MIA LAND AND WATER MANAGEMENT PLAN

EVALUATION
OF
WATERTABLE CONTROL OPTIONS

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MIA LAND AND WATER MANAGEMENT PLAN

WATERTABLE CONTROL OPTIONS TO MITIGATE SALINITY TRENDS.

(GROUNDWATER PUMPING IN LARGE AREA FARMS)

CONTENTS

SUMMARY

The various components of the surface and sub-surface water balance have been put together to give an overview of the main factors which affect salinity. These factors are recharge and discharge to the shallow groundwater system, and volumes entering and leaving the surface drainage system. It is found that of the about 920 GL/year of diversions and 610 GL of rainfall onlarge area farms in the MIA about 105 GL becomes groundwater accessions. Of the latter all but about 30 GL returns to the surface by means of capillary rise and uptake by deep rooting species.

High groundwater levels at about 1.0-1.5 metres from the surface occur in more than 70% of the MIA. Salinity surveys have been carried out to assess current conditions and to allow prediction of present and future salinity trends. These indicate that at present about 17% of the large area farm land in the MIA is affected, but that this will increase to about 31% by 2024.

Drainage water salinity in the MIA is affected by many factors. Of these the existing horticultural tile drainage salt load is likely to decline from the current about 18,000 tonnes to about 13,000 tonnes over the next 30 years. The large area farm runoff salt load will increase from about 18,000 tonnes to 23,000 tones/year, whilst other factors are likely to stay about the same, or will increase slightly. Overall the average Willow Dam salinity is believed to remain about the same as at present, at about 467 uS/cm, which is good news. The impact of new horticultural discharges of saline effluent on the Wah Wah Irrigation District supply system can be assessed using the models discussed in this report.

The report makes predictions of salinity trends and describes means by which control options can be evaluated. The report focusses on groundwater pumping as a principal watertable control option. Two different types of sub-surface drainage systems are discussed and costs and benefits presented for further economic evaluation. The key to effectiveness for these schemes is minimal pumping rates to reduce costs yet achieve sufficient protection. These aspects have been considered. The two schemes are a vertical drainage bore scheme in the Kooba/Murrami area and a horizontal pipe drainage scheme in Northern Benerembah. The schemes will have a capital cost of about $5.0 to $6.1 million each, but benefits are substantially reduced salinity levels in about 30-40% of the 20,000 hectares for each scheme that will receive protection.

Other watertable control options should be considered in association with the groundwater pumping schemes. This report ofers the methodology by which the evaluation of combined option strategies is possible.

1. INTRODUCTION

The MIA Land and Water Management Plan aims at sustainability of the irrigation areas and downtream users and the environment. The issues that need to be brought under control to achieve sustainability are trends in land salinity within the MIA and water quality degradation in the drainage system. The latter includes salinity, nutrients and pesticide residues.

Trends in salinity are gradual and insiduous. Land salinity increases when capillary rise from groundwater exceeds leaching and these processes often are very slow. Deleterious effects in terms of reduced crop production may take many decades to develop. Strategies depend on an understanding of the causes and effects of these processes and quantification thereof. This is the subject of this report.

Trends in drainage water salinity tend to follow trends in land salinity and will also be slow.

Trends in nutrients and pesticide runoff are also affected by farming and irrigation practices, however in a different way. This subject is being dealt with by a special task force for the Land and Water Management Plan committee.

When considering the factors affecting land and water management and sustainability it is important to identify the context into each of the various factors fits. A good way of achieving this aim is by developing a water balance for the area. Chapter 2 describes the current understanding as to how the various components of the water balance in the MIA fit together.

Chapter 3 describes the extent of high watertable conditions in the MIA, which are the main cause for high capillary rise rates. The hydrogeological conditions vary across the region and therefore the discussion to a degree needs to be sub-district specific. Chapter 4 describes soil salinity conditions in the MIA. Using the available data these conditions have been modeled, allowing predictions of soil salinity in various parts of the region for the present and future on basis of the various groundwater recharge and discharge factors.

This model, whilst still dependent on many empirical relationships is also useful to predict the effect of changed management on land salinity, eg reduced recharge due to reduced channel seepage or rice accessions, growing more trees, or watertable control options. As such it may be used as the principal tool to integrate on-farm and regional options for the LWMP package. This is considered at Chapter 9.

A by-product of the soil salinity assessment model is the assessment of drainage water salinity and salt loads. This aspect is important with regard to the assessment of future downstream salinity impacts and the effect of increased discharges, eg the proposed expansion of horticulture on large area farms with limited discharge to drains. This aspect is discussed at Chapter 5.

Chapter 6 discusses the various watertable control options. These consist of on-farm options, rice growing controls and discharge enhancement by groundwater pumping, with discharge to evaporation areas.

Chapter 7 discusses the design criteria for the groundwater pumping option. The volumes to be pumped are crucial for the design of pipelines and evaporation areas, hence the consideration of the minimum pummping rates to achieve sustainability in most of the landscape is essential.

Whilst groundwater pumping schemes may eventually be required for most areas in the MIA the report discusses two separate and different schemes only, one in the Calorofield/Kooba area and one in North Benerembah. Chapter 8 discusses the design aspects, costs and benefits of these two schemes. If economic, consideration could be given to extension of these schemes to other parts of the MIA where similar hydrogeological conditions occur.

Finally, Chapter 9 integrates the two groundwater pumping schemes with other watertable control and salinity management options and makes comments towards the formulation of a Land and Water Management package.

