding environmental management. In regard to subsurface drainage, discharge of effluent to surface drains is not allowed on large area farms and any other farm growing horticulture that is not "a gazetted horticultural farm". This applies to all recent developments on large area farms. Horticultural farmers are allowed to discharge subject to conditions regarding pollution other than salinity, maintenance and standards of care. There is no charge on horticultural farmers for their perceived "right" to discharge, even though there is a downstream effect in Benerembah and the Wah Wah districts.

Farmers are responsible for maintaining their own tile drainage systems. Metal rods are commonly used to remove roots. Chemicals such as dichlobenyl have been experimented with, with some success (Van der Lely, 1975). High-pressure nozzles have also been used, but these appear more effective in smaller diameter pipes, and less effective with roots.

The LWMP encourages horticultural farmers to monitor their own systems. This involves installing testwells for watertable monitoring, and monitoring pump discharges via the electricity meter. This has been only partially successful, and many farmers still do not make a significant effort in this regard.

The overall system is monitored only via the water quality monitoring stations in main drains, from which trends may be observed. However, drainage flows are mixed up before they reach these locations, making separating the various sources a difficult exercise. Surveys of effluent volumes and salinity of tile-drained farms once every ten years provide additional data to help determine baselines and trends.

In large area farms a few farmers have private tube well installations for drainage. These installations will eventually be licensed by the DLWC. The private company, Murrumbidgee Irrigation, may determine the appropriate conditions for effective environmental operations. The MIA LWMP has permitted no new subsurface drainage in LAF.

In Coleambally, there is a commitment to not consider implementing subsurface drainage for salinity control during the first 15 years of the planning period. This may exclude situations where groundwater salinity is below 3 dS/m, allowing conjunctive use on-farm. The implications of not using subsurface drainage in rice based farming systems are minimal because waterlogging and salinity have a very marginal effect on rice yields. However, the effect on other crops within the area will see economic losses in these situations. Whether this is an appropriate decision remains to be seen.

In summary, farmers are accountable to the irrigation authorities, and these in turn are responsible to government agencies for overall performance monitoring.

Funding

FUNDING

It has been the policy in the past that the Water Conservation and Irrigation Commission (WCIC) would investigate land within horticultural farms at no charge to determine their suitability for tile drainage, and to design drainage systems (Ellis and Higgins, 1973). It was also policy that the commission would meet the costs of pumping and disposing of drainage effluent from horticultural farms, involving supply, installation, operation and maintenance of a pumping unit where necessary and part of the cost of any necessary electricity transmission line extensions (Ellis and Higgins, 1973).

Currently, there is no funding for subsurface drainage implementation in the MIA or Coleambally. The LWMP, however, proposes to provide some support to those farmers who need to construct subsurface drainage to protect high value crops and are required to construct evaporation ponds. The amount of support is still to be negotiated.

There is government support for research, e.g. the CSIRO has just completed a large project on SSD and guidelines for the use of evaporation areas. The LWMPs of Coleambally and the Murrumbidgee Irrigation areas do not yet include funding for implementing community based evaporation areas.

Farmers do receive low cost loans from the NSW Government for SSD via the Rural Assistance Authority.

Farmers now pay for all costs of operating and maintaining their systems. Where there is a community-sized tubewell in horticulture, the costs are recovered via water charges; hence there is a cross-subsidy between landholders. Water charges also pay for the cost of monitoring.

Issues and trends

ISSUES AND TRENDS

- Horticultural drainage discharge needs to be further reduced.
- In large area farms, subsurface drainage is not economically viable, except where higher value crops are involved.
- There is no agreed model for identifying the benefits of subsurface drainage. The models used include the DESM (MDBC, 1992), the NSW Agriculture LP Model (Marshall *et al.* 1994), and the Model used by the Economics Unit of DLWC (Stanton, 1996). None has a high credibility, and they depend on inadequate methods of estimating soil salinity trends with or without a LWMP.
- The MIA has not yet developed a viable plan for future disposal of salinity in drainage.
- There is a shown trend towards higher soil salinity in large area farms.
- In significant areas of the MIA the soil permeability in large area farms may be too low to make subsurface drainage technically feasible, but generally this comes back to economics.

In conclusion, there has been a shift from a problem of waterlogging and drainage design to a problem of effluent disposal that satisfies economic and environmental criteria.

Research requirements

RESEARCH REQUIREMENTS

Horticulture

- Drainage design and management to reduce salt load disposal problems from such systems.

Large area farms

- Models to estimate soil salinity trends.
- Hydraulic loading research to estimate groundwater flow from rice to adjacent areas and the resultant subsurface drainage requirement.
- Consequences of creating designated rice areas, with alternative crops on the rest (70%).
- Development of more appropriate models to estimate benefits of avoiding soil salinity and waterlogging loss on a regional scale.
- Low cost drainage systems for heavy soils.

The main issue is the lack of productivity of the current RBFS, and this suggests that research priorities related to subsurface drainage need to be aimed at cost reduction, such as the work undertaken on moles by Muirhead (*et al.* 1995) and Christen (1994).

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ORD RIVER IRRIGATION AREA

ORD RIVER IRRIGATION AREA

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The Ord River Irrigation Area (ORIA) is located in the Kimberley region of north Western Australia. Kununurra is the commercial and administrative centre of the area. Irrigated agriculture was first established in 1963, and since the completion of the Kununurra Diversion Dam on the Ord River in 1963 and the Lake Argyle Dam in 1972 over 13,000 ha of land have been released for farming. There is currently a proposal to develop more than 30,000 ha (Ord Stage II development) in areas to the north of and next to the existing irrigated area.

Local hydrogeology

LOCAL HYDROGEOLOGY

The Ord River Irrigation Area is underlain by alluvial sediments resting on a paleotopographic surface of bedrock that comprises of basalt, sandstone and limestone. Within the alluvial plains, groundwater occurs in the alluvial sediments and weathered and fractured bedrock. Although drilling conditions did not allow the identification of bedrock types or depth in most deep bores located throughout the area, it is likely that bedrock is generally in poor hydraulic connection with the superficial aquifer.

The alluvial sediments can be subdivided at a regional scale on the basis of lithology, into sand and gravel, and silty clay. The course sand and gravel units are the main aquifer and represent former riverbeds of the Ord River, which flowed through the Cave Springs Gap. There is evidence of hydraulic connection between individual gravel sequences and the Ord River, Lake Kununurra, and the numerous supply channels and drains. Detailed reports on the hydrogeology of the area are given in Laws (1991), McGowan (1983, 1987), Nixon (1995) and Yesertener (1997).

Crops and management

CROPS AND MANAGEMENT

The main crops grown in order of area are sugar cane, annual field crops (cotton, chickpea, maize and others), annual horticulture crops (mainly cucurbits) and perennial tree crops (leuceana, mango, sandalwood). Subsurface drainage is not currently used for any crops grown in the Ord, with shallow groundwater only occurring in a few localised areas. The main soil type used for crop production is the self-mulching Kununurra Clay that has clay content of 40 to 60%. Crops on this soil are almost exclusively irrigated, using surface furrow irrigation. There are adjoining areas of lighter textured soils with small areas mainly irrigated using microsprinkler or trickle irrigation.

Description of the drainage problem

DESCRIPTION OF THE DRAINAGE PROBLEM

The Ord River Irrigation Area has been operating since 1962, and further major expansion is planned. Monitoring data indicate that groundwater levels are rising under the irrigation area and in some localised areas they are now close to the surface (Yesertener 1997).

A drilling program began in 1964 to monitor the effects of irrigated agriculture on groundwater. At that time, groundwater levels were from 16 to17 m from the soil surface over much of the area. Since then, groundwater levels have risen steadily to a point where there are now a few localised areas within 1.5 m of the surface (Yesertener 1997). Groundwater salt concentrations vary and are generally low (less than 2 dS/m) although there are isolated areas where groundwater salinity is much higher (Yesertener 1997). As a result, the main issue associated with rising groundwater is initially the potential for waterlogging although in the longer term, without adequate management, there is also potential for land degradation through salinisation (Sherrard 1998).

The area's climate is typified by a concentrated wet season from around November to March followed by a dry season with rainfall rarely occurring. Wet season rainfall varies, but averages 780 mm per year. This has the effect of "topping up the watertable". Before irrigation it is likely that wet season accessions drained from the groundwater system through the dry season, resulting in groundwater levels at equilibrium well below the surface over most of the area. Since irrigation began, groundwater accessions from dry season irrigation have increased total annual accessions from rainfall and irrigation to beyond the drainage capacity of the groundwater system, resulting in a net rise in groundwater levels. About 25% of accessions associated with irrigation are from the main supply and drainage system infrastructure.

Drainage methods used

DRAINAGE METHODS USED

To date, no major subsurface drainage operations have taken place in the Ord Irrigation Area. The only method used has been limited dewatering associated with a study to examine its feasibility as a groundwater management tool (O'Boy 1997-98). Groundwater is currently within 1.5 m of the surface in only a few, localised areas.

Drainage design tools

DRAINAGE DESIGN TOOLS

Recent research has included using production bores to evaluate groundwater pumping, as an option for groundwater management. Results indicate that dewatering is likely to be a successful groundwater management option for much of the Ord Irrigation Area where rising groundwater is an issue.

Other research is underway to examine the feasibility of dewatering using spearpoint bores where transmissivity is too low to use production bores successfully.

Site investigation conducted

SITE INVESTIGATION CONDUCTED

Results from the dewatering feasibility study using production bores have shown that this method is likely to be very effective in managing rising groundwater over a significant part of the Ord Stage 1 area (O'Boy 1997-98). The results from the short-term pumping test on the Ivanhoe Plain of the ORIA indicated that the underlying gravel aquifer could vertically drain the overlying soil. This was confirmed by the long-term testing where significant drawdown was measured at distances of up to 630 m from the production bore and with effects projected to go beyond 1,000 m.

Results from the Packsaddle bore site were complicated by the presence of two gravel aquifers. However, pumping caused drawdown in both aquifers with drainage from the overlying soils into the upper aquifer. The drawdown was extrapolated to extend to a maximum distance of 1,500 m.

Results indicate that continuous pumping of bores on the Ivanhoe Plain at about 4,000 kL/day could effectively hold groundwater levels steady at a distance of up to about 1,000 m. Bores on Packsaddle would probably only need to be pumped intermittently at a similar rate to achieve a similar result. This management strategy, with four bores on critical areas on Ivanhoe and two on Packsaddle, could effectively control groundwater over about two-thirds of the Ord Stage 1 area.

Drainage water quality

DRAINAGE WATER QUALITY

Generally, groundwater is suitable for use in irrigation either directly or with conjunctive use with supply system water. Salinity levels over much of the area are below 3 dS/m (Laws 1991).

Drainage water disposal

DRAINAGE WATER DISPOSAL

While there is no subsurface drainage yet in the ORIA, it is likely that this will occur as groundwater levels rise and that most drainage water will be used for irrigation. Using the existing surface drainage system for drainage of irrigation water from the irrigation area could also be examined as an option for disposal of drainage water.

Drainage system management

DRAINAGE SYSTEM MANAGEMENT

Subsurface drainage in the ORIA is likely to occur in the future with use of dewatering and a range of options is available for its management. This could include management by the Ord Irrigation Cooperative, which now manages the supply of irrigation water to farms in the ORIA.

It is likely that dewatering would be undertaken to maintain groundwater at a designated level below the ground surface. Drainage water quality will need to be monitored and its disposal properly managed.

Drainage water monitoring

DRAINAGE WATER MONITORING

With no subsurface drainage occurring to date there is no monitoring. When drainage starts, the responsibility for monitoring could be with any of a number of organisations including the Ord Irrigation Cooperative, the WA Water Corporation and the WA Waters and Rivers Commission, all of which are currently responsible for some aspects of monitoring of surface water drainage in the ORIA.

Drainage funding

DRAINAGE FUNDING

A funding structure has not been negotiated at this time.

Research requirements

RESEARCH REQUIREMENTS

Research has identified dewatering using production bores as feasible for managing of rising groundwater over much of the ORIA.

Additional research is underway to examine strategies for reducing groundwater accessions and hence subsurface drainage requirements.

Alternative management options will be required for subsurface drainage in areas where groundwater continues to rise and where dewatering with production bores is likely to be unsuccessful because transmissivity is low. Within these areas, research is planned to identify where low yield, localised dewatering may be possible, using spearpoint bores.

If groundwater levels rise close enough to the surface, mole or tile drainage will be considered and research done to examine the feasibility of this option.

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RIVERLAND REGION

RIVERLAND REGION

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Regional hydrogeology

REGIONAL HYDROGEOLOGY

There are three major aquifer systems in the Riverland Region:

> the Renmark Group confined aquifer
> the Murray Group limestone aquifer
> the Loxton-Parilla Sands aquifer (Smith & Tonkin 1994).

These aquifer systems are recharged in the higher rainfall areas around the margins of the Murray Basin, mainly the Great Dividing Range, the Grampians and the Mt Lofty Ranges.

Groundwater moves very slowly under low gradients in all aquifer systems, from recharge areas at the margins toward the River Murray in the centre of the basin. The rate of movement is estimated to be about 2 m/year, which results, for instance, in a travel time of 200,000 years from the Grampians to the river.

Because of its low elevation, the River Murray is the focus of groundwater discharge in all aquifer systems and consequently acts as a drain. The salinity of the river increases dramatically in many downstream reaches as a result of this groundwater discharge. Groundwater salinities next to the river can be high (more saline than seawater - 58 dS/m) after the long journey from the recharge areas where groundwater salinities were low (around 1.8 dS/m) initially.

Downstream of Overland Corner, the watertable lies within the Murray Group limestone aquifer, which is directly connected hydraulically with the river.

Upstream of Overland Corner, the limestone dips below the river valley and the watertable then occurs in the Loxton-Parilla Sands, which are also hydraulically connected to the river.

The Renmark Group confined aquifer underlies both of these aquifers and discharges groundwater by leaking slowly upwards through low permeability clays, which form a capping or confining layer on top of the aquifer.

Table 19 presents the range of salinities in the three major aquifers.

Table 19.

TABLE 19. RANGE OF SALINITIES IN THE THREE MAJOR AQUIFERS

Aquifer	Range of salinities (dS/m)
Renmark Group	12.6 to 63
Murray Group Limestone	25.2 to 63
Loxton - Parilla Sands	25.2 to 180

Source: Sinclair Knight Merz, 1997

Before river regulation and irrigation developments, groundwater inflows to the river would have been relatively small because of the very low watertable gradients from the distant recharge areas and the seasonal fluctuations in river flow. River regulation structures and irrigation have raised groundwater levels in floodplain areas.

Irrigation on highland next to the river valley has led to relatively low salinity water, excess to evapotranspiration, percolating down to form a mound on top of naturally occurring saline groundwater. This mounding forces much greater volumes of saline groundwater discharges to the river valley, resulting in floodplain degradation and increases in river salinity. In addition the clearing of native vegetation from the Mallee area has enhanced the recharge rate and will cause a rise in watertables and increased salt discharges to the river in the future.

Crops

CROPS

A wide range of horticultural crops, 30,000 ha in total, are grown in the Riverland. The dominant crop types are grapes (mainly for wine production) and citrus. There are significant areas of stone fruits, vegetables and nut crops. An estimated 21% of horticultural crops in the Riverland are drained.

An estimated 75% of irrigated crops use various forms of sprinkler irrigation, 10% of crops are drip irrigated and about 15% remain under furrow/flood irrigation.

Recent major new developments are overhead sprinkler or drip irrigation of wine grapes, low level sprinkler irrigation of citrus and nut crops (mainly almonds) and centre pivot irrigation of vegetable crops.

Important technological changes leading to improved irrigation management have been:

1. **Identifying**
    > soil characteristics in detail
    > crop suitability
    > water holding capacity of the soil

2. **Evaluating**
    > performance of irrigation system

3. **Designing-design checking**
    > irrigation systems to recognised standards

4. **Undertaking**
    > irrigation systems upgrade
    > soil water monitoring
    > irrigation scheduling
    > watertable monitoring.

Preparing irrigation and drainage management plans and intentions to adopt the techniques is mandatory for new developments where water allocation transfers or amalgamations are involved. All or some of these techniques are widely applied on the larger individual developments and efforts are now being made to improve the rates of adoption among the smaller properties in the group irrigation trust areas.

Drainage problems

DRAINAGE PROBLEMS

Climate

The climate can be described as semiarid, characterised by hot summers and cool winters. The annual average rainfall of 250 to 300 mm is fairly evenly distributed over the year, with the higher rainfall months occurring from late autumn to early spring. (Smith, Van der Lela and Poulton 1988).

Evaporation greatly exceeds precipitation, particularly in summer. Class A pan evaporation ranges from 1,600 mm for sites within irrigated areas, to 2,300 mm for flat open dry land sites. Maximum daily temperatures average 32°C in January and 16°C in July. The minimum daily temperature averages 15°C in January and 5°C in July.

Some locations, particularly inter-dune swale areas are prone to frosts from April to November, with most frosts occurring during June, July and August. (Enrich 1984)

Development of drainage problems

DEVELOPMENT OF DRAINAGE PROBLEMS

Waterlogging and salinisation of soils occurred within a decade of irrigation developments being established. Subsurface drainage of properties began in the early 1900s and has continued in various forms at varying installation rates to the present so that an estimated 21% of all irrigated area in the Riverland is drained.

Irrigation has resulted in applications of water as much as five to six times the annual rainfall. Where due care was not taken, groundwater mounds built up beneath the irrigated areas inducing saline groundwater flows to the river and river valley with subsequent detrimental salinity and environmental impacts.

Irrigated plantings in the topographical depressions of the highland were generally the first areas to be affected, and in some places seepage lakes formed. Waterlogging in the form of perched waterbodies were prevalent in soils with relatively impermeable subsoils.

Before irrigation the soils contained some salts. The measured electrolyte concentration of the irrigation water as an indicator of the salt concentration, in general ranges from 0.3 to 0.8 dS/m at 25° C at times of high and low river flows respectively.

Irrigation results in average applications of salt amounting to 3 t per irrigated hectare every year. The high evaporation rate brings about hazardous concentration of salts in the rootzone thus inhibiting the plant's ability to obtain water.

Reasons for developing drainage problems are:

> over-irrigation (the most common reason)
> inefficient irrigation methods
> inefficient irrigation applications
> a general rise in regional groundwater levels
> lateral movement from adjoining holdings.

Cultivation, irrigation and drainage have brought about physical and chemical changes to the soils, which only add to the complexity of drainage problems.

Drainage methods

DRAINAGE METHODS

A drainage water disposal system is in place and operative before drainage installations commence. Drainage installations begin at the disposal point, which is usually at the lowest point of the property or general area being drained.

As part of a single operation, drainage contractors using chaindiggers with laser equipment trench and lay drainpipe within a coarse sand envelope.

The drainpipe is generally bedded on, packed and covered with a coarse washed sand envelope. In some instances a continuous wrap or sock of geofabric material is used.