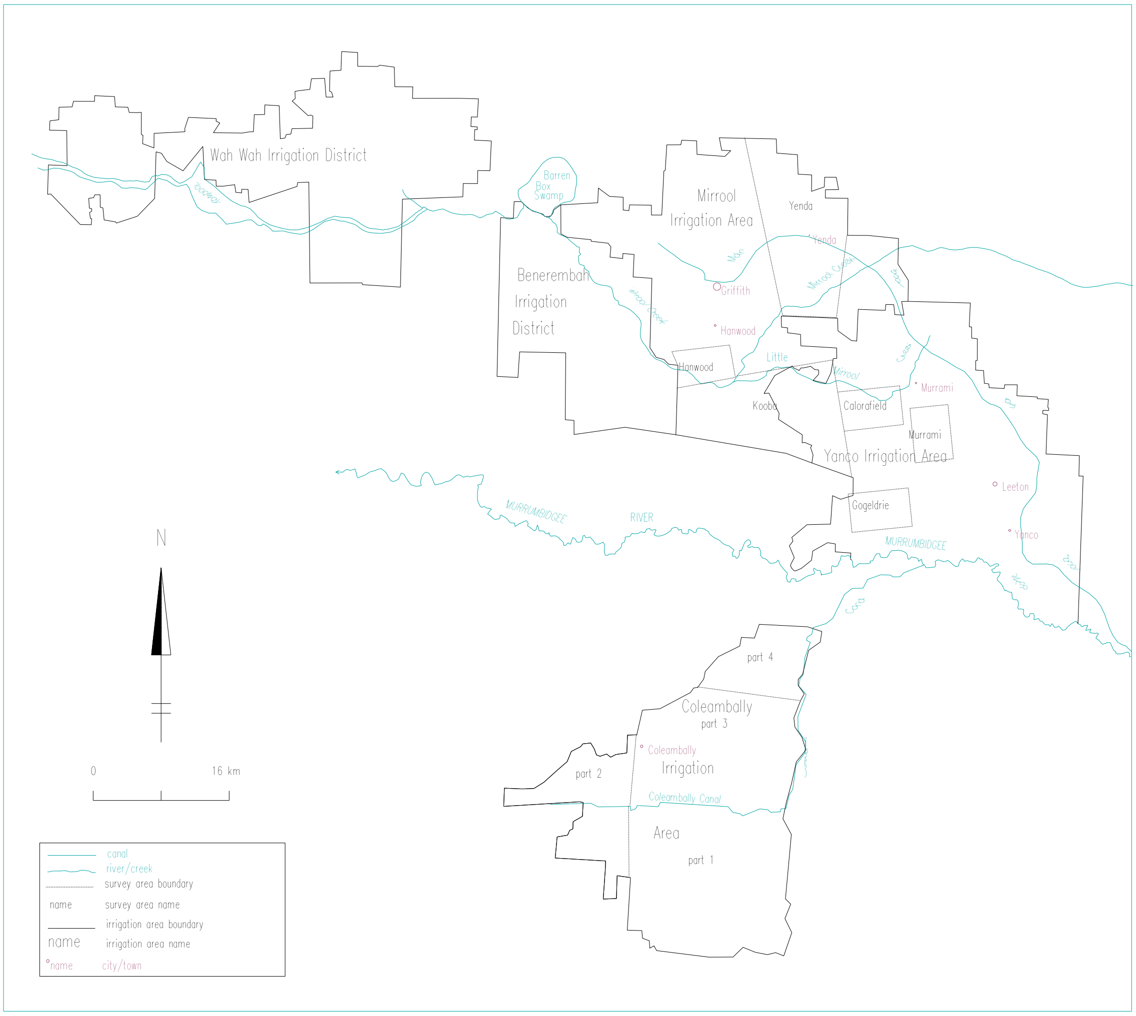

Figure 1.1 : Location map of the MIA and surrounding districts.

2. WATER BALANCE FOR THE MIA

When considering the factors affecting land and water management and sustainability it is important to identify the context into which each of the various factors fits. A good way of achieving this aim is by developing a water balance for the area. Such a balance needs to show the relativities beteen supply and drainage, between irrigation and groundwater accessions, between groundwater accessions and discharges, and between groundwater systems.

The purpose is to come up with values which identify relativities between volumes, so that when remedial measures in the Land and Water Management Plan are proposed, these are discussed within the proper context of the other volumes and factors affecting sustainability.

When considering the surface and sub-surface water balances it is necessary to consider to which areas these are applied. This is discussed first.

2.1 AREAS

A location map of the MIA is at Figure 1.1. The area comprises some 207,500 hectares (source: DWR Annual reports). Water is diverted from the Murrumbidgee River at Berembed and Gogeldrie weirs for growing of horticultural and large area farm crops. The main irrigation areas upstream of Barren Box Swamp are the Yanco, Mirrool and Benerembah Irrigation Areas and District. Water is also used in the town of Leeton and the City of Griffith. Drainage from the MIA returns to the river in parts of the Yanco area, but most areas drain to Mirrool Creek which drains to Barren Box Swamp. Along Mirrool Creek drainage water is partially reused in the Benerembah Irrigation District via diversions at Brays Dam.

Several parts in the MIA have no drainage or drainage is not towards Mirrool Creek. These includes the part of Yanco that drains to the river, the Lake Wyangan basin, the Warburn swamp catchment, and the Warrawidgee part of Benerembah.

These features of the region mean that the total area of the MIA may be split up in several ways:

1. By Landuse

Horticulture	15,000 ha	
Large Area Farms	188,500 ha	
Other Lands	4,000 ha	(*1)
Total	207,500 ha	

(*1) : includes towns, the Lake Wyangan area and the Warburn Swamp catchment

NSW Agriculture has estimated that the large area farm land of 207,500 ha includes 65,500 ha of not irrigated lands. These lands either are areas that are never irrigated (mostly on hill slopes adjacent to irrigated areas and at Lake Wyangan) or are not irrigated in a specific year.

2. By Drainage Areas

Draining to River Horticulture	4,000 ha
Draining to River Large Area	30,000 ha
Lake Wyangan area	2,000 ha
Warburn Area swamp	1,000 ha
Draining to Willow Dam	159,500 ha
Benerembah Stage 4 Area	11,000 ha
Total	207,500 ha

The area draining to Willow Dam of 159,500 ha may be split up as 11,000 ha horticulture, remainder towns (1000 ha) and (mostly irrigated) large area farms (147,500 ha). Some of the large area farm land is never irrigated and therefore not subjected to groundwater conditions and salinisation.

2.2. SURFACE WATER BALANCE

The aim is to prepare a water balance for the early 1990's period, this being the current scenario for current landuse patterns. Water usage and rainfall varies from year to year, hence it is necessary to use a reference period over which values may be averaged. Three reports are relevant in this respect.

1. Barren Box Swamp Model prepared by DWR Statistical Hydrology (Paul Pendlebury and associates). The inputs of this model are based on flow data of an unknown shorter period, however for rainfalls data over 65 years were used. The model also generates drainage flow over this longer period, which then could be used to prepare frequency distributions.

2. Farm Drainage Study by DWR. This 1993 report by ArunTiwari is based on three years of farm runoff data measured for 9 small horticultural and large area farm catchments. These data were used to establish the relativity between escape flows and farm runoff in the the overall drainage flows in the Mirrool Creek Catchment.

3. Water and Salt Balance for the MIA and Benerembah, by Ary. van der Lely (1992). This is based on 12 years of recorded monthly data (1978-90) in the supply and drainage system and aimed at establishing impacts of the Benermebah surface drainage scheme.

There are some inconsistencies between these reports, due to the reference period used and the timing of the report. The LWMP investigations teams of NSW Agriculture and DWR have considered these inconsistencies and proposes values which are believed to be of sufficient accuracy for the purposes of this report.

Figure 2.1 shows schematically the flow paths of water in the MIA. Surface water from the river and rainfall together supply large area farms. towns and horticultural areas. The MIA hydrological model (BBSWAMP) data suggest the diversions average 1080 GL/year. Rainfall over the 1979-1991 reference period was 388 mm/year on average, giving 676 GL over the study area. This is split between the horticultural farms, towns and large area farms.

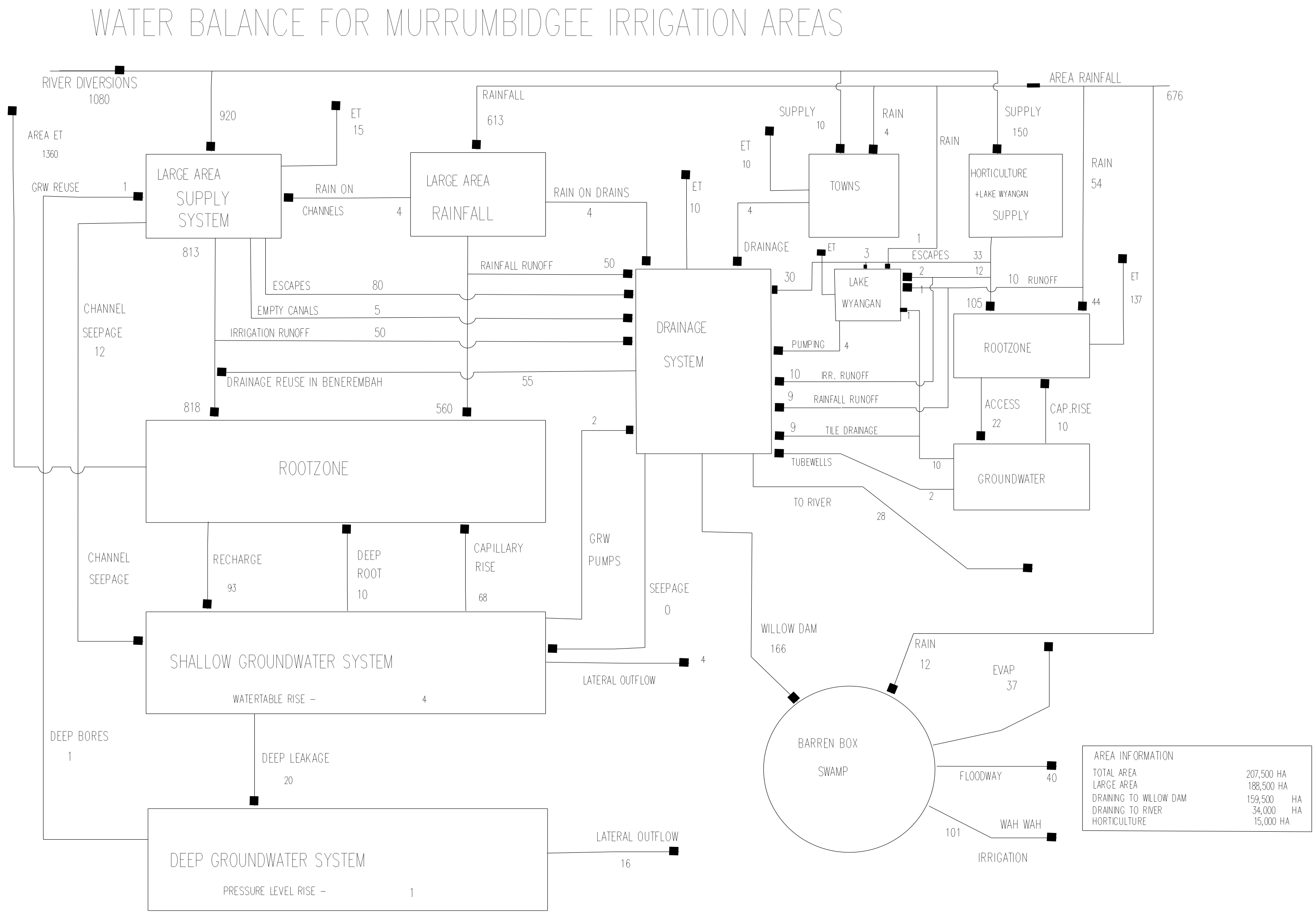

Figure 2.1 : Schematic overview of water balance components in the MIA

Drainage to Willow Dam and diversions at Brays Dam are the main two other values for which measurements are available. Many other values have to be estimated, and are based on reports 2 and 3 above. The flow at Wilow Dam over twelve years was found to be about 170 GL and Brays Dam diversions 48.5 GL. To the latter a nominal 6.5GL was added for pumping in Benerembah, giving 55 GL/year. Considering that about 28 GL from the Yanco area drains back to the river it is found that total drainage in the MIA is about 250 GL/year, of which 195 GL/year leaves the area.

As far as large area runoff is concerned, the MIA Water and Salt Balance study suggest a fairly even balance between runoff and escape flows. This results was more or less confirmed by the Farm Drainage Study. The BBSWAMP model on the other hand suggests farm runoff is above escapes by a fair proportion, however this result was not verified against actual data. For horticulture management of the supply system is more difficult and the escape flows are well above farm drainage. The tile drainage flows are known to be about 10 GL/year (eg David Hoey, 1980) and vertical bore drainage from Leeton area horticulture is about 2 GL/yr.

Some losses occur from the supply and drainage system. These are the seepage losses and evaporation from the channel surface and plants along the edge. The supply channel system is about 1000 ha in size. Consequently the evaporation losses are estimated at 15 GL. The seepage loss in the MIA has not been assessed as yet, however the incidence of prior streams in the MIA is less than the comparable Coleambally Irrigation Area, and watertable levels are higher. Both these two factors reduce seepage volumes, even although the number of locations where a seepage spot has been reported next to the channel may actually be higher. In Coleambally the average seepage loss from investigations was found to be 9 mm/day, with 65% of the channels leaking less than 3 mm/day. It was concluded that in the MIA the average seepage rate would be no more than about half of the rates experienced in the Coleambally Irrigation Area. At 4.5 mm/day over 270 days a seepage volume of 12 GL was computed.

Considering all these factors and the results of the studies the distribution of drainage flows and runoffs was allocated to the various components in the system as shown at Figure 2.1. This then leaves the volumes which are actually used on the farms and may be assumed to enter the rootzone.

2.3 GROUNDWATER BALANCE

Figure 2.1 also shows the various components entering and leaving the groundwater system. For the purpose of this report the large area farm groundwater balance is the most important. The recharge factors and discharge factors together determine the height of the watertable and henceforth, the salinity risk. The horticultural groundwater balance is not discussed.

The various recharge and discharge component values were determined individually as part of the setting up of the soil salinity assessment model (SSAM), discussed at section 4. Figure 2.1 shows that the accessions passing the rootzone for the MIA as a whole are in the order of 93 GL/year, and channel seepage 12 GL/year (previous section). These volumes enter the most shallow groundwater system, which incidentally is mostly already charged, with 70% of the area having watertables within 2 metres from the surface (Chapter 3). The full 105 GL entering the system has to be discharged, except for about 4 GL/year, which contributes to continuing watertable rise and expansion of the high watertable area.

Consideration of leakage to deeper aquifers (see Appendix 1) led to the view that no more than 18 GL/year is involved in this factor, whilst lateral outflow through the shallow groundwater system is not believed to exceed 8 GL/year. About 2 GL are pumped by tubewells in large area farms. The remainder of accessions, about 78 GL, discharges in the form of capillary rise in the high watertable area, or is absorbed by deep rooting trees or other deep rooting species. The total area of trees remaining in the MIA is believed to be no more than 1000 ha in total.

2.4. SALT BALANCE

The salt balance for the MIA consists of inputs and outputs. Many people consider the salt loads coming in through the irrigation system and compare with the salts leaving through the drainage system. This computes a net salt accumulation in the MIA of some 40,000 tonnes/year. However, this assessment is considered irrelevant in the overall scheme of things. Salt loads are also moving with the groundwater systems, there is leaching and capillary rise, etc. The MIA may contain about 200 tonnes of salt in the soil profile above bedrock, adding up to some 30 million tonnes. From that angle the 40,000 tonnes/year are just a "pin prick" added to the "sleeping giant".