Adaptations of subsurface drainage on properties began in the Renmark area in the early 1900s. Totally manual tile drain installations started in a number of areas throughout the Riverland in the early 1920s. These installations involved 0.3 m long butt jointed unglazed earthenware tiles with a strip of tarpaper covering the top two-thirds of the joint and a covering of topsoil. The use of tarpaper over the joint and topsoil as a partial envelope often resulted in significant resistance to flow of water into the drain.

Corrugated slotted polyethylene is currently the most commonly used drainpipe. The use of a coarse washed sand envelope ensures that there is negligible resistance to flow of water into the drain.

Drainage design

DRAINAGE DESIGN

Soil examination and testing

The following information is obtained from boring holes or examining excavated soil pits:

- > assessment of geology/hydrogeology
- > origin of surface soils
- > presence or absence of Blanchetown Clay
- > underlying aquifer/s
- > depth and classification of each soil layer and soil horizon
- > identification of soil texture
- > assessment of clay content
- > determination of soil colour (Munsell)
- > B horizon or subsoil layers or both
- > red hues tend to indicate good drainage
- > yellow and grey hues indicate poor drainage
- > assessment of lime (fine earth carbonate) content – reaction to 1N HCl
- > carbonate layer classification (Wetherby, 1990)

Class I		Fine soil carbonate in clay	Usually poor drainage
Class II		Sheet or boulder calcrete	Sheet can restrict drainage Boulder usually enhances drainage
Class III	A	< 30% calcrete fragments	Drainage medium to poor
	B	30–60% calcrete fragments	Drainage good
	C	> 60% calcrete fragments	Drainage excellent
Class IV		Fine soil carbonate in S to SL	Drainage generally excellent

- > assessment of rock that might incur additional drainage costs
- > depth to and thickness of limepans and hardpans
- > pH (Inoculo Kit)
- > soil salinity
- > 1:5 soil / water suspension ($EC_{1:5}$)
- > conductivity of saturated paste extract (EC_e)
- > assessment of porosity of undisturbed samples
- > intensity and depth of root growth
- > stability of soil, particularly at assessed preferred drain depth
- > depth to capillary fringe – nearly saturated soil
- > depth to watertable – saturated soil
- > depth to impermeable layer.

Any previous soil surveys are also valuable references.

Hydraulic conductivity measurements

HYDRAULIC CONDUCTIVITY MEASUREMENTS

The auger hole method is a rapid and reliable method for measuring the hydraulic conductivity of soil below a watertable. The process for doing this is as follows:

- > A hole is bored into the soil to, say, 0.3 to 0.5 m below the watertable.
- > When the water level in the hole has returned to static equilibrium (soils with low permeability may require a 24-hour wait), water is bailed from the hole and as water seeps into the hole, the rate at which the water rises is measured.

It is important that the time interval between stopping bailing and measuring the rate of rise is kept to a minimum particularly in permeable soils. Best results are obtained if measurements are restricted to the time it takes for an amount equalling 20% of the removed water to flow into the hole.

If a test hole is already installed, it can provide a reliable measurement from a suitable reference point to the watertable, and then immediate measurements are taken at a new hole bored 1 m away.

The measurement data are used to compute the average hydraulic conductivity of the soil layers extending from the watertable to a small distance below the bottom of the hole.

For reliable measurements and the successful use of this method, the hole must remain stable from when it is dug to when measuring the rate of rise is completed.

The formula for measuring hydraulic conductivity is as follows:

$$k = C\,(\Delta y/\Delta t_{av})$$

where k = hydraulic conductivity (m/day)
$\Delta y/\Delta t_{av}$ = rate of rise of water in hole during selected period of measurement
C from a graph is a function of: the radius of the hole (m)
the initial depth of water in the hole (m)
the average hydraulic head during the interval of the measurement (m)
the depth to the impermeable layer (m).

Processing and interpreting field measurements

The first decision is to determine if there is a drainage problem or an irrigation problem or a combination of both. Engaging an irrigation management consultant is recommended if there is any indication of an irrigation problem.

With all the information available from examining the soil, assessments include:

- > rootzone or potential rootzone depth
- > optimum design drain depth taking into account
  - - depth to the impermeable layer
  - - required minimum depth to watertable midway between drains
  - - likely approximate drain spacing
- > drainage impacts due to carbonate layers and hardpans
- > need for soil amendments
- > need for leaching salts.

Hydraulic conductivity measurements are used to calculate theoretical drain spacings.

Design drainage rate

DESIGN DRAINAGE RATE

The drainage rate, or drainage coefficient, is defined as the discharge of an agricultural pipe drain system, expressed as a depth of water that must be removed within a certain time (millimetres per day or litres per hectare per second). Adopting an appropriate design drainage rate takes into account climate, topography, soils, irrigation methods and application efficiencies.

A design drainage rate of 2 mm/day (0.23 L/ha/sec) is considered appropriate for large individual on-farm agricultural pipe drain systems where there are horticultural properties with well-managed sprinkler or drip irrigation. The total area that will ultimately be drained is taken into account.

For small areas with serious drainage problems, adopting a drainage rate nearer 5 mm/day is considered prudent.

Drain spacing design

DRAIN SPACING DESIGN

Unsteady-state equations

A first impression is that unsteady-state equations for calculating drain spacings should best suit conditions associated with irrigated horticulture in the Riverland Region. However lack of enough reliable information of drainable porosities has limited the use of unsteady-state equations.

The unsteady-state Glover-Dumm Equation is:

$$L = \pi \left[\frac{kdt}{\mu}\right]^{1/2} \left[\ln 1.16 \, \frac{h_0}{h_t}\right]^{-1/2}$$

where: L = drain spacing (m)
k = hydraulic conductivity (m/d)
d = equivalent depth of the soil layer below drain level (m)
t = time after instantaneous rise of watertable (d)
μ = drainable pore space (-)
h_0 = initial height of the watertable at $t = 0$ (m)
h_t = height of the watertable midway between the drains at $t > 0$ (m).

Steady-state equations

The steady-state Hooghoudt equation is used as a guide to determine drain spacing together with empirically derived spacings related to soil types and soil textures.

The steady-state Hooghoudt equation for “homogeneous” soils where the drain is on or above the impervious layer is:

$$L = \sqrt{8\left(\frac{K}{q}\right) d(m_0 - h_1) + 4(Kq)(m_0^2 - h_1^2)}$$

where: L = drain spacing (m)
K = hydraulic conductivity (m/d)
q = drain discharge (m/d)
d = equivalent depth of the soil layer below drain level (m) (Refer Table of values for equivalent depth)
d = 0 when the drain is on the impervious layer
m_0 = height of watertable above drain level midway between drains (m) (account should be taken of required minimum depth to watertable midwaybetween drains determined during soil examination)
h_1 = height of watertable above drain centre in the drain trench (m)
h_1 = 0 where a permeable envelope is placed around the drainpipe.

Other steady-state equations are used for layered soil situations e.g. Hooghoudt-Ernst.

Empirically derived drain spacings

Empirically derived drain spacings have also been developed by the CSIRO for a range of soil types in horticultural lands along the River Murray from Woorinen in Victoria to Waikerie in South Australia, which includes most of the highland irrigation areas in the Riverland Region. Recommended drain depths and spacings for a range of soil types are shown in Table 20.

Table 20.

TABLE 20. RECOMMENDED DRAIN DEPTHS AND SPACINGS FOR A RANGE OF SOIL TYPES

Soil types	Depth (m) warranted by soil profile	Reclamative drain spacing (m) Plants damaged	Preventive drain spacing (m) Plants healthy
Winkie sand, Murray sand, Berri sand, Berri sandy loam, some grey Mallee Soils, Type 13 (Renmark)	1.8 to 2.1	27	40
Barmera sand[1], Barmera sandy loam[1], Moorook sandy loam, Tatchera sand, Tyntynder sand	1.7 to 1.8	20 to 27	30 to 40
Tatchera sand	1.5 to 1.7	20	30
Coomealla sandy loam[2], Bookmark sandy loam, Loveday sandy loam	1.4 to 1.5	13	27
Tatchera sandy loam, Vinifera loam, grey Mallee (usual profile), Sandilong loam	1.2 to 1.4	13	20
Coomealla loam, Beveford loam, Woorinen loam[3], Mildura loam4, Irymple loam[4], Irymple clay loam[4], Nookamka sandy loam[2], Nookamka loam, Benetook loam[4], Merbein loam[4], Cureton loam	1.2	7 to 13	13
Nyah clay loam3, Beveford clay loam	3 1.1 to 1.2	7 to 13	13
Bungunyah clay, Pomona clay, Merbein clay loam, Belar clay loam	Drainage inadvisable		

Notes

Soils with shallower phases in some localities. The drain depth varies from 1.4 to 1.7 m.

Soils with light variants. Coomealla sandy loam may be 1.7 to 1.8 m. Nookamka sandy loam may be 1.5 m.

Drainage reaction at any particular site is doubtful.

Drain below the gypsum layer if possible.

Source: Lyon and Tisdall, 1942. (This table has been converted to metric from the original imperial measures.)

Drain depth

The optimum design drain depth is determined while examining the soil. Any variation (e.g. due to topography) is for the optimum design drain depth to be a minimum depth rather than an average depth to ensure that the rootzone is protected adequately for the whole of the area being drained.

Modifications to drain design are not made simply on readily available trenching machine constraints alone.

Drain sizes and grades

Sizes of drains range from 150 mm ID for mainlines down to 50 mm ID for short laterals, depending on grades available, area to be drained and the design drainage rate. Minimum grades of drains are used that will give velocities not less than 0.3 m/s when the drain is running full are given in Table 21.

Table 21.

TABLE 21. MINIMUM GRADES OF DRAINS

Drainpipe ID (mm)	Minimum grade %
150	0.15
100	0.25
80	0.35
50	0.60

A pipe commonly used is 100 mm OD corrugated slotted polyethylene. A minimum grade of 0.30% is recommended for this pipe.

Drainage system design plans

Preparing a detailed farm layout and contour survey plan is an essential prerequisite for a subsurface drainage system design. The plan should include the position of test wells and the location and method of disposal of the drainage water.

Installing drains parallel or normal to one another ensures minimum drain lengths are used to drain a given area.

Drainage into the slope is preferred where impermeable layers or barriers occur along the contour. Water accumulating at the base of a sandy ridge is an example of this situation.

Design leaching fraction and drainage coefficients

Currently, within the Riverland District there is a target to achieve an irrigation water use efficiency of 85% or better by 2004 (leaching fraction of 0.15). A leaching fraction of 0.1 may be achievable under optimum irrigation methods and management.

A range of drainage coefficients are applied in the Riverland Region, from 2 mm/d for large, well-managed sprinkler or drip irrigated areas up to 5 mm/d for small, poorly managed furrow irrigated areas or seriously salinised areas requiring adequate leaching. Keeping a depth of 0.9 to1.0 m to the watertable midway between horizontal drains ensures adequate leaching of the rootzone of salt-sensitive horticultural crops grown in a semiarid climate.

Drainage water quality, quantity and disposal

DRAINAGE WATER QUALITY, QUANTITY AND DISPOSAL

Drainage water quality

Salinity

Salinity levels of drainage water in perched watertables or in locations unaffected by regional groundwater salinities are in the range of 1.8 to 4.5 dS/m.

Salinity levels of drainage water, which can include varying amounts of regional groundwater, may range from 5.4 to 54 dS/m.

Drainage water collecting and disposal systems generally include a combination of low salinity perched watertable and high salinity groundwater. Costs to build and operate dual systems are high.

Salinity trends

There is some evidence to suggest that under and next to some of the older established irrigation areas (1890s to 1920s) the original groundwater of approximate seawater salinity has been displaced with (and/or diluted to) groundwater with a salinity level about one-fifth to one-tenth that of seawater.

Boron

Relatively high levels of boron in drainage water ranging from 1 to 8 mg/L are common. Boron rather than salinity can in some instances be the limiting factor in proposals for reuse. High boron levels become a concern where reuse is contemplated and then it is necessary to take account of boron tolerance as well as salinity tolerance in the choice of crop or plant receiving the reuse water.

Nutrients

Phosphorus, nitrogen and silica are elements essential for plant growth but they are potential serious pollutants. They encourage nuisance growth of algae and other aquatic plants when there are relatively high levels of these nutrients in drainage water that is discharged to disposal basins or to the river at times of high river flows.

Sampling drainage water to analyse water quality parameters including nutrient levels has been done on a one-off specific investigation basis. The investigations for which data regarding nutrient loads in Riverland Irrigation Area's drainage water are:

- Till, 1973, *Re-Use of Drainage Water as a Means of Disposal*, commissioned by the South Australian River Murray Salinity Control Committee
- Drainwatch 1990, a joint Riverland/Sunraysia program implemented under the Murray-Darling Basin Natural Resources Management Strategy.

Parameters selected for comparison are:

- SiO_2 (reactive silica), a measure of the silica in a sample that reacts with molybdate
- NO_x (oxidised nitrogen), a measure of the amount of nitrate and nitrite after the reduction of the nitrate
- TP (total phosphorus), a measure of the phosphorus in a sample that reacts with molybdate after acid hydrolysis.

Harrison (1994), selected the following criteria to highlight relative differences of nutrient levels in irrigation drainage water originating from diverse sources and areas:

> SiO_2	Low < 5 mg/L	Moderate 5–20 mg/L	High > 20 mg/L
> NO_x	Low < 0.5 mg/L	Moderate 0.5–2.5 mg/L	High > 2.5 mg/L
> TP	Low < 0.1 mg/L	Moderate 0.1–0.5 mg/L	High > 0.5 mg/L

The nutrient levels in samples taken from a number of drainage caissons throughout Riverland areas in March 1973 are presented in Table 22. These samples may have included a component of groundwater entering the bottom of caissons in addition to the drainage water piped into the caissons.

Table 22.

TABLE 22. NUTRIENT LEVELS IN RIVERLAND DRAINAGE CAISSONS MARCH 1973

Investigation	Sampling date	Location	SiO_2 mg/L	NO_x mg/L	TP mg/L
Potential reuse	27.03.73	LX4 Caisson Loxton	19	20.1	0.03
	27.03.73	Monash North Caisson Berri	23	27.2	0.03
	27.03.73	LN1 Caisson Cobdogla	20	8.6	0.07
	27.03.73	No 1 Caisson Cooltong	24	20.0	0.05
	27.03.73	No 5 Caisson Renmark	25	7.7	0.01

These results indicate generally high levels of silica, very high levels of nitrogen and low levels of phosphorus.

The nutrient levels in samples taken on the same day in March 1973 from inlet drains to the caissons tabled above are presented in Table 23.

Table 23.

TABLE 23. NUTRIENT LEVELS IN RIVERLAND INLET DRAINS TO CAISSONS MARCH 1973

Investigation	Sampling date	Location	SiO_2 mg/L	NO_x mg/L	TP mg/L
Potential reuse	27.03.73	LX4 inlet drain Loxton	18	31.0	0.06
	27.03.73	Monash Nth inlet drain A or A6	18	13.7	0.02
	27.03.73	Monash Nth inlet drain A6 or A	19	5.4	0.05
	27.03.73	Monash North inlet drain B	26	41.6	0.05
	27.03.73	Monash North inlet drain B6	23	27.2	0.03
	27.03.73	LN1 inlet drain Cobdogla	18	12.9	0.05
	27.03.73	No 1 inlet drain Cooltong	24	22.9	0.04
	27.03.73	No 5A inlet drain Renmark	31	20.6	0.30

Although the evidence is inconclusive, most of the samples indicate a higher level of nutrients in the drain water than in the caisson water, which may include a component of groundwater.

Nutrient levels in samples collected during the Drainwatch Program conducted in November 1990 are presented for comparison in Table 24.

Table 24.

TABLE 24. NUTRIENT LEVELS IN RIVERLAND DRAINS NOVEMBER 1990

Investigation	Sampling date	Location	SiO_2 mg/L	NO_x mg/L	TP mg/L
Drainwatch	21.11.90	LX 3 inlet drain Loxton	19	6.8	
	22.11.90	Monash outfall drain Berri	9	2.9	
	28.11.90	Loveday outfall drain Cobdogla	27	5.8	
	21.11.90	Main outfall drain Cooltong	25	23.2	
	21.11.90	No 8 outfall drain Moorook	24	4.1	
	22.11.90	Ramco outfall drain Waikerie	25 1	3.8	

Drainage water quantity

DRAINAGE WATER QUANTITY

In group irrigation areas, large drainage flows in the early 1970s caused overtaxing of both the gravity main drain collecting part of the system and the disposal pipelines and channels.

Annual volumes exceeded 4 ML per drained hectare in some areas.

Two events initially brought about dramatic reductions in drainage flows. The first was the introduction of weekly availability of irrigations, which replaced the traditional roster system, and the second was rehabilitation of the irrigation distribution system (pipelines and meters replacing channels and sluice gates) together with the benefit of water on order.

The third event that significantly reduced drainage flows is not documented but is presumed to be as a result of generally improved irrigation methods and management.

Annual volume are now generally in the range of 1 to 2 ML per drained hectare.

Drainage water disposal

DRAINAGE WATER DISPOSAL

The first drainage outlets were seepage shafts discharging to an underlying sandy aquifer or gravity outfalls discharging generally to the floodplain with a few discharging directly into the River Murray. It is now recognised that irrigation development and disposal of drainage water have badly degraded vast areas of the floodplain. There is broad community support for rehabilitating disposal basin areas. Redirecting drainage water away from some disposal basins dramatically reduces salt loads currently delivered to those basins. Flushing flows through abandoned basins at times of high river flows have more chance of gradually establishing less saline environments in and around the basins. In some cases, being able to subsequently introduce wetting and drying cycles may further enhance the rehabilitation process.

In the topographic depressions away from the valley, drainage shafts or bores were constructed as drainage outlets, with discharge being to the shallowest aquifer. In irrigation areas such as Berri, Cooltong and Loxton, the shaft/bore type outlet was superseded by a comprehensive drainage scheme (Smith & Watkins 1993).

Comprehensive drainage schemes

COMPREHENSIVE DRAINAGE SCHEMES

A Comprehensive Drainage Scheme (CDS) is generally a system of sealed gravity pipelines collecting drainage water from a group of properties and disposing from individual drainage catchments by gravity or more often by pumping. Comprehensive drainage schemes serve about 44% of the irrigated land in the Riverland.

The first CDS was built in 1922 to serve the Cadell Irrigation Area and was subsequently rehabilitated in the 1970s. A CDS for the Berri Irrigation Area was constructed between 1940 and 1952. Then followed schemes for Cobdogla, 1952 to 1956, and Cooltong 1956. Schemes were also constructed at Loxton, Lyrup, Ral Ral and Renmark in the 1960s.

With a few minor exceptions of discharge to highland depressions, these CDS discharge to disposal basins on the floodplain.

The Disher Creek disposal basin receives drainage water from Ral Ral and Renmark irrigation areas, and Berri disposal basin receives drainage water from the Berri Irrigation Area. Basin water levels are kept at or below mean river level by pumping to the Noora disposal basin about 20 km east of Loxton as part of a salinity control scheme effectively reducing salt loads to the river.

An area of irrigated land served by a CDS indicates that a collecting drain is within or close to a property boundary. The said land may or may not be actually drained.

A drained area is irrigated land that actually has subsurface agricultural drains installed capable of collecting 'free' water (excess to field capacity) in the soil where groundwater levels have risen above drain level and discharging into the CDS. Major areas with comprehensive drainage schemes are indicated in Table 25 (Smith & Watkins 1993).

Table 25

TABLE 25. MAJOR AREAS IN THE RIVERLAND SERVED BY COMPREHENSIVE DRAINAGE SCHEMES

Major areas	Irrigated hectares	Served by CDS	Drained hectares	Drained %
Berri	3,303	3,109	1,495	45
Cadell	395	290	55	14
Cobdogla	2,858	1,801	1,001	35
Cooltong	546	527	334	61
Loxton	2,809	2,573	1,407	50
Lyrup Village	321	270	70	22
Moorook	364	201	94	26
Ral Ral	487	336	105	22
Renmark	4,540	3,800	1,500	33

DRAINAGE WATER DISPOSAL BASINS IN THE RIVERLAND

Discharge of about 20 GL annually carrying about 100,000 t of salt is sent to disposal basins on the floodplain. On average some 4 GL of the drainage water with 43,000 t of salt discharged to Disher Creek and Berri basins is relifted to Noora disposal basin about 20 km east of Loxton. Information relating to drainage water disposal basins in the Riverland is shown in Table 26 (Smith & Watkins 1993) and a diagrammatic layout of the basins is shown in Figure 26.

Releases to the river from the major floodplain located disposal basins occur when river flows exceed 15,000 ML/d.

Drainage water reuse

DRAINAGE WATER REUSE

The most noteworthy drainage water reuse scheme in the Riverland Region is in the Qualco Sunlands Drainage District, northwest of Waikerie and incorporating about 2,700 ha of irrigated plantings.

Large scale irrigation developments in the district began in the 1960s. Perched watertables, waterlogging and salinisation of soils in some parts of the district then developed and have had serious impacts on irrigated plantings.

Agricultural pipe drains were installed to lower watertables and protect plantings. Drainage water was disposed of to drainage bores drilled into underlying aquifers. The groundwater mound beneath the district built up quickly rising to or close to the surface of topographical depressions in the centre of the district. Some of the drainage bores became ineffective and the situation was aggravated by rainfall.

A drainage water reuse scheme was implemented involving drainage water being pumped to Section 11, Hundred of Cadell, adjoining the southwest side of Sunlands Irrigation Area. The water was used to grow lucerne. The reuse scheme has been added to from time to time on a needs basis. Diversions over recent years have averaged 560 ML annually. Electrical conductivities of the reuse water range from 2.5 to 3.0 dS/m at 25°C, (pers. comm. Kalms, 2000).

A Groundwater Pumping Scheme incorporating tubewells is proposed to lower the groundwater mound beneath the district. A more extensive drainage water reuse scheme is proposed to more effectively use the low salinity perched watertable groundwater and this will enhance the effectiveness of the Groundwater Pumping Scheme (Ken Smith Technical Services 1999).

A drainage water reuse project "Woodlots for Salinity Mitigation" was conducted by Primary Industries SA on a 4.6 ha site adjoining the eastern side of the Loxton Irrigation Area. The diversion averaged 46.4 ML/year during the 6-year project from 1990-91 to 1995-96 (pers. comm. Meissner, Stevens, Frahn, 1997).

Table 26.

TABLE 26. DRAINAGE WATER DISPOSAL BASINS IN THE RIVERLAND

Disposal basin	Area (ha)	Annual inflow (ML)	Salt load (t)	Basin mean salinity (mg/L)
Berri[1]	150	4,000	25,000	5–10,000
Cadell[1]	20	700	4,200	5–10,000
Cobdogla[1]	30	260	3,600	35–50,000
Cooltong[2]	81	900	1,400	10–35,000
Disher Creek[1]	100	4,400	43,000	10–35,000
Hart Lagoon[1]	45	50	60	5–10,000
Holder[1]	1–2	5	5	5–10,000
Katarapko Is[1]	75	4,000	7,300	< 5,000
K Country[2]	14	530	1,700	< 5,000
Loveday[1]	300	2,600	6,700	5–10,000
Loveday South[2]	2	600	650	< 5,000
Lyrup East[1]	5	6	4	5–10,000
Lyrup South[1]	40	100	80	50–100,000
Mid Pike[2]	30	12	20	35–50,000
Noora[2]	1,700	4,200	43,000	10–35,000
Ramco Lagoon[1]	87	12	40	5–10,000
Wachtel Lagoon[1]	600	80	80	< 5,000

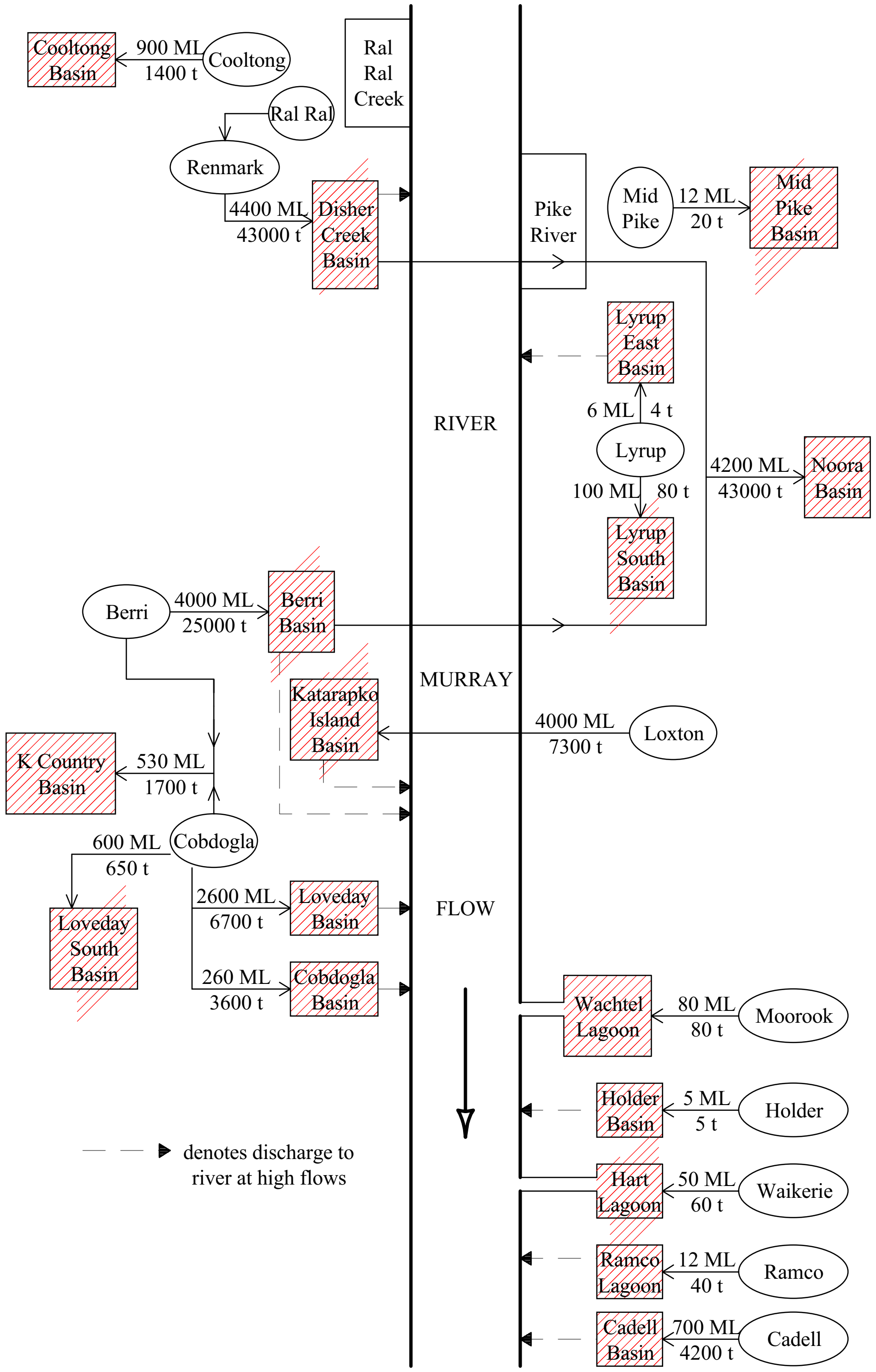
1 Disposal basin located on floodplain.

2 Disposal basin located in natural depression in highland

Figure 26.

FIGURE 26. ANNUAL DRAINAGE WATER DISPOSAL IN THE RIVERLAND

Source: Smith & Tonkin, 1994



Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

On-farm drainage system management and monitoring is the responsibility of each individual irrigator, with the exception of the Golden Heights, Ramco Heights and Sunlands Irrigation areas.

Local Action Planning groups together with Irrigation Trust authorities are encouraging irrigators to install testwells to monitor watertables in a number of Watertable Watch programs.

The management and monitoring of comprehensive drainage schemes in a number of irrigation trust areas are the responsibility of each particular trust authority. The drainage pump hours run, and kWh readings are collected regularly.

The management of most of the disposal basins is the responsibility of the Department of Water Resources. This department also monitors volumes and salinities at selected major outfalls to some disposal basins.

Irrigation and Drainage Management plans (IDMPs) are required to be submitted and approved before the start of new irrigation developments. Included in IDMPs are the following:

- Soil surveys and estimates of Readily Available Water (RAW) values.
- Intended soil moisture monitoring and irrigation scheduling techniques.
- Commitment to be responsible for dealing with all future shallow watertable drainage problems and a commitment to be responsible for disposal of drainage water.
- Commitment to be responsible for preventing lateral displacement of drainage water that could affect neighbouring properties or the floodplain.
- Commitment to be accountable for future deep drainage groundwater accessions including a concept design for groundwater collection and disposal. Arrangements are to be agreed for establishing a trust fund dedicated to the property, which can facilitate the construction of future works, be they on property or part of a future community drainage scheme.

Drainage funding

DRAINAGE FUNDING

With the exception of the Golden Heights, Ramco Heights and Sunlands Irrigation areas, the costs of installing, operating and maintaining on-farm drainage systems is the responsibility of each individual irrigator. No subsidies or specific loans are available.

Costs for installing on-farm systems are about $5,000/ha. Additional costs are incurred where sumps are installed at drain junctions and where rock is encountered.

Water supply charges (irrigation rate) imposed on irrigators within trust areas generally include a component for the recovery of costs and other liabilities in relation to comprehensive drainage schemes.

Groundwater lowering schemes in the Qualco Sunlands Drainage District and interception works in the Lock 4/Bookpurnong Area are in the planning stage. Cost sharing arrangements are to be negotiated between the irrigators and the relevant State and Federal Government funding sources. In addition, a Phase II extension of the Waikerie Salt Interception Scheme (an MDBC Salinity and Drainage Strategy Initiative) is being considered.

Current issues and trends

CURRENT ISSUES AND TRENDS

Rehabilitating irrigation distribution systems (pipelines and meters replacing channels and sluice gates), introducing water-on-order and a general improvement in on-farm irrigation practices has resulted in a dramatic reduction in drain flows (up to 50%) over the past two decades. The more widespread adoption of soil water monitoring and irrigation scheduling techniques could result in even less water going to drainage past the rootzone.

Volumes of water excess to evapotranspiration percolating to regional groundwater mounds beneath some of the long established irrigation areas have been much reduced but the mounds are still active in forcing saline groundwater to the river and floodplain.

On-farm drainage installations are increasing at a very low rate and are generally limited to small-localised trouble spots.

Costly proposals are currently being considered to redirect drainage water away from some disposal basins to existing disposal basins that already have some measure of control on the extent of salinity and environmental impacts they impose. Implementing these consolidating proposals would offer an opportunity for rehabilitating the abandoned basin areas.

Research requirements and knowledge gaps

RESEARCH REQUIREMENTS AND KNOWLEDGE GAPS

Annual water balance studies of the rootzone of irrigated plantings at a property or a district level are being used to estimate volumes and depths of water going to drainage (in this context, water percolating past the rootzone) where the total water applied exceeds the total water use of the planted area. If the total water demand of the planted area exceeds the total of applied water, then there is a water deficit.

The water balance is expressed in the terms:

$$\text{Irrigation} + \text{Rain} - \text{Water use} = \text{Drainage} \qquad (1)$$

and

$$\text{Water demand} - (\text{Irrigation} + \text{Rain}) = \text{Deficit} \qquad (2)$$

where:

Irrigation = volume of irrigation water applied during the year (July to June);
Rain = volume of total rainfall for the year (July to June); and
Water use or water demand = the sum of the volumes of crop water requirements plus, in the case of crops with a part-year growing season, the volumes of evaporation-water use from bare soil-covercrops during the non-growing season.

The irrigation performance of each property and each district is assessed by calculating the annual water balance efficiencies thus:

$$\text{AWBE} = \text{Water use} \times 100 / (\text{Irrigation} + \text{Rain}) \qquad (3)$$

where:

AWBE = Annual Water Balance Efficiency expressed as percent;
Water use = the sum of the volumes of crop water requirements plus, in the case of crops with a part-year growing season, the volumes of evaporation-water use from bare soil-covercrops during the non-growing season;
Irrigation = volume of irrigation water applied during the year (July to June)
Rain = volume of total rainfall for the year (July to June).

Transposing equation (3) thus:

$$\text{Water use} = \text{AWBE} \times (\text{Irrigation} + \text{Rain}) / 100 \qquad (4)$$

and substituting in Equation (1), then:

$$(\text{Irrigation} + \text{Rain}) - (\text{AWBE} \times (\text{Irrigation} + \text{Rain}) / 100) = \text{Drainage} \qquad (5)$$

which can be expressed in the form:

$$(\text{Irrigation} + \text{Rain})\ (1 - \text{AWBE} / 100) = \text{Drainage} \qquad (6)$$

Given specific annual water balance efficiencies, equation (6) can be used to estimate or predict volumes and depths of water going past the rootzone.

The reliability and acceptance of the annual water balance studies described in this section on 'Research requirements and knowledge gaps', relies heavily on:

- the accuracy of metered irrigation supplies and rainfall measurements
- the accuracy of crop age and area data
- theoretical crop water requirement closely matching actual crop water requirement
- the calculated annual water balance efficiency reasonably matching actual water balance efficiencies throughout the year, i.e. from one irrigation cycle or rainfall event to the next.

Drainage volumes derived from an annual water balance of the rootzone can be realistic if the input data is accurate and if irrigation is well managed throughout the year. Water balances of the rootzone over one irrigation cycle to the next would provide better results for volumes of water percolating past the rootzone but this would involve more costly and intensive monitoring, data acquisition and analysis. The question still remains as to whether there are ways of refining the water balance techniques described above or are there better and easier ways to monitor irrigation performance (and drainage impacts) both at the property and district scale.

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SHEPPARTON IRRIGATION AREA

SHEPPARTON IRRIGATION AREA

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Introduction

INTRODUCTION

This report describes the current status of subsurface drainage practices for the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP). Groundwater pumping research, trials and strategy development for salinity control in the region began in the 1960s.

The Subsurface Drainage Program for the Shepparton Irrigation Area is supported by a comprehensive set of policies, guidelines and procedures developed over time. These are only briefly described here.

Location

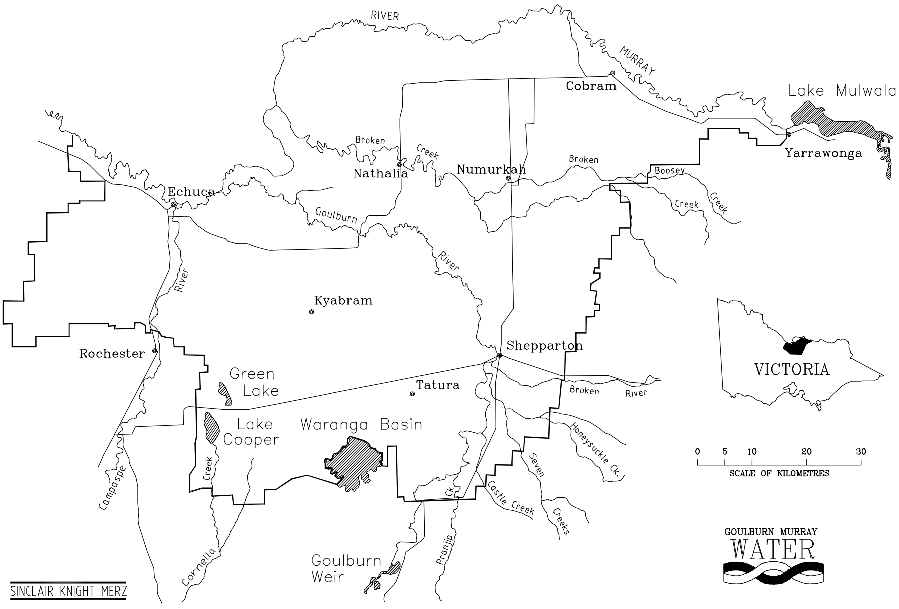
LOCATION

The Shepparton Irrigation Region (SIR) is located within the Murray Darling Basin on the southern edge of Riverine Plain in northern Victoria. The area covers more than 500,000 ha including about 487,000 ha of farm holdings within the Rochester, Central Goulburn, Shepparton and Murray Valley Irrigation areas.

Note. The Campaspe Irrigation District adjoins the Rochester Area. The western part of the district (about 5,000 ha) has its own salinity management plan and is not part of the SIR in terms of the SIRLWSMP. While there are differences between the Campaspe and Shepparton plans, they are not described in this publication.

Figure 27.

FIGURE 27. SHEPPARTON IRRIGATION REGION



Climate, soils and land use

CLIMATE, SOILS AND LAND USE

The climate is semiarid with an average rainfall of between 380 and 500 mm/year. As evaporation in the region averages 1350 mm/year, irrigation is necessary to support summer, autumn and spring crops.

The soils in the SIR fall into two main groups, the red–brown earths and the grey–brown soils of heavy texture. The first includes the coarser surface sediments deposited close to ancestral stream courses. The second group was deposited further out on the floodplain.

Irrigation development in the SIR began when the Rodney Irrigation Trust under the *Irrigation Act* was established in 1886. Currently, about 280,000 ha of land within the SIR are developed for irrigation.

Irrigation water has traditionally been applied by flood irrigation of pastures, and a mixture of flood and furrow irrigation for horticulture. Over the past twenty years, pasture irrigation has improved water use efficiency through laser-controlled grading of irrigation bays. Very few pasture developments have moved to overhead sprays or travelling irrigators. Horticulture is now mostly irrigated with under tree mini-sprinkler systems. Irrigation intensities are typically in the range of 4 to 10 ML/ha /yr with pasture typically requiring 10 ML/ha/yr and horticulture 7 ML/ha/yr.