The salt balance of the rootzone is the salt balance that has most relevance to the MIA Agricultural viability. It is appropriate to consider this salt balance, and determine whether on average leaching processes or capillary rise processes are the dominant feature in the MIA.

Table 2.1 below identifies all the relevant factors of water entering and leaving the rootzone. The volumes are based on the surface water balance of section 2.2, whilst the areas and the split up for the sub-districts are based on the discussion of Chapter 3 and the rest of this report.

Table 2.1: Assessed Salt Balance for the MIA and identified Sub-districts

a) Volumes entering and leaving the rootzone

FACTOR	GOG	KOON	MUR	KOO	WHAN	YEN	NBEN	SBEN	WWG	MIA
Area (ha/1000)	24.0	15.2	17.0	9.9	9.6	20.6	11.6	22.2	16.7	146.8
Irrigation (+)	145	91	110	66	64	129	63	120	90	878
Rainfall (+)	95	61	68	40	38	82	46	89	66	585
Irrigation Runoff (-)	8.3	5.2	5.9	3.5	3.4	7.2	4.1	7.8	2.0	47.4
Rainfall Runoff (-)	8.3	5.2	5.9	3.5	3.4	7.2	4.1	7.8	2.0	47.4
Accessions (-)	21.0	9.0	10.5	9.5	6.5	7.0	6.0	17.0	10.0	96.5
Capillary Rise (+)	10.6	5.1	8.4	4.4	5.5	5.8	5.1	8.1	6.1	59.1
Deep Rooted Species (+)	1.2	0.9	0.3	0.6	0.3	1.2	0.4	1.3	0.6	6.8
Evaporation (=sum)	214.2	138.6	164.4	94.5	94.5	196.6	100.3	185.8	148.7	1337.6

b) Salinity of water volumes (estimated from water and salt balance, in uS/cm)

FACTOR	GOG	KOON	MUR	KOO	WHAN	YEN	NBEN	SBEN	WWG	MIA
Irrigation	150	150	150	150	150	150	180	220	250	174
Rainfall	15	15	15	15	15	15	15	15	15	15
Irrigation Runoff	240	280	300	240	300	300	330	330	350	297
Rainfall Runoff	240	280	300	240	300	300	330	330	350	293
Accessions	2400	2800	3000	2400	3000	3000	3300	3300	3500	2925
Capillary Rise	3600	8000	10000	8400	10000	15000	8000	8000	10000	8149
Deep Rooted Species	3600	6000	6000	6000	6000	6000	6000	6000	6000	5570

c) Salt Loads of Volumes entering and leaving rootzone

FACTOR	GOG	KOON	MUR	KOO	WHAN	YEN	NBEN	SBEN	WWG	MIA
Irrigation (+)	13050	8190	9900	5940	5760	11610	6804	15840	13500	90594
Rainfall (+)	855	549	612	360	342	738	414	801	594	5265
Irrigation Runoff (-)	1195	873.6	1062	504	612	1296	811	1544.4	420	8319
Rainfall Runoff (-)	1195	873.6	1062	504	612	1296	811	1544.4	420	8319
Accessions (-)	30240	15120	18900	13680	11700	12600	11880	33660	21000	168780
Capillary Rise (+)	22896	24480	50400	22176	33000	52200	24480	38880	36600	305112
Deep Rooted Species (+)	2592	3240	1080	2160	1080	4320	1440	4680	2160	22752
Net Addition (tonnes)	6763	19592	40968	15948	27258	53676	19634	23452	31014	238305
Net Addition (kg/ha/year)	282	1289	2410	1611	2839	2606	1693	1056	1857	1623

The volumes are estimated with a reasonable degree of accuracy, however the salinity of the accessions and the capillary rise are subject to doubt. This greatly affects the salt balance itself, which with the shown numbers indicates that in the MIA on average 1.6 T/yr is added to the rootzone, the values being less in the southern areas Gogeldrie, Kooba and South Benerembah than in the northern areas. The total salt loads involved with some factors are in the order of 200-300,000 T/yr, which is much higher the the 40,000 mentioned earlier this section.

The salinity of the accessions is taken as ten times the salinity of the irrigation runoff. Plants use water and transpire, leaving salts behind. If on average 90% of all water applied is transpired, and about 10% of water added results in accessions, then the salinity of the accessions would be ten times higher than the salinity of the irrigation water.

The values used in table 2.1 reflect this simple assessment of the salinity of the accessions. More complicated assessments could be tried, for instance the salinity of the accessions is not necessarily related to runoff salinity, but rather the average of runoff salinity and the combined irrigation + rainfall salinity. Such assessment would tend to make the salinity less, not higher, and the salt balance would look even worse.

The salinity of the capillary rise is an other contentious issue. The value shown relates to the average groundwater salinity of the sub-district, the same value as used for the soil salinity assessment models. It is based on piezometer samples. The watertable salinity varies even more than groundwater salinity. There is no easy way to resolve these issues. This means there will always be uncertainty with regard to the salt balance for an area.

Despite these uncertainties, there appears no doubt that there is a net accumulation of salts in the lands of the MIA. It needs to be noted however that the increase does not apply to all the lands, but to a smallish proportion only. This proportion is assessed in this report at Chapter 4. In the majority of the landscape (50-90%, dependent on sub-district) there is little or no salt accumulation.

3. WATERTABLE CONDITIONS

3.1 HYDROGEOLOGY OF THE MIA

The geology of the MIA has been described by Pels (1960). Figure 3.1 shows the geological map. Bedrock dips from the northern boundary of the MIA, which is also the edge of the Riverine Plain, to the south. Near the line through Gogeldrie Weir and Wilbriggie the depth of bedrock is in the order of 100 metres. Overlying bedrock are Tertiary sediments, which also dip down from north to south. In the Bilbul area, which was occluded from the influence of the main river system, lignites and some brown coal may be found at 60-100 metres. The top of the Tertiary sediments consists of pipeclays and fine sands mixed with alluvium. These occur at about 20-40 metres depth to the north and 40-50 metres in the south. Overlying these sediments in turn is the alluvium which was deposited by braided rivers and finally, prior streams.

In the MIA the prior streams traversing from east to west are older systems, with the consequence that the associated levee soils have been covered by fine textured materials originating from more recent streams to the south. The prior stream in south Benerembah is such a younger system. The older systems in the MIA have been partially obliterated by the more recent activity. Remnants may be found near Stanbridge and at Whitton.

Whilst the surface horizons in the MIA large area farm lands appear to consist of mainly low permeable clays, significant areas in fact have more permeable materials not very far from the surface, sometimes within 1.5 - 3 metres. This feature is particularly present in the southern half of the MIA.

To the north Mirrool Creek deposited its own floodplain consisting of mainly clays with shoestring sands. The whole MIA has also been subjected to aeolian deposition (parna from the west, and wash offs from the rocky outcrops to the north, forming colluvial soils adjacent to Scenic Hill at Griffith, the Cocoparra Range and hills in the Wumbulgal/ Murrami areas and Corbie Hill. These lighter textured soils are not underlain by aquifer systems of the prior stream era, but have been found very suitable for horticultural development.