Surface water for irrigation within the system generally varies from 0.05 to 0.15 dS/m (without groundwater inputs) depending on the source of supply, time of year and location within the system.

Regional hydrogeology

REGIONAL HYDROGEOLOGY

The riverine plains of the Shepparton Irrigation Region comprise unconsolidated alluvial deposits with comparatively flat surface, and gentle northwesterly slopes of around 1 in 2500. The depth of the unconsolidated deposits above bedrock varies, and typically ranges from 20 to 150 m thick with a maximum recorded thickness of 200m.

The sedimentary sequence is complex and changes with depth, with the deeper deposits generally being coarser grained. The deepest formation, called the Renmark Group, mostly occurs to the north and west of the area. The overlying Calivil Formation is more extensive in the SIR and generally follows the present day courses of the Murray, Goulburn and Campaspe rivers. The hydraulically undifferentiated Calivil Formation and Renmark Group aquifers are commonly referred to as the "Deep Lead".

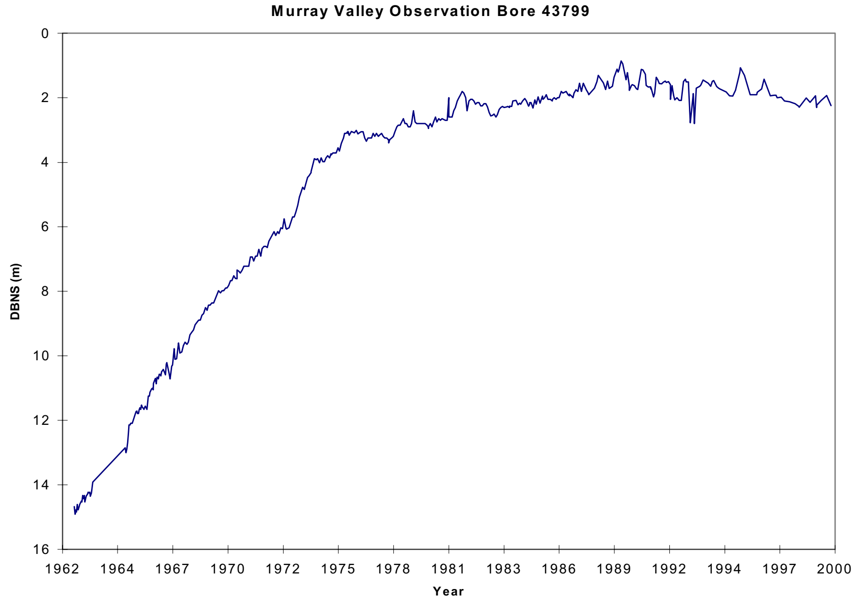
Alluvial sediments of the Shepparton Formation overlay the Calivil/Renmark aquifer and extend from surface to 80 m deep. Although the Shepparton Formation is often thought of as one hydrogeological unit, the mixture of mainly clays and silts interspersed with lesser quantities of sand and gravel form a complex system of aquifers and aquitards. To differentiate this complexity the unit is often divided hydrogeologicaly into the Upper (< 25 m) and Lower Shepparton Formations.

Nature of the problem

NATURE OF THE PROBLEM

Figure 28.

FIGURE 28. MURRAY VALLEY OBSERVATION BORE 43799



Before European settlement, groundwater levels were more than 30 m below surface. Clearing native vegetation and irrigation development have disrupted the natural hydrologic cycle and the Upper Shepparton Formation aquifers and enclosing clay aquitards have become saturated.

Groundwater levels are now at less than 2 m below surface over much of the Shepparton Irrigation Region. Studies undertaken during the development of the plan estimated that about 274,000 ha would be subject to groundwater levels within two metres of surface by the year 2020.

Groundwater pressures in the deep regional aquifer system (Deep Lead) have also been rising. However, local scale recharge and discharge processes in the Upper Shepparton Formation are the main contributors to salinity problems in the region. Modelling in the Girgarre Area suggested lateral flow in the shallow systems was about 15% of total vertical recharge.

The hydraulic connection between the deep regional aquifer system and the shallow systems is generally poor beneath the Irrigation Region. Thirty-day pump tests were undertaken on two existing private Deep Lead bores during August-September 1996, one near Rochester and the other near Katunga in the Murray Valley. In both of these tests, groundwater levels in the Upper Shepparton Formation did not respond notably to the Deep Lead pumping. Analyses indicated that, at best, downward fluxes were 9 and 1.8 mm/yr for the Rochester and Katunga sites respectively. This indicated that deep aquifer pumping was not an effective management option for groundwater and salinity control.

Drainage methods used

DRAINAGE METHODS USED

Background

Some waterlogging problems and, to a lesser extent, salinity problems were evident in the region in the 1930s. Early attempts to solve the problems focussed on providing surface drainage. In a few locations, particularly horticultural areas, tile drains were successfully used, mainly to stop waterlogging.

In the early 1960s, the broader problem of shallow groundwater levels and associated waterlogging and salinity problems became evident in the Murray Valley Irrigation Area. This resulted in the gradual implementation of groundwater observation bore networks across the SIR, and groundwater pumping trials began in the Murray Valley.

The trials showed that pumping from the Upper Shepparton Formation aquifers was effective in controlling groundwater and salinity over an area of up to several hundred hectares where suitable aquifers exist. Consequently, work began on the development of potential groundwater pumping strategies to address the emerging groundwater and salinity problems within the SIR.

During the very wet years of 1973 and 1974, both serious and incipient waterlogging and salinity problems emerged and an estimated 30% of the region's horticultural area was lost. In response, the Phase A Groundwater Control Program was implemented as an urgent measure to protect major horticultural areas.

The Phase A Program was completed in 1985 by which time one hundred and seventy target areas had been investigated, 79 pumps were installed (excluding Shepparton East), twenty sites were deferred and sixty eight were abandoned. The estimated area protected was 3,400 ha of horticulture and 14,600 ha of adjoining pasture.

In 1975, it was also proposed that a much larger Phase B Groundwater Control Program would be required in the future to protect pasture areas. In the early 1980s, the economics and downstream impacts of the Phase B program (in its original form of essentially public dewatering works with groundwater disposal to channels and drains) were questioned. In addition, private pumping of moderately saline groundwater and on-farm reuse were adopted on a significant scale. With regular and consistent pumping, this could potentially provide on-farm groundwater and salinity control as well as provide an additional resource.

In the early 1980s, public and private groundwater pumping trials were initiated in pasture areas to build on the Phase A experience and to provide input to developing a hybrid Phase B strategy comprising public and private works. The main trials were in the Campaspe Irrigation District (administered by the Rochester Area), in the Tongala area and the Girgarre Salinity Control Project.

Subsurface drainage management areas

Groundwater level projections to 2020 and regional scale hydrogeological mapping of the Upper Shepparton Formation broadly identified a number of potential subsurface drainage management types for strategic planning purposes. The management types were designated B and C Type areas as follows:

- > B1 - high groundwater levels, aquifer yields medium to high and groundwater salinities high (> 11.7 dS/m)
- > B2 - high groundwater levels, aquifer yields medium to high and groundwater salinities moderate (5–11.7 dS/m)
- > B3 - high groundwater levels, aquifer yields medium to high and groundwater salinities low (< 5 dS/m)
- > C - high groundwater levels, aquifers non-existent or low yield and groundwater salinities low, moderate or high.

The current disposal strategy for groundwater more saline than 10 dS/m is to basins. For groundwater less than 10 dS/m, which cannot be used productively on-farm, disposal is to the channel or surface drainage network. When on-farm reuse is viable, some winter disposal for salt balance is encouraged when favourable disposal conditions exist.

There were also areas within the SIR, which had insufficient information to describe a management type, and areas where no salinity problem was envisaged to 2020. The mapping and categories were coarse in scale for regional planning purposes. At the local project scale, all of the categories can be encountered within close proximity because the Upper Shepparton Formation varies considerably.

Subsurface drainage program

The subsurface drainage component of the plan currently targets moderate to high capacity private and public groundwater pumps where technically feasible. An economic evaluation of moderate to high capacity pumping undertaken in 1993-1994 indicated a benefit:cost ratio of 1:7.

The plan provides for tile drainage or low volume pumps where there are no suitable aquifers. However, tile drainage or low capacity pumping is currently restricted to horticultural areas pending the development of a cost-effective strategy for C Type pasture areas.

Overall plan (1998) targets are shown in Table 27.

Table 27.

TABLE 27. PLAN TARGETS (1998)

Drainage method	Target by 2023	Area protected
Install new private groundwater pumps	365 pumps	40,820 ha
Consistent pumping of existing private pumps	395 pumps	44,180 ha
Install new tile drains in non-horticultural areas	14,000 ha	43,000 ha
Install new tile drains protecting existing horticultural areas	300 ha	NA
Install new private groundwater pumps for existing horticultural areas	40 pumps	1,000 ha
Install new public pumps (includes 50 evaporation basins)	425	85,000

The private groundwater pumping program encourages regular pumping and reuse in season to provide on-farm groundwater and salinity control. Winter disposal for salt balance is encouraged when favourable disposal conditions are available. The type of installation (i.e. private or public) is site specific and depends on reuse-disposal options. The current nominal salinity limit for private pumps is 3.5 dS/m.

Public pumps are considered when private pumping is shown to be not feasible, a salinity problem is evident and there is enough support from the likely direct beneficiaries. Operation is aimed at salinity control rather than full groundwater control and disposal is to the regional channel and drainage system when salinities are nominally less than 10 dS/m, and to evaporation basins for higher salinities.

Prioritising works

The Subsurface Drainage Program favours private works where feasible rather than public works and also favours working with recognised landholder groups to maximise regional benefits. Funds allocated for private works are further prioritised by confirming that the property is subject to groundwater levels within 2 m of surface. Properties are given priority based on the following:

- with known salinity problems
- which have the potential to provide salinity control to adjoining land with known salinity problems
- where some lowering of the generally high groundwater levels can be achieved.

Where private works are not feasible, site investigations for public pumps are currently scheduled on the basis of order in which the application is received and accepted.

Investigation, design and construction

INVESTIGATION, DESIGN AND CONSTRUCTION

Investigation, design and construction standards for private and public works differ and have evolved over time to meet specific needs. Wellpoint systems connected to a surface-mounted centrifugal pump are better suited to local conditions for both private and public pumpsites in place of single bores fitted with submersible pumps. This is largely because of the shallow depth and limited thickness of the aquifers commonly encountered. The current procedures for private and public pumps are briefly described in this chapter.

New private pumps

The aim of installing new private pumpsites under the plan is to achieve on-farm integration of the works to achieve plan objectives in consultation with the landholder. The plan provides incentives and assistance to individuals for locating and installing pumpsites. A typical investigation under the plan would comprise:

- a geophysical (EM 34) survey to assist in identifying drilling targets
- first pass exploratory drilling, gamma ray borehole logging and groundwater salinity sampling to assess pumping and reuse potential
- if the first pass results are promising, a second round of drilling, gamma logging and sampling to better delineate the target
- installing two trial well-points if a suitable site is located
- connecting a temporary header line and three day pump test.

Information from the field investigation is used to determine aquifer parameters (T and s) and the configuration and sustainable yield (short term and over the season) of a completed system at the site. In addition, a safe reuse volume, in terms of applied irrigation salinity and pumping intensity, is calculated to determine the allocation for annual extraction.

The current recommended safe salinity limit for the shandied groundwater and surface water is 0.8 dS/m for no production loss on flood irrigated perennial pasture on a medium textured soil. Site specific salinity limits can be varied depending on crop and soil type. The following guidelines have been adopted for zero productivity loss for some other crop types.

> Lucerne (flood irrigated)	1.2	dS/m
> Fruit trees (deciduous)	0.5	dS/m
> Eucalypts (first year)	3	dS/m
> Eucalypts (subsequent years)	5	dS/m.

The current pumping intensity limit is set at 3 ML/ha/yr over the area of groundwater use. This limit aims to reduce the risk of rapid aquifer salinity increases and degradation due to over pumping.

No effort is made to determine the area of influence of the pumpsite. This is not considered to be warranted, as there is no cost sharing between potential direct beneficiaries of the site. For plan progress monitoring purposes, every 1 ML pumped is assumed to protect one hectare of land. This assumption is based on regional estimates of recharge rates under pumping conditions.

Some groundwater disposal in winter for salt balance is encouraged if practicable to reduce salt accumulating in the pumped aquifer. This is calculated by determining the amount of salt in the channel irrigation water over the area contributing to the pump. The area contributing is currently assumed to be the area protected plus 30%.

The plan has minimum materials and construction standards for private pumps installed with plan capital grant assistance. Detailed design is not undertaken for private sites; however, hydrogeological and engineering advice is provided to the landholder on request when installing a system. The landholder arranges site installation by contractors and the two trial wellpoints installed during the investigation are generally incorporated into the final system of typically 10 to 12 wellpoints.

Public pumpsites

Public pumpsites are only considered when private works are not feasible, there is a demonstrated salinity problem and there is enough support from potential direct beneficiaries. The investigation, design, construction and commissioning of public pumpsites (which become Goulburn-Murray Water assets) is, by necessity, more rigorous and of a higher standard than private works. Current practices for establishing a public pumpsite are briefly described in the next section.

Feasibility investigation

A reasonable amount of information is usually available for the general target area as a result of the mandatory prior investigation to determine the feasibility of private works. The main subsequent activities are:

- > preliminary assessment of disposal options and downstream impacts, including environmental
- > visual salinity assessment and refining the target area(s) in consultation with the landholders
- > follow-up exploratory drilling to delineate the target aquifer
- > trial wellpoint installation (typically four), development and short term testing
- > connect a temporary headline and 21-day pump test
- > calculate aquifer parameters (T and s) and 60-day design yield of a completed system (using Jacob's straight line approximation method, image well theory and the Thesis Equation)
- > refine disposal options and impacts, including environmental

- > distance-drawdown analysis to identify direct beneficiaries, their level of service and rating liability and environmental benefits
- > preliminary estimate of capital establishment cost
- > site specific economic analysis using the Murray Darling Basin Commission's Drainage Evaluation Spreadsheet Model v3
- > document direct beneficiary agreement by means of a vote
- > document the results of the investigation and submission to the regional approval process.

The purpose of the 21-day pump test is twofold. Firstly, because of plan cost sharing arrangements, there is a requirement to identify the direct beneficiaries and their level of service with some confidence.

The second purpose is to identify any impermeable or recharge boundaries. The Phase A experience demonstrated that tests of shorter length could result in significant errors in long-term design yield due to the almost random distribution of boundaries within the Upper Shepparton Formation.

Design, construction and commissioning

The overall aim is to create a subsurface drainage asset to G-MW's standards and to minimise annual operating and maintenance costs. Main activities in the design phase are:

- > Complete hydrogeological input. Additional wellpoints if required; pressure, sand production and quarter hour pumptests; and determine specific yields and whether drawdown tubes are required.
- > Inspect site with landholder(s) to discuss access arrangements; power and potential for three-phase cost sharing; pump enclosure, header and discharge line location and alignment; existing or proposed on-farm works (landholder and regional) that need to be considered in the design; and proposed leasing/licensing arrangements.
- > Initiate survey and provide power supply.
- > Detailed hydraulic, civil, electrical and mechanical design and cost estimate.
- > Prepare detailed specifications and drawings.

Goulburn-Murray Water's Construction Unit manages site construction, mostly using external contractors. Post construction activities comprise of:

- > constructed survey and drawings
- > preparing leasing/licensing plans and documents
- > cost comparison between actual, design and feasibility estimates
- > identifying construction problems/issues encountered
- > identifying potential design and construction improvements.

The public pump program is actively supported by an R&D and review process to ensure that current best practices, materials and technologies are used.

The operating criteria for public pumps are based on two 60-day periods of continuous operation per year (on average) to provide leaching opportunities and salinity control. For planning purposes, 0.5 ML pumped is assumed to serve one hectare. The first of these 60-day periods is also used to commission the site and to confirm the level of service and rating liability of the direct beneficiaries.

Pumpsite operation is monitored and any minor problems encountered are rectified. In some instances (about 10% of sites), excess gas production can cause major operational problems, and installing a gas extraction unit may be required. The detailed design provides for a gas tank, which can be fitted retrospectively if required.

On successful commissioning of the site, handover documentation is prepared with enough detail for operational and asset management and to implement local beneficiary rating.

Tile drains

TILE DRAINS

Tile drainage activity under the Shepparton Plan is currently limited to horticultural areas pending the development of a strategy for tiles in pasture areas. Some tile drains under pasture have been installed in the Campaspe Irrigation District under the Campaspe West Salinity Management Plan.

Drainage design is typically based on soil hydraulic conductivities and target depth-to-watertable under steady state conditions. Generally, the open auger hole method is used to estimate soil hydraulic conductivities and Hooghoudt's equation is used to determine drain spacing.

Some tile drainage trials have been undertaken in Campaspe in the mid 1980s and at Katandra in the 1990s. Preliminary economic analysis of the Katandra trial indicated that tiles under pasture may be economically justified if current and forecast salinity losses are significant, e.g. currently 10%, increasing to 30% over twenty years.

A "serial biological concentration" trial is also in progress at Undera within the region. The concept involves groundwater pumping and irrigating salt-tolerant crops, which are tile drained. The tile drain effluent is then disposed to a series of evaporation basins. Aquaculture potential within the basins is also being evaluated as a means of offsetting the high establishment costs.

Groundwater quality

GROUNDWATER QUALITY

Groundwater salinity is currently the key parameter in terms of subsurface drainage management type and groundwater disposal options. Groundwater salinities are highly variable and range from low (< 1 dS/m) to high (> 12 dS/m).

Some studies have been undertaken in the SIR on groundwater chemistry and contaminants, which found similar variability in other parameters including SAR (from < 8 to > 20). Potential nutrient loads associated with groundwater disposal would not seem to be significant when compared to diffuse surface sources.

In general, the studies indicated that raw groundwater (in isolation) within the Upper Shepparton Formation beneath the SIR is of limited beneficial use. However, when used conjunctively with surface water supply, groundwater can provide an additional productive resource.

Some sampling and analyses for trace elements and metals were undertaken at Girgarre Basin as part of the project establishment. The results indicated that parameters such as selenium were not a major concern. However, the sample set was limited.

Management and monitoring

MANAGEMENT AND MONITORING

Goulburn-Murray Water is the authority responsible for overall groundwater management in the SIR. Management and monitoring of private and public subsurface works and groundwater disposal has evolved over time and is subject to ongoing development and refinement. The current status is briefly described below.

Private pumps

Before implementing the plan, little was known about the extent of private groundwater pumping and the salinities of the groundwater being pumped. A small selection of private pumps across the region was metered and monitored for volumes and salinities for some seasons in the mid 1980s. In addition, some groundwater usage surveys were undertaken to provide indicative numbers for regional planning purposes.