The hydrogeology of the area is consistent with this pattern. Groundwater levels were deeper than 20 metres below the land surface when irrigation commenced, however infiltration from irrigated lands and channel seepage caused large volumes of accessions, particularly in areas where sandy aquifer systems occurred close to the surface. Watertable levels started to rise. To the north the more permeable surface layers became saturated and perched watertables developed, which slowly dissipated again by capillary rise or (slow) groundwater flow through the shoestring sands where present.

The developing pressure levels in shallow aquifers may dissipate to deeper aquifers. The deeper aquifers to the south and west particularly have high transmissivity and carry away any leakage that may occur from above. This is an important phenomena and provides significant protection to the MIA, which otherwise would be subjected to more rapid soil salinity increases over larger proportions of the area. This feature is to be considered in any sub-surface drainage scheme.

The initial salt content of the groundwater systems increases from low values in the east to higher values in the west. In the areas where dissipation laterally or downwards is very slow, such as in the north, the soil profile contains higher salt levels. The salt levels are mostly derived from rainfall over many millennia. The raised groundwater levels tend to dissolve these salts and convey them to discharge locations in the landscape.

3.2. WATERTABLE CONDITIONS

A large number of piezometers have been installed in aquifers occurring at various depths below to MIA. The installation depth generally ranges from 8 to 45 metres. About 700 of these piezometers have been retained for the mapping of regional groundwater trends. Readings are taken twice a year. The September readings are considered the most relevant for comparison between years. The 1993 readings were used to identify conditions in the various sub-districts.

Subdistricts were selected on basis of perceived changes in hydrogeological conditions, but also to separate areas with a longer and shorter history of high watertable conditions. The latter is important when predicting present and future soil salinity. The final choice is also influenced by the need to keep the number of sub-district small. Figure 3.2 shows the outline of the eight sub-districts that were were selected.

SELECTED LARGE AREA FARM SUB-DISTRICTS IN THE MIA

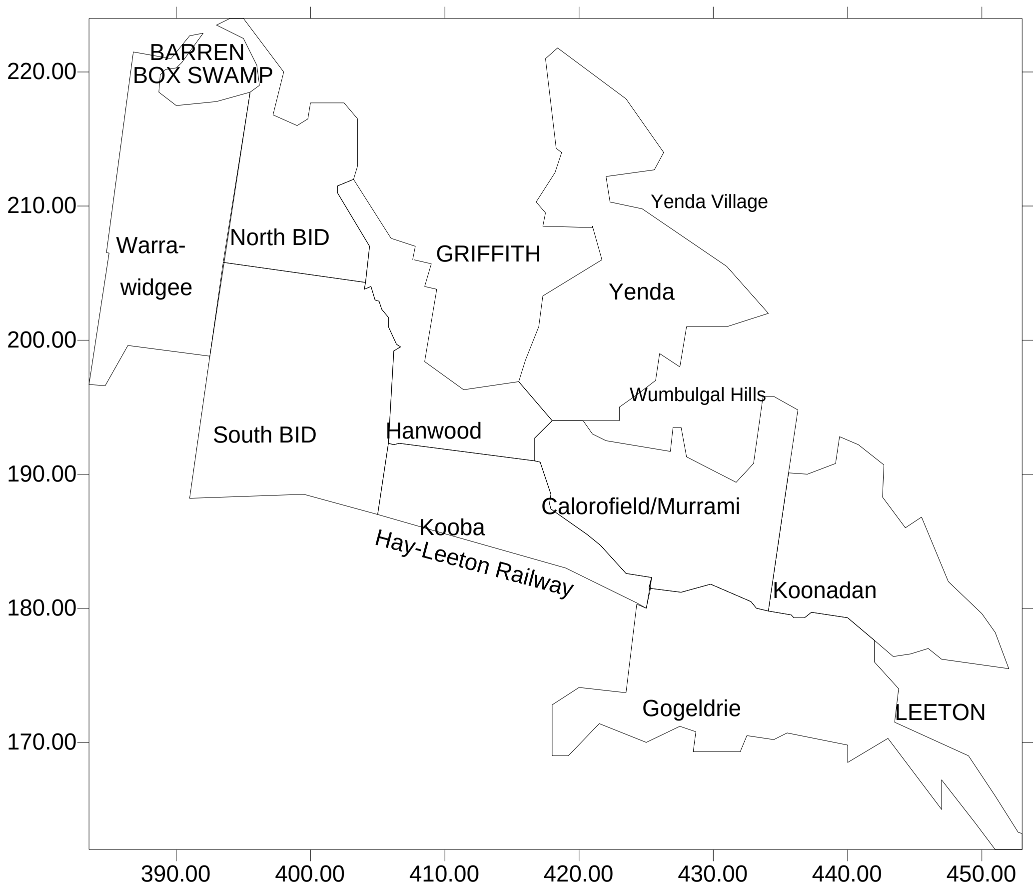

Figure 3.2: Selected sub-district in MIA for watertable conditions and salinity assessment.

The Lake Wyangan district and the Wah Wah Irrigation District are not being considered in this report. For a discussion of the watertable conditions in the Wah Wah District, see the Wah Wah Environmental Status report by Arun Tiwari (DWR Griffith, 1994).

Names were given to each of the sub-districts. These names are artificial to the extent that the area represented may not be true, eg north and south Benerembah include parts of Mirrool and Tabita, the Yenda, Koonadan and Murrami areas do not show some large area farm lands not irrigated, or within the influence of aquifer activity. The addition of the areas of the eight sub-districts was 147,000 hectares, which is the principal part of the MIA in which watertables and salinity may develop. The averages found for each subdistrict would be representative for the locality and can be used as such.

Piezometer readings are not necessarily the same between shallower and deeper aquifer systems within the 8-45 metres range. This particularly applies to those areas west of Hanwood and into Benerembah, but not so much for the Gogeldrie, Koonadan, Murrami, Yenda and Kooba sub-districts of Figure 3.2. All available piezometers therefore could be used to assess watertable conditions in the latter sub-districts, but in the Hanwood and Benerembah sub-districts only the piezometers within 12 meters from the surface were used.

Appendix 1, provides the necessary background information on groundwater conditions in the MIA. It comprises the following:

- a groundwater conditions report for the MIA as a whole
- groundwater contour maps for the eight sub-distrcits for 1993
- groundwater contour maps for the eight sub-districts for 2013
- hydrographs of watertable behaviour over time and between different aquifers in various parts of the region
- a groundwater salinity map for the shallow groundwater systems in the MIA

Table 3.1 provides an overview of the average watertable and the watertable distributions.