In 1989, the plan implemented a private groundwater pumping incentive scheme by subsidising operating costs aimed at encouraging regular and consistent pumping and providing more reliable data on pumped volumes and salinities. This scheme had some success, however, there was limited confidence in the reliability of the data as pumped volumes were largely estimated by indirect means.

Implementation of a Groundwater Management Plan (GMP) for the region began in July 1999, largely to facilitate the implementation of the private pumping component of the region's subsurface drainage program. The GMP includes the direct metering and extraction license reviews for about 1,000 private pumps. Pumped volume and salinity monitoring are part of the GMP and more reliable data should be available with time.

Public pumps

Public salinity control pumps become G-MW assets for operation and maintenance in perpetuity. G-MW has financial and physical performance monitoring systems in place and routinely report to the plan.

Groundwater disposal

GROUNDWATER DISPOSAL

Groundwater disposal is fundamental to implementing the Region's Subsurface Drainage Program. The plan has regional salt disposal guidelines and standards set by the Victorian Government and the MDBC based on the benchmark period (1975 to 1985) for the River Murray. However, the plan also acknowledged that salt disposal guidelines would need to be developed at the subregional and local scale as implementation proceeds.

Operating targets for public salinity control pumps disposing to the channel and drain network are two 60-day periods of continuous operation per year (on average) to provide leaching opportunities and salinity control. One 60-day period is in-season, with the other out-of-season when favourable disposal conditions exist. The adopted average recharge rate for public pumps is 0.5 ML/ha/year.

Off-farm discharge from private pumps is generally not permitted in season. However, private pumps are encouraged to discharge specified amounts for salt balance out-of-season when conditions allow. The current status of salt disposal guidelines for the region is briefly described below.

Regional streams

The Murray River has no set upper salinity limit and groundwater pump operation is scheduled to fit within the plan's EC limits according to standards and guidelines set by the Victorian Government and the MDBC.

Early in the plan implementation phase, out-of-season disposal was initiated when observed flows at Torrumbarry Weir exceeded 10,000 ML/d and there was a reasonable expectation that these conditions would persist for 60 days or more. In 1998, more robust and objective operating rules for salt disposal were developed based on real time flow conditions at key points within the Murray and Goulburn River systems.

For the Goulburn River, out-of-season groundwater pump operation is in accordance with the Murray schedules. Modelling of the Goulburn River in the early 1990s estimated that average salinities due to the fully implemented plan would increase from 0.192 to 0.257 dS/m and that daily salinities could exceed 0.5 dS/m about 3% of the time. It was recommended that the aim should be to keep the river salinity below 0.5 dS/m as a general rule. This limit was acknowledged to be conservative.

The lower reaches of Broken Creek are seen as an important fishery for Murray cod and crayfish. Advice (1996) from DNRE's Kaiela Freshwater Research Station on current knowledge of freshwater fauna salinity tolerances was:

> Adult fish	15 dS/m
> Juvenile fish, (more sensitive, tolerance unknown)	
> Macrophytes	6 dS/m
> Macroinvertebrates	1.6 dS/m

Modelling of salinity increases in the lower reaches of Broken Creek as a result of the plan using the Murray disposal schedules indicated salinities would be within the adopted upper salinity limit of 1.5 dS/m. However, additional rules better suited to Broken Creek flow conditions were developed to minimise potential salt disposal impacts.

The Broken and Campaspe rivers have no set salinity limits under the Shepparton Plan. Salt disposal to these streams is not considered an issue for the plan as only minor inputs and impacts are expected.

Channels

In-season channel groundwater disposal guidelines developed during the Phase A program are still current. A flow weighted average limit of 0.5 dS/m was adopted and is based on a zero productivity loss for horticulture on a medium textured soil.

> Flow weighted average seasonal salinity < 0.5 dS/m
> Maximum average for any seven consecutive days < 0.75 dS/m
> Maximum at any time 0.85 dS/m.

Goulburn-Murray Water's Irrigation Management System and System Planning Modules include a channel salinity simulation subsystem. The flow and salinity simulation model is run in conjunction with planned deliveries to manage the operation of public pumps discharging to the channel system.

Drains

Drain flows and salinities are highly variable, both spatially and temporally, within the region. In 1998, upper salinity targets resulting from in-season groundwater disposal to drains were developed and adopted as follows:

> For existing, flow-weighted, average seasonal drain salinities less than 0.53 dS/m, an upper target of 0.8 dS/m
> For existing, flow-weighted, average seasonal drain salinities > 0.53 dS/m, an increase of 50% with an upper target of 1.7 dS/m.

The upper targets are aligned with the salinity limit guidelines adopted for the conjunctive use of groundwater for irrigation. The 0.8 dS/m is based on zero productivity loss for perennial pasture. The upper limit of 1.7 dS/m (estimated 15% productivity loss) is the current irrigation salinity limit guideline for private groundwater pumps installed without plan assistance.

Average conditions over the 1994-95 to 1996-97 seasons have been adopted as base or "benchmark" conditions for the drainage system. A substantial number of subregional drainage catchments within the region have continuous flow and salinity monitoring stations at their outfalls. Currently, a simple drain network mass balance modelling approach (calibrated against monitoring stations) has been adopted to account for the effect of new pumps and also to assess potential impact of proposed pumps.

Cost sharing

COST SHARING

Establishing works

The costs for feasibility investigations and capital establishment of public works are currently met by State and Federal funds. The State also funds the capital component of the region's Salt Disposal Entitlement. The plan provides a range of varying incentives for investigating and establishing private works and has a comprehensive set (not reproduced here) of policies and guidelines for new and existing works.

Annual costs

Cost sharing principles and a beneficiary pays tariff structure have been developed by the plan for annual costs (including renewals for public works) associated with the region's subsurface drainage service. These have been implemented for the Murray Valley, Central Goulburn and Rochester Irrigation areas. The Shepparton Irrigation Area has adopted the principles for new works but has yet to resolve cost sharing issues for Phase A works.

Table 28.

TABLE 28. COST SHARING ARRANGEMENTS

			Distribution of cost (%)	
Activity		**Local Government**	**Local beneficiary**	**All irrigators**
Direct costs				
Phase A		0	50	50
New public pumps		17	41.5	41.5
Additional channel/drain O&M	– Phase A	0	50	50
	– New	17	41.5	41.5
Private pump & surface drain SDA		17	0	83
Non operational sites	– Phase A	0	0	100
	– New	17	0	83
New sites before rating		17	0	83
Private pump management		17	41.5	41.5
Indirect costs				
Land & water administration		17 2	0	83
Accounts receivable		17 2	0	83
Other indirect		17 2	41.5	41.5
Private pump concession for Private/public pump overlapping areas		0	50	50

The annual costs of the subsurface drainage service are met by those directly benefiting from public pumps (via Local Beneficiary Fees), all irrigators (via a Service Fee on water use) and Local Government. The total Local Beneficiary contribution to any service is split equally between a Local Benefit Area Fee and a Local Benefit Water Use Fee.

The 1999-2000 subsurface drainage pricing schedule for the region is given in Table 29.

Table 29.

TABLE 29. PRICING SCHEDULE 1999-2000

	Murray Valley	Shepparton	Central Goulburn	Rochester
Local Benefit Area Fee ($/area unit)	2.8703	-	2.8283	3.9264
Local Benefit Water Use Fee ($/water unit)	0.4951	-	0.5409	0.9319
Local Benefit Municipal Fee ($/area unit)	11.4812	-	11.3132	15.7055
Service Fee ($/ML water use)	0.2148	0.5645	0.4980	0.0785

The local or direct beneficiary rating liability is based on the property's average level of service. This is based on the observed groundwater drawdowns during the first 60-day period of continuous operation and applying relative benefits to areas within drawdown categories.

The principles for deriving the average level of service are not reproduced in this report. However, for example, the 1999-2000 rating liability of an eighty hectare dairy farm in the Murray Valley with a water use of 440 ML and average level of service of

1.58 would be $802 ($708 in local fees and $94 via the Area Service Fee).

Before July 1999, the costs of private groundwater pump management were met by government but it was agreed that part of these costs will in future be charged to the Subsurface Drainage Service, subject to the removal of the current exemption from groundwater charges.

The exemption was lifted in July 1999 with the implementation of the region's Groundwater Management Plan and fixed ($49.50 per licence) and volumetric charges ($1.10 per ML of licence allocation) were introduced for 1999-2000 to partly cover management costs from users. Further shifts are likely to occur as implementation proceeds and evolves. The Local Government contribution is restricted to new works, i.e. no Phase A costs are met by Local Government.

The plan is to pay the fixed charge in 1999-2000 recognising the community salinity benefits from regular groundwater pumping. The region's Water Service committees have agreed to pay the fixed fees from the Subsurface Drainage Service in future years for those that meet plan requirements.

Areas served by existing, regularly used private pumps or tile drains within the area of influence of public pumps can receive a concession by a reduction in the rating service level for the overlapping area. This reduction in the rate base and potential shortfall in revenue is recovered equally from local beneficiaries and all irrigators.

Issues and requirements

ISSUES AND REQUIREMENTS

Groundwater management and salt disposal are fundamental to implementing the SIR's Subsurface Drainage Program. The plan (1989) in its original form, estimated that a Murray River salt disposal entitlement of 16.7 EC credits would be required to fully implement the Subsurface Drainage Program. Shepparton currently has 3.4 EC and indications are that the region may receive 10 EC credit in the long term.

Implementation of the plan has proceeded based on best bet assumptions and guidelines derived from available information and knowledge and is subject to ongoing review and refinement. Some areas that may require further policy or technical development or both are briefly listed as follows:

> tile drains and low capacity groundwater pumps in areas where aquifers are limited or non-existent
> public and private evaporation basins, including opportunities for other potential uses of basins to offset costs
> protecting environmental features including level of service required and cost sharing principles
> impacts of increasing irrigation supply salinities
> alternative disposal methods for moderate to high salinity groundwater to reduce overall need for salt credits
> options for generating salt credits
> the amount of pumping required for groundwater or salinity control or both
> operational guidelines and schedules to maximise disposal opportunities to channels and drains
> safe groundwater pumping intensity levels for resource sustainability in terms of aquifer salinity increases
> land and water management options to reduce the amount of subsurface drainage required.

A five-year review is currently in progress for the subsurface drainage component of the Shepparton Irrigation Region Land and Water Salinity Management Plan. This review will identify constraints and further strategic and technical development requirements in more detail.

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Shepparton Irrigation Region Land and Water Salinity Management Plan Policy Papers

SOUTH WEST IRRIGATION AREA

SOUTH WEST IRRIGATION AREA

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Location

LOCATION

The South West Irrigation Area (SWIA) runs along the western edge of the Darling Range from about 100 to 170 km south of Perth, between Waroona and Dardanup. The average width is about 15 km.

The total irrigable land area within the SWIA is about 30,000 ha and 9,780 ha are currently (1998-9) irrigated. Five dams, built in the Darling Ranges to the east, supply the water by gravity to the SWIA. The Waroona, Samson and Drakesbrook dams in the north supply about 1,000 ha of irrigation land, the Logue Brook, Harvey and Stirling Dams in the centre supply 4,600 ha and the Wellington in the south supplies about 4,100 ha.

Climate

CLIMATE

The climate is Mediterranean with warm, dry summers and cool, wet winters with 977 mm annual average rainfall spread mainly from May to August.

January mean daily temperature is a maximum of 30.9°C and a minimum of 15.5°C. July mean daily temperature is a maximum of 16.7°C and a minimum of 8.0°C. Class A pan evaporation is 1,825 mm.

The largest climatic problem is the high level of winter rainfall, which causes waterlogging of the heavy soils.

Hydrogeology and soils

HYDROGEOLOGY AND SOILS

There are three main aquifers, the superficial Guildford Formation within 20 to 30m of the surface, the Leederville Formation that is up to 300 m thick and the Yarragadee Aquifer several hundred metres thick, below. The superficial formations consist of from 20 to 30 m of alluvial-estuarine clays to the east and limestone to the west. A thin strip of sand occurs as the Yoganup Formation on the eastern edge, against the Darling Fault. Groundwater salinity is generally highest towards the central and eastern edges of the SWIA. The Leederville Formation is the main saline aquifer at depth, and can be artesian in western areas, with a thin overlying section of fresh water to the east. Even though this aquifer can have artesian pressures, it has little impact on the surficial hydrology because of the 20 to 30 m of clay aquitard (K_{sat} from 0.1 to 1 mm/day) separating it from the surface (Hirschberg, 1986).

The SWIA is located on the Pinjarra Plain (McArthur & Bettenay 1960) which is an alluvial tract sloping very gently westwards. The elevation at the eastern margin is about 30 m AHD sloping down to about 15 m at the western edge. The surface of the plain is slightly undulating and consists of coalescing piedmonts and riverine deposits (Wells 1989). Deltas of riverine origin occur where the Samson and Drakes Brook, Harvey, Brunswick and Collie rivers enter the plain from the Darling Range.

The soils, mainly unconsolidated alluvial material of Quaternary age, are of three main types:

> duplex soils with shallow to deep sandy to loamy topsoils which are moderately well drained
> gradational soils with mottled yellow or greyish-brown clay loam topsoils and poor drainage
> uniform black and grey self-mulching cracking clays that are very poorly drained.

Occurring less, but of greater agronomic importance in their natural state, are coarse textured yellow-brown loamy sands associated with river alluvium, which are well drained.

Crops

CROPS

About 30% of the total irrigable area is currently irrigated.

Most of the area (9,500 ha) is surface or flood irrigated to produce pastures and fodder. Most of the area is perennial pasture for dairy (5,650 ha) and beef (2,475 ha). A small area of perennial pasture is seeded in autumn (locally called ‘early germination’, 975 ha) and various fodder crops (410 ha) make up the balance. Typical whole-farm gross margin returns from irrigation of dairy pastures (assuming one-third of the farm is irrigated) are from $50 to 100 per ML of water applied.

Vegetables total about 200 ha with the majority being furrow irrigated. A centre-pivot system irrigates 40 ha.

Wine and table grapes and citrus near Harvey are irrigated almost exclusively by trickle methods. The current estimated area of these crops is about 400 ha. Investment in wine grapes on the freer draining alluvial soils has been accompanied by installation of subsurface drainage (SSD), because of the impact of winter waterlogging.

The whole of the SWIA is serviced by surface drains, many of which were installed before the irrigation system to drain winter floods.

Tile drainage was installed in the Harvey district of the SWIA after 1914 when citrus was the first main crop. Most of these drains, the majority of which were installed in the alluvial soils, were lost when citrus orchards gave way to irrigated pasture.

In the late 1990s new SSD works were started as high value crops such as wine grapes were grown. These new systems have often intersected the old tile drains during construction.

SSD is currently being installed for about 300 ha of wine grapes near Harvey and for less than 20 ha of cereal variety and bulk seed grain cropping near Dardanup. Other commercial irrigators are trialling various areas of SSD for pasture and fodder production. SSD is a significant current activity, with over 500 ha of the SWIA being drained in recent years.

Agriculture Western Australia (AgWest) and South West Irrigation (SWI) are researching the physical and economic effects of SSD on a dairying enterprise on 16 ha at Benger.

Description of drainage problem

DESCRIPTION OF DRAINAGE PROBLEM

Poor drainage combined with soil salinity is the biggest agronomic problem within the whole of the SWIA. Heavy winter rains cause waterlogging of soils that reduces trafficability and plant growth between June and September.

The SWIA is close to the sea, (about 15 km from it) and the local weather patterns in both summer and winter have brought in sea salt over the millennia. Groundwaters are typically from 9 to 18 dS/m and within 1 to 5 m of the surface. Groundwater trends have been established by monitoring over the past 20 years and it appears that water levels are now stable, being affected mainly by climate and land use change.

Winter rainfall delivers about 200 kg of salt per hectare per year.

Salinity in water delivered to the Collie River Irrigation District has reached 2.0 dS/m (1200 mg/L TDS, 1998/9). Salinity of the Wellington Dam has increased gradually over the fifty years since it was built, as a result of clearing in its catchment. An active catchment restoration program is now underway.

The Collie River District comprises about 40% of both the irrigable area and water sales of the SWIA. In this district, there is a combination of waterlogging and salinity effects, with waterlogging causing the major part of the problem. The high salinity level in the irrigation water in this district restricts the range of species that can be grown. For example, the salinities are too high for most horticultural crops such as those that can be grown in areas supplied by the other dams. Some small areas of sweetcorn, melons and other vegetables, which have a higher salt tolerance, are grown in the district. The salinity of the applied irrigation water is not enough to substantially affect the yield of the main perennial species grown (kikuyu, white clover and ryegrass). Rather it is the effect of high levels of soil salinity built up through evapoconcentration, together with waterlogging, which has the major effect.

Water from the other four dams supplying the SWIA averages about 0.25 dS/m and does not cause a salinity problem.

Monitoring of shallow (1 to 2 m screen interval) groundwater levels show that they typically rise to the surface during winter, and fall to about 1 m during summer. A typical hydrograph is shown in Figure 29. Waterlogging problems resulting from irrigation are due to both perched watertables that develop during winter and irrigation, and shallow groundwater levels.

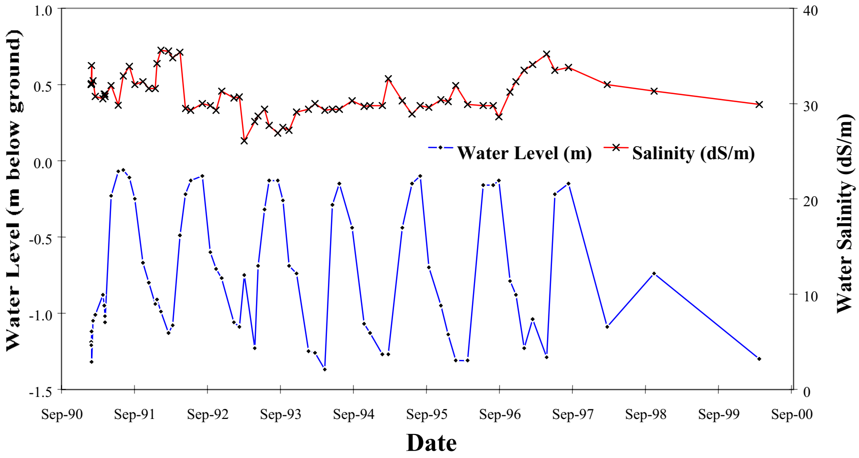
Salinity mapping techniques using GPS, EM38 and EM31 mounted on a quad bike have been developed in recent years (Bennett and George, 2000). This mapping has been undertaken at the farm scale on over 20 farms to date, with a proposal to complete most of the irrigation area over a number of years.

There are 284 km of earthen channels in the SWIA, which inevitably leak some water, but the heavy nature of the soil suggests that the effects of this are not large. SWI has put major effort into delivery automation, which reduces the frequency of wetting and drying of channels, thereby reducing seepage. SWI also contributes to a national study on channel seepage.

There are 148 km of concrete lined channels, which are built with weep holes to reduce groundwater pressure derived from waterlogged conditions, especially on supply channels that run along the base of the scarp. Weep holes leak in summer and in one area the volume was measured at 2 ML per day.

Figure 29.

FIGURE 29. GROUNDWATER LEVELS AND SALINITIES FROM A SHALLOW (2 M DEEP) BORE IN THE SWIA AT WATERLOO



Drainage method used

DRAINAGE METHOD USED

Surface drains service all of the SWIA. These drains were installed before the irrigation area was developed after 1914. They drain westwards to estuaries and the sea using either purpose built drains or existing river systems. They mainly function during winter with relatively little flow during summer.

Subsurface drainage systems currently in use in the SWIA are horizontal subsurface slotted pipe drains built using trenching machines. Composite systems with pipe mains and mole drain laterals are used beneath pastures. These are built to outfall into the surface drainage network.

Current gravity drainage systems are installed with laser-controlled trench diggers, which lay corrugated, slotted continuous plastic pipe. This sometimes has an external sleeve to stop problems with fine soil particles. The grade is commonly less than 0.2%. Surface slopes are similar.

It is common for a layer of gravel or other coarse material of about 15 mm average size to be laid around the top and sides of the pipe to within 30 cm of the soil surface. Mole drains, which are installed later, intersect and drain into this permeable material. The trench is then backfilled with topsoil.

The size of the lateral pipes is usually from 80 to 100 mm with the main collectors up to 150 mm. Lateral drain spacing is from 40 to 60 m and installation depth is commonly from 1 to 1.2 m. It has been found that it is important to place a lateral pipe close to the end of the irrigation bay to more effectively drain water at the bottom of the paddock and facilitate mole drainage installation.

Mole drains intersect the permeable fill above the plastic pipe at right angles and are installed at 2 to 3 m intervals and from 400 to 500 mm depths. Mole and SSD design and installation techniques for the SWIA can be found in Bennett *et al.,* (1999).

There has been a large gap in applying drainage technology with well-known and effective techniques being used in the early part of the 1900s and being rediscovered in the late 1990s. Thus there is a quantum leap from traditional hand dug clay tile drains to laser-controlled continuous plastic pipe installation techniques.

Drainage design

DRAINAGE DESIGN

Tools

The major purpose of SSD is to reduce both winter and summer salinity and waterlogging. Reducing salinity is especially important in the Collie River District, to leach salinity from the soil surface horizons during winter to create better year-round plant growing conditions. EM38/31 surveys are being used to target paddocks and parts of paddocks in most need of drainage.

Target watertable depth varies with season and soil type. In winter it is from 0.3 to 0.5 m on all soils. In summer watertables often recess to 1 to 2 m between irrigations and it is sometimes necessary to restrict the flow of drainage pipes to stop both the soil draining and irrigation water being lost too quickly. The rapid loss of irrigation water via crack flow, before it has time to fully infiltrate the heavy soil peds, can be a problem unless restrictors are installed at the pipe outflows. This mainly applies to surface irrigated situations where the intention is to stop applied water draining below the rootzone of the plants too rapidly.

Drainage in winter is targeted at achieving maximum water loss. Subsurface drains have achieved discharge rates of up to 20 mm/day. The drainage system design is based on the capacity of the drains to remove from 10 to 20 mm/day. This rate is required to manage water during the 700 mm of rainfall that falls during winter and spring. Collector pipe drain spacings are commonly from 40 to 50 m when used in conjunction with mole drainage. This is because 50 to 60 m is thought to be the maximum practical stable length of a mole drain.

Site investigations

Previous research at the field scale showed that drains from 2 to 3 m deep on heavy soils did not effectively reduce waterlogging and salinity in the medium term. Later, work at Wokalup on medium textures soil showed that spacings of 16 to 32 m and depths from 0.9 to 1.2 m with moles of 65 mm diameter worked very well.

Drains installed too deeply did not intercept macro-pore flow near the surface and were often installed in permanently plastic clays. Early drains did not include moles or have the same thickness of permeable fill. Shallower drains used in conjunction with mole drainage were shown to be more effective (mm/day) and less expensive. The shallow systems now used are designed to intercept and remove perched groundwater rapidly rather than create the traditional "cone of depression" between drains.

Deficiencies of current designs are related to a greater degree of certainty over the lateral and vertical intensity of drains in relation to soil types. It may also be that a further subtlety is introduced for different crops. For example, the needs of low-chill fruit trees when compared to pastures or vines.

Pipe size and the need for a protective envelope are based on best bets from past and external experience. Pipe spacing is currently governed by likely mole drain stability, which uses 50 m maximum length as a rule-of-thumb. A repeatable laboratory soil stability test is required to enable mole stability and hence maximum length and therefore collector-drain intervals to be more accurately assessed.

Drainage water quality

DRAINAGE WATER QUALITY

In the SWI area, drainage water flows occur mainly during winter. There is much less flow in summer from irrigated areas. Conversely it is likely, although not yet shown in other than a broad way, that the concentration of nutrients in flows is greater in summer than in winter. The significance of this, in terms of total loads, is being studied.

A current study (Norton's Study, Table 30) is profiling the drainage water flows and nutrient loads over the seasons during a three-year-period from 8 ha of SSD and 8 ha of non-drained dairy pasture. Preliminary results from this research have shown that in the first two- month period of winter after SSD installation there is an increase in nutrients (N and P) in the drainage water. This is believed to be due to the soil disturbance from installation, the soil disturbance during cultivation for reseeding the pasture and the large nutrient inputs into an intensive maize crop in the preceding summer.

Thereafter, there is a large reduction in nutrients in SSD water compared to undrained areas. For example, at Norton's during summer there have been about a third of the N and an eighth of the P loads in the SSD water compared to the surface water flowing from the undrained area. It is believed that a large proportion of nutrients on undrained areas move by overland flow whereas on drained areas they move through the soil profile and are taken up by plant roots or the soil before they can reach the drains.

Surface loads can be significant even with best practices, such as delaying application until spring when runoff is minimised, leaving buffer strips at the tail drains unfertilised and leaving the maximum lag time between fertilising and irrigation (Anon, 1998).

Initial production measurements show that SSD has increased perennial pasture production (and therefore plant nutrient use) by over 50%. This increase has been because of reduced waterlogging and removal of soil salts during winter (Table 30).

Table 30.

TABLE 30. COMPARISON OF FLOW AND SALT LOAD FROM DRAINED AND UNDRAINED PADDOCKS AT NORTON'S DURING WINTER 1999 (1,000 MM RAINFALL).

	Water flow (mm)	Salt load (t/ha)
Undrained surface	388	6.3
Drained surface	43	0.2
Drained subsurface	508	11
Total drained	551	11.2

There is probably little in the way of herbicides or pesticides in drainage water because of the current low level of horticulture and cropping in the SWIA, and the heavy textured clay soils.

Reuse

REUSE

Very few SWIA irrigators recycle their tailwater therefore there is some potential for the quality (salinity and nutrients) of the drainage water to deteriorate as it drains from the irrigation area. The main solution lies in irrigators adopting better irrigation practices so that the volume of runoff is reduced, particularly in relation to timing of fertiliser application. Automation of flood irrigation bays is a way of reducing the amount of tailwater leaving the bay. AgWest and SWI are actively encouraging this practice.

Dairy producers currently have to obtain Quality Assurance accreditation to supply milk. A significant part of QA requires all dairy effluent to be contained on-farm so that it is not allowed to run into the water supply/drainage system.

SWI and AgWest are also undertaking a program of drainage water quality monitoring to profile the flows and loads of nutrients entering and leaving the SWIA.

Disposal

DISPOSAL

SWI is fortunate in that drainage water runs from the SWIA into the sea via estuaries and inlets within a 15 km distance. The rivers are also largely only winter active, with longer flows now supported by dams constructed upstream. It is also fortunate that heavy winter rains correspond to the time of maximum leaching of salinity from SSD areas so that maximum dilution of winter runoff water occurs. Salinity loads from SSD, while larger during the years following installation, are likely to reduce to below loads generated from the current surface drainage as the salt load in the zone of drainage is depleted.

It has been stated anecdotally that there is a significant positive relationship between inflow of drainage water from the drains and rivers and prawn growth in the estuaries.

While disposal of nutrients is relatively less sensitive than in the eastern states, large engineering schemes such as the 1995 $50 Million Dawesville Cut and 1955 Bunbury Cut have been required to prevent excessive nutrient loading and eutrophication. In both cases, however, nutrient losses from sandy, non-flood-irrigated soils were implicated. Irrigated soils in the SWIA are mainly heavy loams and clays.

Deficiencies

DEFICIENCIES

The management of the surface drainage system is inadequate according to irrigators. In simple terms, while the irrigation supply system is managed by SWI, Water Corporation manages the drainage system under a loosely defined licence.

Irrigators believe that there is not enough capacity in the surface drainage system to remove water efficiently from farmlands during winter. The deficiency is exacerbated by a lack of depth and grade for subsurface drainage outfall in many cases.

There is increasing activity in installing SSD but there is a real need for integrating of this into the total drainage system instead of an individual, piecemeal approach. One of the expected benefits now being observed at the Norton experiment is the reduction in peak flow from drained paddocks. This reduction may reduce the requirement for increasing the capacity of the drains, but only if subsurface drainage is widely adopted.

SWI and the Water Corporation continue to liaise regarding improvements in the drainage flows but real solutions seem to be some way off.

Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

The Water Corporation manages the surface drainage system under a licence from Office of Water Regulation.

The drainage licence does not address any issues such as water quality or optimal watertable depth. There are no formal rules and the only guideline of any significance is that water should not stand on farmland for more than 72 hours after rainfall.

There is a maintenance program but its application is largely *ad hoc* and reactive to complaint by landholders. It does not seem to have a significant component of preventative maintenance with regard to water flow in drains in the SWIA. Monitoring and performance management are done by the Office of Water Regulation, which issues the licence. The licence has not yet been audited as far as SWI or AGWest is aware.

In terms of SSD, if the stated aim is to manage waterlogging there is no licence requirement or other control or approval. This may change in the future.

Drainage funding

DRAINAGE FUNDING

The Western Australian Government provides funding for drainage under a Community Service Obligation (CSO) payment to the Water Corporation. The annual payment is about $7 million for the whole of the southwest. It is not known how much is attributed to the SWIA as a separate area, which is about one-quarter of the total drained area to which CSO funding applies.

There are no drainage rates, subsidies or loans. There is no role by the shire councils in anything other than road drainage.

The total drainage operations and maintenance budget for the whole of the South West is less than $1 million. The Water Corporation funds it out of the CSO payment from government. It is not known what allocation is made to the SWIA as a separate area. In the event of special or urgent needs, separate funding is available.

SSD is totally funded by individual irrigators within their normal business operations.

The average cost is about $1,500/ha depending on the amount of survey and off-site drainage work needed.

Current issues and trends

CURRENT ISSUES AND TRENDS

SSD is being rapidly taken up by early adopters. For others, the cost-benefit of the technology needs to be established. There is also the issue of having enough capital and access to contractors.

Dairy deregulation is forcing irrigators to look at producing more efficiently and alternative production options other than pasture. Almost all of these will require better-drained soils than currently exist. Up until now, salt and waterlogging-tolerant pastures have sustained the dairy industry. This is now changing as external pressure on farmgate prices forces a rethink on the use of irrigation water. Some dairy farmers will make no further investment and continue to hold on to the *status quo* for as long as possible or until they retire.

It has been shown that the salinity effects in the Collie River Irrigation District have been caused by clearing in the catchment of the Wellington Dam, which in turn has affected the quality of irrigation water. If a portion of the funds being spent on restoration of the catchment were spent on SSD in the Collie River District, plant growth conditions would improve rapidly at a fraction of the cost and time.

It will be necessary to integrate all drainage in the SWIA into a single managed entity to ensure drainage efficiency. SWI is able to provide this service through its Geographic Information System.

No significant drainage issues affecting the environment have arisen in recent times. AGWEST and SWI are providing R&D and management resources to understand drainage flows and to stop possible problems.

SWI believes that instead of reuse, irrigators will move towards minimising runoff in summer. Winter disposal of rainfall runoff and SSD will continue to be into the ocean, via coastal estuaries, inlets, rivers and drains.

Research requirements

RESEARCH REQUIREMENTS

At present we have largely best-bet parameters for the spatial intensity and dimensions of SSD structures. It will be necessary to expand this knowledge to understand the relationships with soil types and possibly crop types.

Root penetration and blockage have not been issues to date. Should these problems arise in the future, prevention methods using plastic pipe will become important. This is only likely to be of significance where perennial trees and vines are planted. Blockage of pipe slots with iron precipitate is another potential problem and requires research on longevity and de-scaling methods.

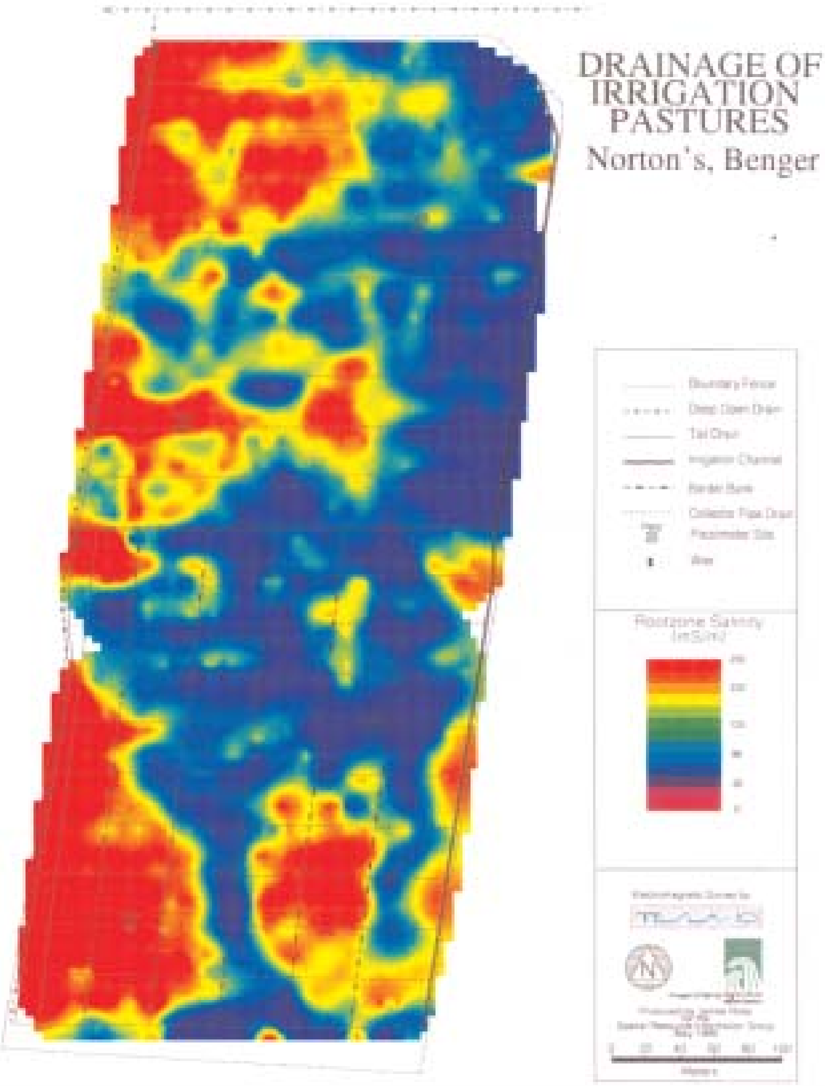
Constraints to drainage include the perception that the capital cost of installation is too high. Early economic analyses show SSD to be a worthwhile investment. Through additional data and economic analysis of production from drained and undrained areas, additional SSD will result.

Some sectors of the community have the perception that draining saline areas is against the interests of the environment because the salt and nutrients are transported downstream to another area or sink and along rivers and streams with detrimental effects. Research is required to look at SSD at the next scale up and on its impacts in rivers, on flood risk and specific 'in-paddock' design issues.

The National Program for Irrigation Research and Development (NPIRD) and related funding instruments should continue to view the stage of development of each of the regions separately, supporting staged research and development on an as-needed, when-needed basis.

Figure 30.

FIGURE 30. SUBSURFACE DRAINAGE TRIAL LAYOUT AT NORTON'S, BENGER W.A.



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SUNRAYSIA IRRIGATION AREA

SUNRAYSIA IRRIGATION AREA

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Location and hydrogeology

LOCATION AND HYDROGEOLOGY

The Sunraysia Region extends along the River Murray from Robinvale to Merbein. The major irrigation development is at Mildura, which lies at longitude 143° and latitude 34° South. However, the drainage problems and practices described in this report apply to the pumped irrigation districts in the Swan Hill District (Nyah, Tresco and Woorinen). The report may be relevant to new irrigation developments in the Mallee Region, from Boort in the south to the South Australian border in the north-west.

The climate in the Sunraysia area is semiarid and mean monthly temperatures range from a maximum of 23.9°C to a minimum of 9.4°C. Daily temperatures range from an average maximum of 32.7°C and minimum of 16.4°C in January and a maximum of 15.4°C and minimum of 4.4°C in July. Class A pan evaporation ranges from 1,500 mm for sites within irrigated areas to 2,300 mm for flat open dryland sites. While the annual rainfall of 270 mm is adequate to support dryland cropping, irrigation is required to support intensive horticulture.

The geology of the district is dominated by relict aeolian landforms. A thin aeolian cover from 2 to 10 m thick, overlays fluvio-lacustrine and marine deposits. There are also small areas of river flat adjacent to the River Murray. The aeolian landforms are either east to west longitudinal dunes formed from reworked fluvio-lacustrine deposits or parabolic and jumble dune systems formed from reworked beach sands.

The soils range from deep sands at the top of a dune ridge through sandy loam soils overlying calcareous clay subsoils in the midslope to shallow clay loam and light-medium clay soils in the swales between dunes.

Land use

LAND USE

Irrigation began in 1894 when 20,000 ha were set aside for irrigation development. Since this time a number of small irrigation settlements, from 2,000 to 6,000 ha in area, have been developed. The major development occurred in the periods following the first and second world wars as settlement schemes for soldiers returning from overseas.

Today irrigated horticultural crops cover some 31,000 ha with the major developments (26,000 ha) being on the south or Victorian side of the River Murray. The major crop is grapes (23,000 ha) followed by citrus (7,000 ha) with vegetables and other tree crops making up the balance.

The River Murray is from 20 to 30 m below the general elevation of the district. The water salinity ranges from 0.3 to 0.6 dS/m, with high salinity occurring in the downstream sections of the district during periods of low flow in the River Murray. The irrigation allocation varies from 6 to 14 ML/ha depending on the crop grown. Within irrigation settlements from 70 to 90% of the land area is planted to horticultural crops.

Nature of problems and adopted solutions

NATURE OF PROBLEMS AND ADOPTED SOLUTIONS

Furrow irrigation is still used by about 50% of irrigators in the older 'soldier settlement' Irrigation Areas (Merbein, FMIT - Mildura, Red Cliffs and Robinvale). However, conversion to sprinkler and micro irrigation-systems is occurring at a steady rate. New irrigation developments are almost exclusively irrigated with sprinkler and micro-irrigation systems.