Table 3.1 : Watertable distributions for MIA selected sub-districts

Sub-district	Area (*1)	<1 m	<1.5 m	<2 m	<3 m	<4 m	<6 m
Gogeldrie	236.5	0.01	0.14	0.35	0.71	0.88	0.98
Koonadan	151.7	0.25	0.70	0.88	1.00	1.00	1.00
Murrami	170.6	0.39	0.71	0.91	1.00	1.00	1.00
Kooba	99.5	0.08	0.29	0.67	0.85	0.92	0.98
Hanwood	96.4	0.41	0.68	0.80	0.90	0.95	0.98
Yenda	206.0	0.12	0.65	1.00	1.00	1.00	1.00
Nth Ben	115.8	0.58	0.88	0.96	0.98	1.00	1.00
Sth Ben	222.3	0.19	0.44	0.62	0.81	0.91	0.96
Wwidgee	167.5	0.31	0.50	0.61	0.77	0.87	0.93
Total	147.1	0.31	0.58	0.78	0.91	0.96	0.99

(*1) sq. kms

Maps and hydrographs at Appendix 1 show that the deepest watertables are being experienced in the Gogeldrie area, which is adjacent to the river south of Trunk Road 80 and between Narrandera and Whitton. Table 3.1 shows that in the south Benerembah area about 57% of land still has a watertable deeper than 2 metres, whilst this is about 67% in the Kooba area. These three areas have the most benefit of dissipation of groundwater to the south and west, and also to deeper aquifers. On the other hand watertables are within 2 metres in excess of 80% in the Koonadan, Murrami, Hanwood, Yenda and north Benerembah areas. In the latter two areas the watertable conditions are mostly perched.

As far as averages are concerned, Table 3.2 provides some basic information.

Table 3.2 : Average depth to groundwater and groundwater salinity in sub-districts of the MIA

	Ave 1993 WT depth	Ave 2013 WT Depth	EC dS/m	EC adopted dS/m (*1)
Gogeldrie	2.89	2.37	3.7	3.6
Koonadan	1.39	1.40	8.4	8.0
Murrami	1.29	1.19	10.9	10.0
Kooba	2.15	1.84	8.4	8.4
Hanwood	1.62	1.18	14.7	10.0
Yenda (*2)	1.51	1.48	26.3	12.0
Nth Ben (*2)	1.31	1.26	6.8	6.8
Sth Ben (*2)	2.06	1.40	9.0	8.0
Warrawidgee (*2)	2.10	1.46	N/A	10.0
Weighted Average	1.88	1.55		8.0

(*1) For modeling purposes

(*2) Lack of watertable data caused difficulties with the estimation of numbers for these sub-districts.

The adopted watertable and groundwater salinity values vary somewhat from the measured values fron SURFER generated maps because in some sub-districts the salinity contours were being distorted by too few available data, some of which were in the more extreme range.

3.3. WATERTABLE TRENDS.

The average groundwater level rise over the last decade for the Benerembah, Mirrool, and Yanco areas may be derived from Figure in Appendix 1. Figure 3.3a and Figure 3.3b (copied from Appendix 1) are for Benerembah and for the Yanco area and may be considered representative for the conditions.

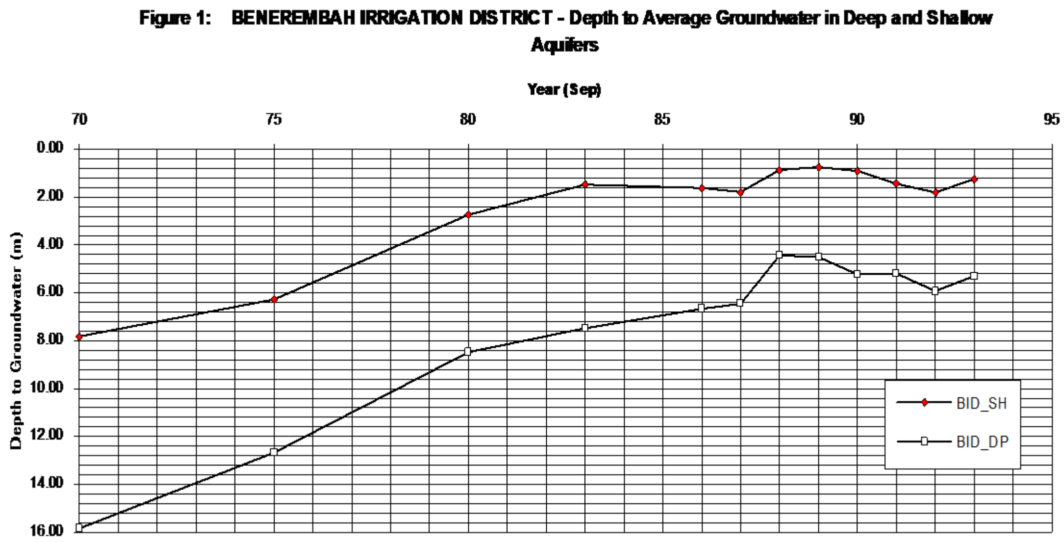

Figure 3.3 a: Average Hydrograps for deeper and shallower aquifers in Benerembah

In Benerembah the groundwater depth of the shallow (5-12m) piezometers is substantially less than for the deeper (12-35m) piezometers.

The levels of the shallow piezometers seem to have stabilised since about 1983, and in the deeper piezometers after about 1988. The 1988-1990 period has been characterised by wet winters. Since that time groundwater levels have dropped a little.

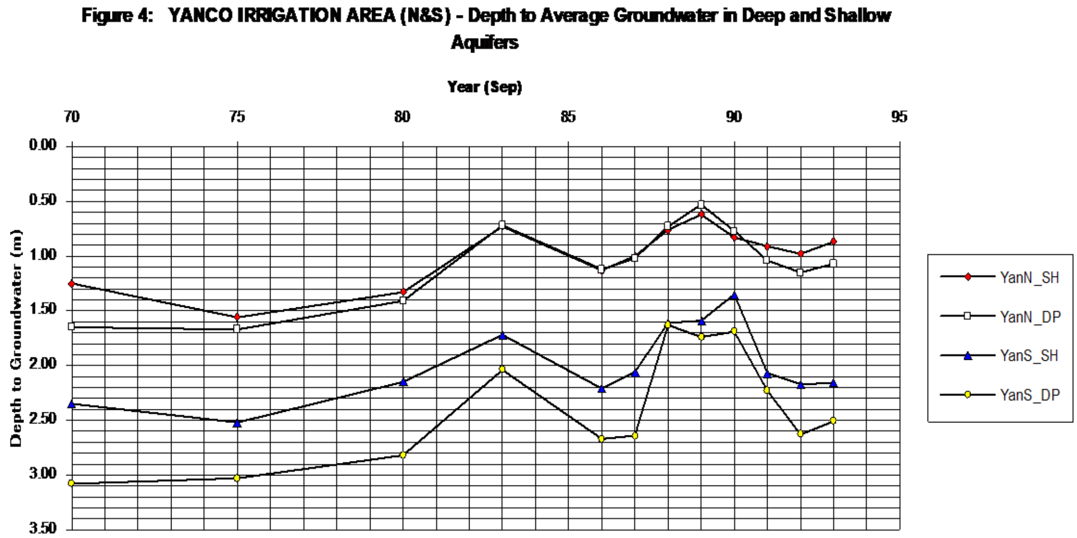

Figure 3.3b Average Hydrographs for shallow and deeper piezometers in the Yanco Area

Figure 3.5c shows that in the Yanco area watertable levels are on average deeper towards the Gogeldrie area, whilst in the north the difference between shallow and deeper systems is only slight. The Mirrool Area shows similar behaviour between the Kooba subdivisions and the northern parts.