Under furrow and sprinkler irrigation, a perched watertable is formed over the calcareous clay subsoil. The watertable generally fluctuates between the soil surface and a depth of 2 m as the result of irrigation and rainfall. In addition, hillside seepage problems occur where the deep sand of the dune crest gives way to the shallower soil further down slope. The perched groundwater has an electrolyte concentration of from 2 to 4 dS/m and a boron content of ~2 mg/L. Shallow fluctuating watertables led to waterlogging and salination in the original irrigation settlement at Mildura.

The later irrigation settlements learned from this experience and drainage is regarded as essential in maintaining productivity under current irrigation systems. Initially tile drainage systems were installed and groundwater disposed into 30 m shafts that penetrated a regional aquifer system. However, these shafts were both costly and ineffective for draining large areas. Government collector drains were installed and excess tile drainage effluent disposed to evaporation basins. Tile drainage effluent is either reused or disposed back to the River Murray.

The quantity and point of disposal for the region is shown in Table 31. The amount of drainage has declined in recent years, (see Page 167, Drainage Rates). Farms in the Nangiloc-Colignan area dispose to inland basins and, to a small extent, the river.

Table 31.

TABLE 31. QUANTITY AND POINT OF DISPOSAL FOR THE REGION BEFORE 1993

Source of drainage water	**River** ML/year	Evaporation basin ML/year	Bore (shaft) ML/year	Flood plain ML/year
Merbein	2,250	3,900	860	
FMIT	2,300	7,500		
Red Cliffs	2,180	4,860		
Robinvale	4,760	970		
Lake Hawthorn	2,760			
Total	14,250	16,260	860	970

Description of drainage methods used

DESCRIPTION OF DRAINAGE METHODS USED

While the exact area of subsurface drainage is not known, it is estimated that 80% of the older irrigation districts and 40% of the more recent developments are drained. This amounts to about 20,000 ha or about two-thirds of the area in the irrigation settlements. Tile drains are installed at the depth and spacing recommended in the soil survey bulletins. These recommendations are based on research by Lyon and Tisdall (Lyon A.V., and Tisdall A.L., CSIRO Bulletin No.149). Drain spacings range from 13 m at 1.2 m depth for the heavier soils to 26 m at 1.8 m depth for the lighter soils. Where soil survey data is not available drain spacing is determined on the basis of a design drainage rate of 5 mm/day, with a watertable notionally at 0.3 m depth.

In recent irrigation developments, sprinkler is the presumed irrigation system and this has allowed drainage practices to be modified. Interception drains are used to control hillside seepage. Grid drainage, usually at a fixed interval of 13.7 m, is used in the clay and clay loam soil types found in the swales between dunes. It is common practice to install a main drainage system before irrigation development begins, and install drain laterals as and when drainage problems develop. This practice avoids disrupting the trellis and pressurised irrigation systems.

The River Murray upstream from Mildura has an electrolyte concentration generally lower than 0.4 dS/m. Under these conditions well-managed micro-irrigation systems have been used without drainage problems developing and recourse to artificial drainage. Presumably the small leaching requirement is adequately balanced by natural drainage to the regional aquifer system.

Drainage interception Sunraysia Region

In addition to the problems associated with the perched watertable, groundwater mounds have developed in the regional aquifers underlying the irrigation areas. The groundwater within the regional aquifer systems generally has an electrolyte concentration of up to 50 dS/m so that groundwater discharge is a potential threat to the viability of the irrigation districts. However, with the exception of one or two areas of limited extent, groundwater discharge has not had a significant effect on crop production in the irrigation areas.

However, seepage of saline groundwater to the River Murray increases the salinity of water for users downstream and lowlying dryland has become saline in some areas. Interceptor drainage has been installed in several areas to prevent return flow of saline groundwater to the river system. These schemes are described briefly below.

Psyche Bend Lagoon Diversion Scheme

Psyche Bend Lagoon is a natural billabong that collected saline groundwater discharge. It is located on the Murray River floodplain near Mildura. Historically the lagoon received irrigation drainage water, which then displaced hyper-saline groundwater from the lagoon to the Murray River.

The Psyche Bend Lagoon Diversion Scheme was established in February 1996 to stop salt being displaced from the lagoon because of irrigation outfalls and to allow for regulated flushing of the lagoon for environmental purposes.

The scheme's drainage diversion works direct drainage flows away from the lagoon, and allow for more controlled flushing of the lagoon at appropriate times of high river flow.

Hawthorn Drainage Diversion Scheme

The Lake Hawthorn Drainage Diversion Scheme involves collecting drainage water from irrigated land in the Mildura-Merbein area of Northern Victoria to stop saline drainage water entering the River Murray, particularly when river flow is low. Water in the lake is either pumped inland to the Wargan Basins for evaporative disposal or is deliberately released to the River Murray during periods of high river flow. The lake also receives stormwater runoff from the township of Mildura and groundwater inflows.

Buronga and Mildura-Merbein Groundwater Interception Scheme

The Buronga and Mildura-Merbein Groundwater Interception Schemes are designed to intercept highly saline groundwater entering the River Murray during periods of regulated river flow. The Mildura-Merbein scheme operates along a 15 km reach on the Victorian side of the river between the townships of Mildura and Merbein, while the Buronga scheme operates along a 3.5 km reach on the New South Wales side of the river from Mildura to Mourquong.

Groundwater from the Mildura-Merbein scheme is initially pumped to the evaporation basins Lake Ranfurly East and West before being transferred further inland to the Wargan Basins. Groundwater from the Buronga scheme is pumped to Gypsum (Morquong) Swamp.

Lamberts Swamp

The scheme stops highly saline groundwater that discharges to Lamberts Swamp (Merbein West) from being pumped to the Murray River. Enhancing the scheme could also divert drainage water from the Merbein West and North West drains and Yelta Drainage away from the Murray River.

Drainage design and investigation

DRAINAGE DESIGN AND INVESTIGATION

Drainage design

Drainage is installed as required in areas with existing main drainage systems, i.e. the older ‘soldier settlement’ irrigation areas (Merbein, FMIT - Mildura, Red Cliffs and Robinvale). Lateral drains are designed to run down the centre of planted rows. This means drain spacing options are constrained by row spacings typically 3.4 m (11 foot) for grape vines and 6.8 m (22 foot) for citrus. Therefore drain spacing is typically 13.6 m, 20.4 m or 27.2 m (every 4, 6 or 8 rows). There is still a preference for installing tile drains, although plastic pipe has become more popular in recent years.

The recommended grade of tile drains is shown in Table 41.

Table 32.

TABLE 32. MINIMUM GRADES RECOMMENDED FOR TILE DRAINS AND PLASTIC PIPES

Type of pipe	Diameter	Grade
Tile pipe	76 mm	0.32/100
	102 mm	0.25/100
	127 mm	0.18/100
	152 mm	0.12/100
Plastic pipe	38—59 mm ID	0.32/100
	59—73 mm ID	0.25/100

For new irrigation developments it is common practice to install main drains before plantings are established. This is because main drains are often across plantings, and by installing these drains first there is less cost and disturbance associated with the irrigation reticulation system. Main drains are installed at a grade of 0.25/100 along the lowest elevation of the swale in the dune/swale topography. Location of power will often determine the downstream end of the main drainage system. The drain discharges into a concrete inspection pit typically from 2 to 4 m in diameter. Relift pumps with automatic float controls discharge groundwater to an evaporation basin or reuse facility, or regional collector system.

In new developments installing drain laterals is deferred until required – often 10 to 20 years after the initial plantings. Incidence of waterlogging is indicated by plant vigour and by using shallow observation wells to detect the presence of perched watertables. Dune areas irrigated with modern irrigation methods (sprinkler and micro-irrigation) rarely require drainage. However, it is common to see hillside seepage problems at the break of slope, or at the transition from the sandy loam soil type of the dune to the clay soil type of the swale. Interceptor drainage is installed upslope from the seepage problem to address the problem. Drain spacing in swale areas is typically 13.6 m.

Drainage criteria

Tile drainage is required to control waterlogging associated with perched watertables. Drainage criteria were originally developed based on the traditional irrigation method of furrow irrigation. Using furrow irrigation, it was not uncommon to see a perched watertable within 20 cm of the surface after irrigation. The minimum watertable depths required for adequate plant growth are shown in Table 33.

Table 33.

TABLE 33. DRAINAGE CRITERIA MINIMUM WATERTABLE DEPTHS IN MALLEE SOIL TYPES

Crop	Soil type	Target watertable depth (m) after irrigation		
		1 week	2 week	3 week
Grapevines	Deep sand/sandy loam	0.9	1.2	1.4
Stone fruit	Loams & clay loams	0.8	1.0	1.1
Citrus	Deep sand/sandy loam	1.1	1.3	1.5

These existing specifications stem from comprehensive work by CSIRO at Merbein. Recommendations were based on first principle soil physics and testing within the districts. Therefore, legacies of satisfactory rule of thumb specifications that cater for furrow irrigation are available.

The recent communal drainage system installed in Nangiloc/Colignan has reduced capacity compared with the older districts. The capacity was based on monitoring drainage from the mainly overhead sprinkler irrigation in the district. Recent new irrigation development in the district has expanded the area to beyond the capability of the new system. This highlights the fact that district drainage capacity involves more than engineering considerations.

Modern pressurised irrigation systems, particularly those part coverage systems such as drip that provide buffering strips of dry soil to absorb rainfall, should require less drainage capacity. In these conditions the waterlogging hazard from occasional heavy storms is more important. The problem now requires incorporating rainfall risk assessment in the solution. There are no specific recommendations for Sunraysia. Recommendations to complement best practice recommendations for micro-irrigation design and management are needed. It is not known how much fieldwork is necessary or if it can be done from modifying existing knowledge to derive new drainage specifications.

Drainage water quality, quantity and disposal

DRAINAGE WATER QUALITY, QUANTITY AND DISPOSAL

Tile drainage effluent water is usually from areas with a perched watertable problem, and is therefore generally low in salinity (from 2 to 5 dS/m). The more saline regional groundwater is usually very deep (from 5 to 15 m) depending on the topography and groundwater mound associated with the irrigated area. There are isolated areas in Merbein and in Nangiloc-Colignan where the regional watertable is close to the surface. In these areas groundwater salinity is much higher, typically from 20 to 50 dS/m.

Drainage salinities from Red Cliffs drains fluctuate about a mean of 1.6 dS/m. Monitoring of main drains from nearby districts shows higher ECs but these results are probably as a result of groundwater contamination as there is no reason to believe that irrigation management differs markedly between districts. Using a rough figure of 0.35 dS/m for river salinity and assuming the bulk of the drainage EC is NaCl, one can derive a crude drainage fraction of 22%.

The clay subsoils are calcareous in the swale and midslope areas and contain high quantities of boron. The high boron concentration and the presence of nematodes in the drainage water, constrains reuse options for drainage water. However, a trial currently being conducted by Sunraysia Rural Water Authority is investigating the potential for reusing drainage water on grapevines. While drainage disposal is generally to evaporation basins, there is increasing use of reuse on to tree-lots and salt-tolerant species as an alternative to evaporative disposal, which is discussed on page 170 in Drainage reuse.

Ratio of Na, Ca and Mg

Drainage water in Sunraysia is mostly assumed to be simply concentrated river water and so the salinity is due overwhelmingly to NaCl. (The Darling River has significantly higher concentrations of CaCl than the Murray but the confluence of these rivers is downstream of the main irrigation settlements.) This assumption is possibly an oversimplification as indications are that although the bulk of the EC is due to NaCl, at specific sites fluctuations can be due to fertiliser or gypsum applications. Furthermore, even after a century of irrigation and subsurface drainage, boron from underlying Blanchetown clay can contaminate drainage water and cause toxic symptoms in crops when drainage water is reused.

There is little information on drainage water composition. There is information on native groundwater composition as a result of problems with interception wells in Sunraysia that suffered from ferric precipitates.

Drainage rates

Under furrow irrigation from 15 to 20% of the applied water is typically intercepted by the tile drainage systems. Under sprinkler irrigation the drainage is from 10 to 20% of the applied water. There is insufficient experience with micro-irrigation (drip and micro-jet) to be confident about the quantity of drainage. Tile drains do not necessarily intercept all the water percolating past the rootzone. There is clearly a component of natural drainage past the tile drain systems. This results in a substantial mound in the regional groundwater system. While the regional groundwater level is usually well below the surface, there is groundwater discharge to the river, and salination in low-lying areas where the regional groundwater level is within 1.5 m of the surface. There is growing evidence that improved irrigation practices are reducing drainage rates and the accession to groundwater.

Drains monitored from 1983 to 1996 show constant mean EC values with no encouraging increase in concentration that would indicate more precise scheduling. The inference is that irrigators are responding to the Irrigation Management Plan by using less irrigation but are not applying it any more accurately. As a result, salt drainage loads are decreasing with drainage volume and there is an unexpected benefit to the river.

The following notes were taken from a workshop in Mildura.

Sunraysia Irrigation Region

Drainage rates for the four representative monitoring sites during the 1998/99 monitoring period are:

Merbein West Drain (414701) = 1.1 ML/ha/yr
FMIT North East Drain (414702) = 1.0 ML/ha/yr
Red Cliffs Drain No. 1 (414703) = 1.5 ML/ha/yr
Robinvale Drain No. 6 (414717) = 1.1 ML/ha/yr

These drainage rates are much lower than the long-term average, which has generally been the case since 1994-95. The 1998-99 flow rates for the representative drains in the Mildura area (Merbein 414701, Mildura 414702 and Red Cliffs 414703) were from 21 to 50% lower than the long-term average. Drainage flows for the Red Cliffs and Robinvale irrigation regions both increased by 21% and 14% respectively on figures for 1997-98.

Drainage flows and salt loads

On a Sunraysia regional basis, irrigation season data over the period 1983-84 to 1998-99 indicate a small downward trend continuing to occur for both drainage flow and salt load. These reductions are encouraging. However, to provide firm evidence for such a trend, a more detailed statistical analysis and the use of the Generalised Additive Model (GAM) method of assessment was undertaken in the 1999-2000 financial year.

The 1998-99 and long-term drainage volumes calculated for all the currently monitored drains in the Sunraysia Irrigation Region and salt loads are shown in figures 31 and 32. The salt load has been reduced in all districts for the 1998-99 financial year with respect to the long-term average.

Figure 31.

FIGURE 31. SUNRAYSIA IRRIGATION REGION REPRESENTATIVE FLOW (1983-84 – 1998-99)

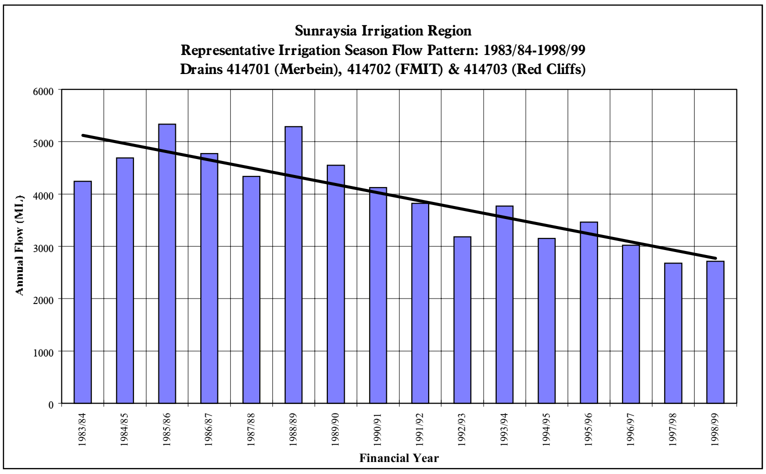
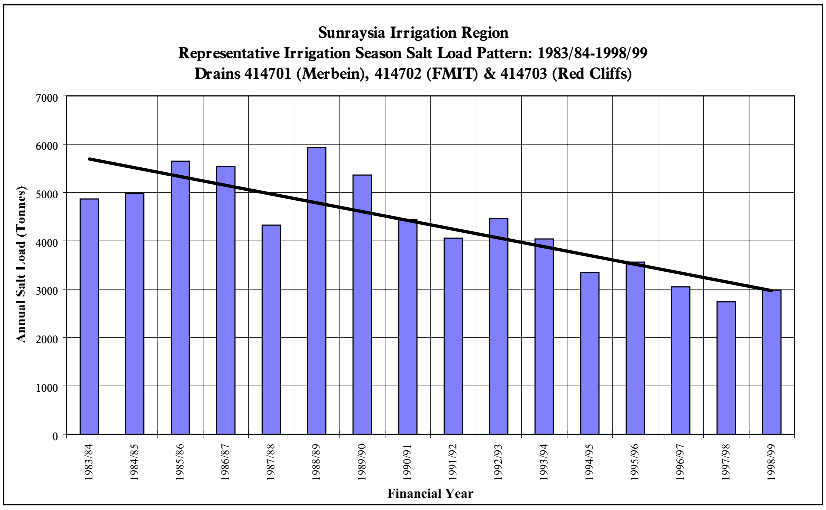


Figure 32.

FIGURE 32. SUNRAYSIA IRRIGATION REGION REPRESENTATIVE SEASON SALT LOADS (1983-84 – 1998-99)



Changes in groundwater quality over time

Before irrigation settlement, the closest aquifer to the surface was in the Parilla Sands and was typically from 10 to 20 m below the surface. This groundwater is as salty as seawater (50 dS/m). Shortly after irrigation started, the seepage past the crop rootzone created a perched watertable close to the surface. Typically it is less than 2 dS/m. This water has seeped further downwards and created a mound under each of the long established irrigation districts. Accordingly a cross section of a district would show groundwater salinities ranging from the low salinity of drainage water to the high salinities of the native groundwater.

It is not known how the salinities are distributed, but seepage into the floodplain and riverbed at Red Cliffs/Mildura/Merbein and at Nangiloc/Colignan is still highly saline. The irrigation mound has greatly increased the flow of highly saline groundwater into the river. At Robinvale the underlying groundwater is much less saline and the impact accordingly much less. The difference at this site is more probably the result of flushing of the aquifer by the river rather than flushing from irrigation drainage. One site where people have had a locally beneficial effect is at Kings Billabong. This is a pondage on the floodplain maintained above river height. Seepage has resulted in an underground plume of freshwater and the woodland between the billabong and the river is healthy, in marked contrast to the adjoining areas that are heavily salinised.

Disposal impacts on rivers

All irrigation drainage in communal irrigation districts is collected in a comprehensive reticulation of subsurface drains. The proportion that drains to the Murray River is via a few large drains that are monitored for flow and in most cases, for salinity also. As a result we have good figures for direct disposal salinity impacts (9.3 EC at Morgan for Sunraysia Salinity Subregion). The impacts from the indirect effects from mobilisation of native groundwater are hard to quantify, as the flows are diffuse. Impacts are inferred from piezometer readings. Although the quantity of extra groundwater expressed into the river by the mounds underlying the districts is far less than the volume of drainage water, the impacts are similar to the drainage as the groundwater is 30 times as concentrated.