To determine future conditions the hydrographs for individual piezometers were extrapolated until 2004, and 2014. To achieve this the average watertable for the period 1986-1989 and the average for the period 1990-1993 were used to calculate the rate of increase for the piezometer. The extrapolated numbers were then plotted and contoured, assuming that in no location the watertable would rise closer than 1.2 metres from the surface. The maps so derived for the eight subdistricts may be found at Appendix 1. From these maps the future areas with high watertables within two metres were determined, resulting in the values of Table 3.3.

Table 3.3. Assessed future areas with high watertables in the MIA for the identified sub-districts (ha/1000)

Area	Area (ha)	1994	1999	2004	2009	2014	2019	2024
MIA total	147.1	107.5	110.2	112.9	115.4	117.8	120.0	122.5
Gogeldrie	23.6	8.4	9.5	10.5	11.4	12.2	13.0	13.7
Koonadan	15.2	13.4	13.6	13.7	13.8	14.0	14.2	14.3
Murrami	17.0	15.5	15.6	15.7	15.8	15.9	16.0	16.0
Kooba	10.0	6.7	6.9	7.1	7.3	7.5	7.7	.79
Yenda	20.6	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Hanwood	9.6	8.5	8.6	8.7	8.8	8.8	8.9	9.0
North Ben	22.5	19.0	19.1	19.2	19.3	19.4	19.5	19.6
South Ben	28.7	16.1	17.0	18.0	19.0	20.0	21.0	22.0

Table 3.3 shows the total area of high watertables is increasing by some 2,700 ha/year, out of a total about 40,000 hectares (of the measured zone) where watertables are still deeper than 2 metres. Over the next twenty years the average watertable in the MIA is expected to rise from 1.88 to 1.55 metres, with most of this increase being in the deeper watertable areas. The increase represents 1.5 cm/year, which over 147,000 ha and a soil porosity of 8% represents a net increase in groundwater storage of about 1800 ML/year. In the groundwater balance of Chapter 2 a value of 3 GL/year is shown at Figure 2.1.

3.4. GROUNDWATER SALINITY

Finally, the available groundwater salinity values were used to assess the average groundwater salinity for each of the eight sub-districts. Figure 3.4 shows the salinity contour map for the MIA as a whole. More detailed maps were produced using SURFER and used to assess the average groundwater salinity in each of the sub-districts. This average value is important in later assessment to determine the rate of soil salinisation. Table 3.2 of the previous section shows the averages used in further analysis.

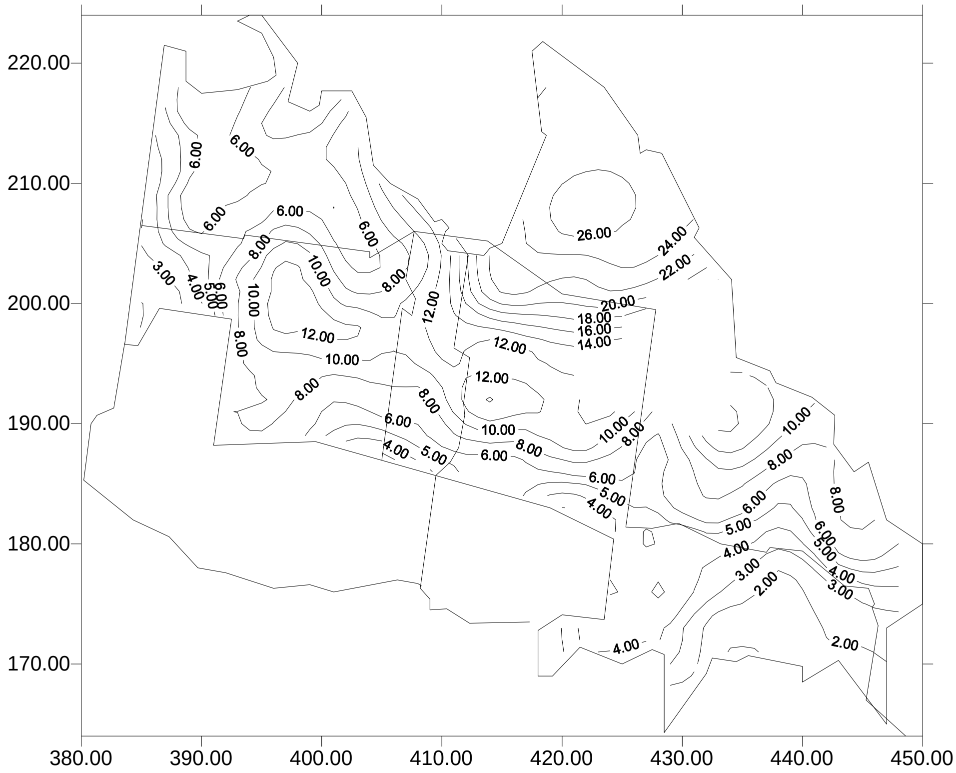

Figure 3.4. Groundwater salinity values in the MIA

The highest groundwater salinities are found in the Yenda sub-district where values over 10-15 dS/m are common. The lowest values occur in the Gogeldrie and Koonadan sub-districts, where the average is about 3 dS/m.

4. SOIL SALINITY

4.1 SOIL SALINITY CONDITIONS.

The best way to determine current salinity conditions is by carrying out a survey, provided this results in an accurate assessment. Different types of surveys could be considered, EM surveys, airborne or on-ground, sampling on a grid system, etc. Since it is important to evaluate trends and determine what the performance of a future Land and Water Management Plan might be, the survey technique selected should be inexpensive, and provide an overview, rather than a mapped outline of where all the saline areas are. A statistical based survey technique, whereby a large enough number of random samples are taken from a sub-district and analysed for percentile values of salinity was selected to meet this minimum requirement. Ahmed (1992) produced a report on the technique, its strengths and weaknesses, with accompanying data for the 1991 and 1992 results.

The results of the 1991, 1992 and 1994 surveys are attached at Appendix 2. The surveys were carried out on a sub-district basis, not much different from the sub-districts of Figure 3.2. Table 4.1 shows a summary of the results

Table 4.1: Summary of Results of Soil Salinity Surveys, 1991.1992, and 1994 (*1)

		95 %			90 %			80 %			50 %		
		1990	1991	1994	1990	1991	1994	1990	1991	1994	1990	1991	1994
Benerembah	10cm	1850	2303	1131	950	1105	875	600	860	638	370	530	425
	30cm	2188	1985	1615	1080	1270	696	500	750	533	310	370	343
Calorafield	10cm	1811	1359	-	1476	839	-	929	312	-	232	231	-
	30cm	2625	1560	4874	2205	1290	3038	1100	473	1688	318	288	457
Coleambally 1	10cm	393	-	-	314	-	-	246	-	-	167	-	-
	30cm	774	-	2660	516	-	1815	326	-	979	192	-	378
Coleambally 2	10cm	-	-	502	-	-	398	-	-	336	-	-	193
	30cm	-	-	1435	-	-	593	-	-	420	-	-	268
Coleambally 3	10cm	-	-	504	-	-	371	-	-	302	-	-	173
	30cm	-	-	421	-	-	371	-	-	310	-	-	234
Coleambally 4	10cm	-	-	377	-	-	294	-	-	247	-	-	177
	30cm	-	-	384	-	-	333	-	-	293	-	-	187
Gogeldrie	10cm	743	2963	1396	542	394	400	320	219	312	128	117	175
	30cm	1684	3940	2432	726	852	454	508	419	310	187	171	229
Hanwood	10cm	4575	1336	1565	2150	1128	1125	1390	1038	674	545	430	388
	30cm	3173	1562	2240	2015	1458	1915	915	938	722	435	410	335
Murrami	10cm	543	1803	2328	443	718	1387	283	360	296	171	185	213
	30cm	997	2362	3074	644	884	2018	294	503	436	173	303	257
Wah Wah	10cm	-	-	1479	-	-	1117	-	-	872	-	-	545
	30cm	-	-	1693	-	-	1024	-	-	697	-	-	431
Yenda	10cm	5670	3800	1581	2890	1470	1030	1390	1060	625	660	520	382
	30cm	3330	3640	2356	1760	1500	1112	1320	1130	887	430	410	390

(*1) data averages shown as EC1:2, uS/cm.