Contaminants in drainage water

Nutrients and other pollutants in tile drainage effluent have been investigated as part of the development of Land and Water Management plans in Sunraysia (*Land Capability and Irrigation Infrastructure Assessment, Stage 2, Volume 3,* Regional Drainage Capacity Assessment, July1998). The contaminants affect the feasibility of reuse. Apart from problems associated with the salt (sodium chloride) content of the water, significant contaminants were reported as follows.

Boron

The average concentration of boron was 1.7 mg/L with values ranging from < 0.5 to 2.9 mg/L. Boron is toxic to many crop species. Further, it is strongly adsorbed to clay colloids used for irrigation, and is difficult to leach from the plant rootzone once present. While boron is toxic to most horticultural crops at quite low concentrations (0.5 to 1 mg/L), some crops, such as lucerne, tolerate it in moderate concentrations (2 to 4 mg/L).

Nematodes

Nematodes have been detected in tile drainage effluent. Reusing irrigation water has been implicated in the spread of nematodes throughout irrigation blocks in the district. Reuse of tile drainage water on horticultural crops is not recommended.

Nutrients

While nutrients do not affect the potential for reuse, they are considered a pollutant when disposed to the river. Concentrations in tile drainage effluent vary depending on irrigation and fertigation practices in the areas drained.

Analyses of subsurface drainage water from four district sites in 1995 are shown on page 176 in Table 36 as median annual values. Phosphorus is not a pollution problem from Sunraysia drainage as all irrigation drainage is subsurface drainage and phosphorus is stripped from the drainage water by the time it reaches the drains. The aeolian formed landscape is composed of humps and hollows with no drainage lines so that even after the occasional heavy falls of rain, there is virtually no runoff to the river from agricultural land.

Herbicides and pesticides

Residual herbicides are used on many irrigation properties as well as other pesticides. Tile drainage effluent from individual properties has in the past found significant concentrations of residual herbicides, however, concentrations at district outfall points are generally very low.

Nitrates

Nitrogen is considered the most important pollutant. The bulk of this is as NO_X. Nutrients are not analysed often enough to develop reliable load figures, and the best estimate is 100 t N per year from Sunraysia. This is possibly an overestimate as samples are taken where it is easy to sample, not at the point where the drainage enters the river. In many instances the drainage water passes through reeds either growing in the channel or in wetlands before finally spilling into the river.

Twice weekly monitoring at a site in Red Cliffs consistently showed a steady diminution in nitrate content at mean levels of about 40 ppm at the end of the drain pipe to levels at the limit of detection by Hoechst nitrate test strips (< 5 ppm), after the water had travelled through a reedy wetland before spilling into the river.

Wetlands

There is one designed wetland at Buronga for urban stormwater. Elsewhere drainage water fortuitously flows through wetlands, which strip the drainage water of nitrate. However, this beneficial effect conflicts with other environmental impacts. Drainage water that meanders across the floodplain exacerbates salinity effects. Naturally occurring wetlands should not be kept continuously waterlogged by drainage water.

Loads from the Red Cliffs site given above were estimated at a low 2 kg/NO_3/ha/year but at that time the dominant crop in the drainage catchment was sultana vines for dried fruit. These vineyards receive low rates (nil to 50 kg/N/ha). Higher loads can be expected as the proportion of more highly fertilised crops such as winegrapes and vegetables, increase.

A best bet solution in the absence of comprehensive data would be to lead the drainage across the flood plain by as direct a route as possible and incorporate narrow artificial wetlands to strip the nitrate from drainage water.

Probably the greatest threat from the current drainage is not the amount of Nitrogen, but the fact it is a constant drip feed of nutrient that ensures that nutrient is present when river conditions favour an algal bloom. Even if wetlands release nutrients at certain times they would be spasmodic events less likely to coincide with times of high bloom hazard.

Drainage reuse

Woodlots and lucerne have been successfully irrigated for drainage disposal on an individual property scale for many years. Small areas of salt-tolerant crops have been grown with drainage water for commercial gain in the region.

Salt-tolerant rootstocks are available for the main horticultural crops (vines and citrus) and experimental plantings have shown that these crops are productive and healthy when irrigated with drainage water.

Nevertheless, large-scale uptake of drainage water for disposal to woodlots or for production has not taken place.

Small woodlots have proportionally large perimeters to allow lateral dissipation of seepage water. Waterlogging is also likely to be a greater hazard for large woodlots.

Although salt-tolerant timber trees and crops on tolerant rootstocks can cope with drainage salinities, symptoms of soil salinisation and soil structure decline have been observed at test sites. Soil decline is likely to be a long-term problem.

Even without considering soil problems there is insufficient incentive to reuse drainage water on a large scale. A recent feasibility study compared the use of drainage water stored in Lake Hawthorn with using fresh water bought as transferable entitlement. The study showed that there was no significant advantage to prospective new irrigation developers from shandying the fresh water with cheap drainage water.

The reuse option with the most potential is to use plants as concentrators of drainage water. If the plants have subsurface drainage, the soil profile will reach salinity equilibrium quickly and the concentration can be kept within acceptable limits by an appropriate leaching fraction. The reduced drainage volumes from reuse can be contained in smaller basins or pumped further at lesser cost or both.

Knowledge gaps associated with reuse are:

> Long-term effects of drainage water on Mallee soil profiles.
> Prevalence and impacts of drainage pollutants such as nematodes and boron on irrigated crops and trees.
> Productivity and quality penalties from using drainage water on salt-tolerant vine and citrus crops.
> Practical systems for draining irrigated eucalyptus plantations.
> Reliable estimates of water use to be expected from eucalyptus plantations irrigated with saline water. Current water use figures are overestimates derived from monitoring of trees using fresh water or sewage effluent.
> Economic evaluations comparing use of drainage water and fresh water for irrigation to obtain comparative costs and returns that will establish how much more expensive fresh water has to become before drainage reuse becomes a realistic alternative.

Drainage disposal on new developments

No new irrigation developments can drain into the Murray River or floodplain. Until recently, Victoria did not make redirection of existing drains a priority but the unexpected scale of new development has made it a possible option to recover EC credits to comply with the MDBC Salinity and Drainage Strategy.

The community is divided on the acceptability of disposal options. There is concern that irrigated woodlots are not sustainable as final disposal options.

Provided that disposal basins are sited far enough from the river any leakage is carried westward with the aquifer flow (i.e. parallel to the river). Monitoring of the main disposal basins for Sunraysia at Wargan has not detected any mound developing under the basins. However, the availability of suitable basin sites is a limiting factor to irrigation development.

Drainage system management and monitoring

DRAINAGE SYSTEM MANAGEMENT AND MONITORING

In Sunraysia the Mallee Catchment Management Authority formulates and administers regulations associated with irrigation development and water management. It has the responsibility for policy regarding drainage disposal. If appropriate, it can expand its responsibilities for other aspects of drainage.

Drains that have been properly installed need little attention. Silt traps and inspection pits are installed at the downstream end of farm main drainage systems. Drainage systems that have been installed with inappropriate grade are prone to blockage with root growth. Drains are usually cleaned by machine to remove root growth.

Testwells installed directly over the drain trench give the best indication of where overpressure and blockage are occurring.

Many tile drainage systems are more than 50 years old. Often records of the location of drains have been lost. This creates difficulties when properties are redeveloped with different layouts. It is recommended properties develop a clear plan of the drainage system, and mark drain rows where drain laterals are. Past aerial photographs have been used to determine the location of drain laterals, since the lighter coloured calcareous subsoil from the drain trench shows up clearly in some aerial photographs.

Drainage funding

DRAINAGE FUNDING

Drainage costs

The following costs are based on 1.2 to 1.5 m deep drains, 13.5 m spacing and 20 m drain length (1992).

Table 34.

TABLE 34. DRAINAGE COSTS

Item	Cost/20 m - $
Trenching and laying	45
Pipes (100 mm diameter x 305 mm) @ $430 per thousand + 30% freight	42
Fibreglass wrap	4
Backfill and clean up	6
Total cost 97 Total cost + 15% contingency	112

Allowing seven drains 100 m long for one hectare and 60 m of main drain per hectare (@$8/m), the cost per hectare is $4,330 per hectare. If a drainage pump and inspection pit are required for each block, 10 ha in size, the overall cost would increase to $4,500 per hectare.

Drainage system – district tariffs

Most drainage systems discharge to district collector drains, which discharge to evaporation basins or reuse facilities or both. District drainage rates vary. Costs include operation maintenance and provision for renewal. There is a service fee (an annual cost paid for connecting to the system), an area charge (paid by all landholders in the district regardless of water use), and a water use fee paid on the basis of total irrigation water use. Typical costs are shown in Table 35.

Table 35.

TABLE 35. TYPICAL COSTS

Area	Service Fee	Area Fee $/ha	Water Use Fee $/ML
Woorinen	68.3	4.704	2.4859
Nyah	81.27	nil	5.6884
Tresco	nil	nil	6.428

For a 10 ha horticultural property using 6 ML/ha of water the annual cost is about $360/year.

While there are no specific costs available for the Sunraysia RWA or FMIT, private diverters are charged 50c/ML for drainage salinity costs indexed from 1994.

CURRENT ISSUES AND TRENDS

Trends in groundwater levels are described below. Trends in drainage rates were outlined on page 96 in Drainage water quality, quantity and disposal.

Trends in groundwater levels

Groundwater levels and salinities: Mildura Area

Observation of the groundwater levels during the 1998-99 monitoring period identified no significant changes in groundwater levels in the Mildura Region (including Red Cliffs and Merbein). In general, bores closest to the Murray River and east of Mildura show slightly declining trends in the past year.

Broad-based statistical analysis of short-term (5 year) and long-term (15 year) trends for the bore hydrograph records suggest that most groundwater levels in the Mildura Region have decreased in the short term. Only bore 7881 (Blanchetown Clay aquitard) has experienced a significant increasing trend (9.7 cm/yr) in the short term, 2 cm/yr above its long-term trend of 7.7 cm/yr.

Trend analysis of the bores monitoring the Parilla Sands Aquifer in the Mildura Region indicates that groundwater levels are either steady, or slightly declining. The short-term declining groundwater trends for these bores generally range between 0.4 cm/yr (7697) and 38 cm/yr (7283).

Groundwater salinity levels for the Parilla Sands Aquifer throughout the Mildura area have remained relatively steady throughout 1998-99 after a significant increase during 1997-98. Typically, salinities range from 29 to 62 dS/m within this aquifer unit. For the Alluvial and Woorinen Formation aquifers, groundwater salinities have remained steady, ranging between 2.2 and 9.6 dS/m.

Groundwater levels and salinities: Robinvale Area

There have been no significant changes in groundwater levels during the 1998-99 monitoring period in the Robinvale Area. In general, all bores except two (26262, 26236) show a slight upward trend in levels in the last year.

Bores monitoring the Parilla Sands aquifer in the Robinvale area have shown a decreasing trend over the short term ranging between 2 cm/yr (26210) and 22 cm/yr (26186). These bores, numbers 26186, 26234, 26222, 26249, 26225, 26236 and 26212, started to show a declining trend over the shorter term, while other bores already exhibited a declining trend over the longer term.

Two of the three bores monitoring the Blanchetown Clay (26274, 26206) indicate a decreasing trend of about 9 cm/yr, while the remaining bore, 26262, is steady over the shorter term. Previously the long-term trend for all these bores was increasing.

No groundwater salinity measurements were available for 1998-99. However, data from previous years indicates steady or slightly increasing trends for the Parilla Sands aquifer, with salinities in the range of 15 to 77 dS/m. Blanchetown Clay groundwater salinities south-east of Robinvale were steady with higher salinity bores ranging from 30 to 40 dS/m, and lower salinity bores ranging from 1.5 to 8.5 dS/m.

New irrigation developments

The Sunraysia Region has been recognised as an area for the development of new irrigation areas. Transfer of water from low value mixed farming enterprises to high value horticulture is envisaged, and considerable expansion of irrigated agriculture. New horticulture development of 7,000 ha is expected.

Hydrogeological investigations carried out in 1988 established a basis for the location of new intensive irrigated horticulture. High impact zones (HIZ) close to the irrigation river are identified, where irrigation development may result in an increase in river salinity. Development is encouraged further from the river, in low impact zones (LIZ), where irrigation is less likely to result in groundwater return flow to the river.

New developments must meet stringent environmental standards. However, the requirements for subsurface drainage are not well understood. The issue of drainage requirements for new development needs to be addressed as part of the environmental standard, and the Irrigation and Drainage Management Plan for a new development. Drainage water must be reused or disposed of within the irrigation development. While the criteria adopted in each region may be different depending on local soil and hydrologic constraints, a common technical base should underpin the aims.

Clearly there is a component of natural deep drainage to the deeper subsoil, regardless of the provision of tile drainage. Areas high in the topography (dunes) do have good internal drainage characteristics, and interceptor drainage at the break of slope may be all that is required.

However, many irrigation developers believe with efficient irrigation management, subsurface drainage may not be required. They argue irrigation is more controlled and uniform with micro-irrigation. Further, trickle irrigation systems wet only part of the soil surface. Dry soil in the centre of each row can absorb rainfall, without the need for subsurface drainage.

This is a major issue. The capital cost of subsurface drainage, and the requirement to set aside 10% of the area developed for future reuse and disposal of tile drainage effluent, are substantial costs in the development. Past practice for new irrigation development has been to install a main drainage system before development occurs, and invest in drain laterals when and as drainage problems arise. Experience shows that investment in drainage can be deferred for at least 10 years by using micro-irrigation and efficient irrigation practices. However, swale areas are likely to require subsurface drainage, if only to provide watertable control during wet winters.

Further research is required on drainage criteria for micro-irrigation and the technical basis for disposal of drainage effluent.

Land and Water Management Plan – SunRISE 21

Sunraysia

New and emerging issues that potentially affect implementing the plan and achieving its long-term objectives are:

> urban drainage and related salinity problems
    irrigation development issues
    SunRISE21 - Land and Water Capability Assessment
> High and Low Impact Zone (HIZ/LIZ) classification
> nutrient and water quality issues and management
> MDBC Cap on River Murray diversions and bulk water entitlements
> impact of other horticultural related pollutants (boron, pesticides, herbicides)
> subsurface drainage infrastructure (life expectancy)
> State, Federal and international classification of environmental areas (e.g., Ramsar)
> River Murray rehabilitation responsibilities.

Nangiloc-Colignan

Several new and emerging issues have been identified in the Nangiloc-Colignan District. These are:

> Increased pressure for further irrigation development in Nangiloc Colignan and hence the development of an approval process.
> Nutrients were identified in the Government response as necessary to assess which were not identified in the Draft Salinity Management Plan. Subsequent monitoring has revealed high nitrogen loads.
> Higher than expected salt loads from some drainage outfalls to the River Murray.

Nyah to the South Australian Border SMP

New and emerging issues, have been identified that potentially impact on implementing the plan and in achieving its long term objectives, are the:

> impact of interstate trade
> monitoring of licence condition compliance
> boundary with Goulburn-Murray Water
> need for an Environmental Impact Statement to be carried out for proposed "Greenfield's" developments
> usefulness of $0.50/ML levy for pasture irrigators
> requirements for permanent and temporary transfers, and temporary trade
> requirements for new channels across HIZ.

De-skilling

There have been no soil investigations to develop drainage recommendations since the post–WW II investigations at Merbein. Water authorities had provided a drainage design service but that has ceased. Most commercial irrigation design houses do not have drainage design expertise. For existing irrigation areas this is not a great problem since the existing infrastructure is long-lived and will cope for the foreseeable future.

For new irrigation areas, the issue is significant as a per hectare cost of drainage is as costly as the irrigation. There are no specifications that match drainage to micro-irrigation on Mallee soils.

Appendix

APPENDIX. - NUTRIENT CONCENTRATIONS AND LOADS

Concentrations

The median concentrations of NO_X, TKN, TN, FRP, TP and SS in 1998-99 are shown in Table 36 for each of the five drains. The ANZECC (1992) guidelines recommend that comparison of water quality criteria be carried out on the 50th percentile value (the median).

Table 36.

TABLE 36. MEDIAN NUTRIENT LEVELS – JULY 1998 TO JUNE 1999

Site	SS (mg/L)	NOx (mg/L)	TKN (mg/L)	TN (mg/L)	FRP (mg/L)	TP (mg/L)
FMIT (414702)	16	4.1	0.63	4.73 (86%)^1	0.007	0.037 (19%)^2
Merbein (414706)	13	3.3	0.89	4.33 (76%)^1	0.003	0.023 (13%)^2
Red Cliffs (414703)	2	9.0	0.50	9.45 (95%)^1	0.011	0.029 (37%)^2
Robinvale (414717)	4	11.0	0.58	11.60 (95%)^1	0.041	0.067 (61%)^2
Robinvale Drain	1 7	10.0	0.51	11.10 (90%)^1	0.052	0.110 (47%)^2

1. The figures in brackets are the ratio of the median concentration of NOx and the median concentration of TN.
2. The figures in brackets are the ratio of the median concentration of FRP and the median concentration of TP.

1998-99 Nutrient monitoring program

Water quality in the Merbein and FMIT drains is generally better than that of the Robinvale and Red Cliffs drains.

- > TP median concentrations are in the low range for all drains except Robinvale Drain 1, which is in the medium range.
- > FRP median concentrations are in the low range for Merbein and FMIT drains, the medium range for Red Cliffs and Robinvale (414717) drains, and the high range for Robinvale Drain1.
- > The ratio of FRP to TP is in the medium range for all drains except Robinvale Drain 1, which is in the medium range.
- > TN median concentrations are in the medium range for Merbein and FMIT drains, and the high range for Red Cliffs and both Robinvale drains.
- > NO_X median concentrations are in the high range for all drains.

Loads

Nutrient load data estimated for 1998-99 indicate that the irrigation drains in the Sunraysia area have a significant impact on the NO_X load in the Murray River during most of the year.

In contrast, the monthly TKN, FRP and TP loads make only a very small contribution to the load in the Murray River.

Comparison with 1997-98

Since the 1997-98 financial year, the Sunraysia Region nutrient loads as a percentage of Murray River at Colignan loads have generally remained the same. However, the actual monthly loads have predominantly increased from the previous year. In particular, the increase in NO_X loads from the Sunraysia Region is especially pronounced over summer.

Lake Hawthorn and Psyche Bend Lagoon samples were taken almost three months later in 1998-99 than they were in 1997-98. Nutrient levels in irrigation drainage waters change between various months of the year. This is as a result of fertiliser applications, crops and pasture types and water application rates. However, a comparison between nutrient concentrations has still been made for this report.

Nutrient levels in Psyche Bend Lagoon in 1998-99 have more than doubled compared with 1987-98, except for NO_X levels, which have halved. Lake Hawthorn nutrient levels have fluctuated, with major increases in levels observed in NO_X and FRP concentrations, which have doubled.

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