The results of Table 4.1 are expressed as Electrical Conductivity in a 1:2 soil/water suspension. The concentration in such a suspension tends to be half of the 1:5 suspension and 3.1 times more diluted than a saturated extract of the clay soils from which the samples were taken.

The general shape of the salinity results in Apendix 2 tends to show that 5-10% of the samples taken have higher salinity values, with another proportion with lesser values but still above a threshhold of about 2 dS/m in a saturation extract. It is found that the areas with a longer history of high watertable conditions, such as at Yenda and Murrami also have higher salinity, compared to areas with a very short high watertable history, such as Kooba and Coleambally. This feature was subsequently used to make predictions for future salinity through the develoment of the soil salinity prediction curves. This is discussed in the next section.

4.2 MODELS TO EVALUATE SALINITY TRENDS.

Salinity assessment comprises two aspects, soil salinity and (drainage) water salinity. High groundwater levels may produce more saline soils over time. The runoff from these more saline soils may gradually become more saline. For a Land and Water Management Plan over a thirty year time frame it is necessary to make the best possible predictions regarding the trends in these two factors. The model used to evaluate these trends is discussed in this section.

Two reports by van der Lely describe salinity assessment aspects:

1 "Present and Future Soil Salinity Conditions in the MIA and CIA" (1993)
2. "Soil Salinity Assessment using Water Balance Data" (June 1994).

The effects of salinity and waterlogging manifest themselves as reduced crop yields on the salt affected soils. Models to assess soil salinity are the intermediate steps towards these estimates. The actual estimating of crop losses due to salinity is within the sphere of responsibility of NSW Agriculture. Graham Marshall et al (1994) produced the report on agricultural effects of soil salinisation and waterlogging during July 1994 from soil salinity data

High watertables are believed to aggravate waterlogging conditions. Transient waterlogging may be defined as a state of temporary perched saturated condition in the topsoil, which affects crop growth. Watertable induced waterlogging on the other hand is from below. The likelihood of the plant roots being in a saturated condition increases when the watertable comes close to the surface. When the watertable for instance on average is at 2.0 metres, only a small proportion of the land will have a watertable within 0.75 metres, which may be the level at which measurable effects occur. If the average watertable rises to 1.2 metres the proportion of land with watertables within 0.75 metres will be greater, hence the effect will be greater.

Finally, the increased moisture levels due to waterlogging may increase the harmful effect of salinity on crops. This effect, first discussed by Lennard-Barrett (1985?) has not been quantified to date and therefore is difficult to cater for in model predictions.

Salinity is a function of leaching and capillary rise in the soil, and this is affected by watertable levels. Since with observations in the field it often is difficult to distinguish between the effects of salinity on crops and the effect of watertable induced waterlogging on crops, it is useful for analysis purposes to lump the two together.

Yield affected by salinity may be studied by analysing crop growth as a function of salinity. The main work for this comes from the USA, eg Maas and Hoffman (1978). Information is now also available for Australian conditions for some crops. This has been summarised by Slavich (1992). Basically, as the salinity increases a threshold level is reached above which crop yield reductions occur. The yield reduction is expressed as a proportion of potential yield for each unit increase in salinity. Soil salinity is measured as conductivity (dS/m) in a soil saturation extract.

4.2.1 General Methodology

The soil salinity SS_t for time t at any location in the landscape is a function of the soil salinity SS_{t-1} at time t-1 plus or minus three critical factors:

- plus the salt content added by the net capillary rise process.
- plus the salt content added by the irrigation water
- minus the salt quantity removed by surface runoff

The general equation is described by David Merrilees (1992) of the MDBC and based on work for the Shepparton Salinity Management Plan.

The salt content added by capillary rise is calculated as the net capillary rise multiplied by the groundwater salinity and by a calibration factor (0.88). Where the leaching process exceeds capillary rise the net salt content added is zero or less.

The salt content added by the irrigation water is the average volume applied (abt. 6 ML/ha in the MIA) multiplied by the salinity (150 uS/cm).

The quantity removed by surface run-off (rainfall, irrigation) is equal to the volume of runoff (abt 0.75 ML/ha for the MIA and CIA) multiplied with the runoff salinity. The latter is a function of the soil salinity SS_t multiplied by the respective area and runoff calibration coefficient (0.2 for the Shepparton study). If the soil salinity is low (below 1000 ppm) the salt quantity removed is estimated from the volumes per hectare involved and the typical drainage runoff salinity (about 240 uS/cm).

Provided suitable data are generated and applied across the whole of the MIA the above equation therefore is capable of providing estimates of soil salinity and runoff salt loads with time

4.2.2. Soil Salinity Predictive Trends

The Land and Water Management Plans are for 30 year time frames. Therefore predictions are necessary of the salinity status of the district for which the plan is prepared. Within the district each farmer may be affected in a different degree.

The report “Present and Future Soil Salinity Conditions in the MIA and CIA” (van der Lely, 1993) describes the procedures by which the soil salinity predictions have been made. It was assumed that the current irrigation management practices will continue and cropping patterns remain the same. The end result of this report are curves of predicted salinity versus time of high groundwater levels. Such a curve has been assessed for each of a range a watertable level conditions that may occur, eg the categories 0-70 cm depth, 70-90 cm, 90-110, 110-130, 130-150 cm depth. For each watertable category a separate curve exists. The curves are based on the theoretical equations described above, however they were calibrated against data derived from actual soil salinity field surveys in the MIA and CIA, hence some confidence exists that the prediction curves are realistic.

After calibration polynomial curves were developed to closely approximate the data. The coefficients for these curves, shown at Figure 4-2, may be found in Table 4-2.

Table 4-2: Coefficients for soil salinity prediction curves

Watertable Category	a (x Y^2)	b (x Y)	c
<0.7 m	-1.13	224	300
0.7-0.9m	-0.21	55	300
0.9-1.1m	-0.09	27	300
1.1-1.3m	-0.04	17	300
1.3-1.5m	-0.02	8.5	300

(*1) Y represents the age (years) of the high watertable condition

The curves of Table 2 apply for typical groundwater salinity in the MIA, which is about 8.0 dS/m (Table 3.2). To find the appropriate curves for area where groundwater salinities are different, the coefficients for the curve are to be multiplied by a linear ratio (ECgrw / 8.0).

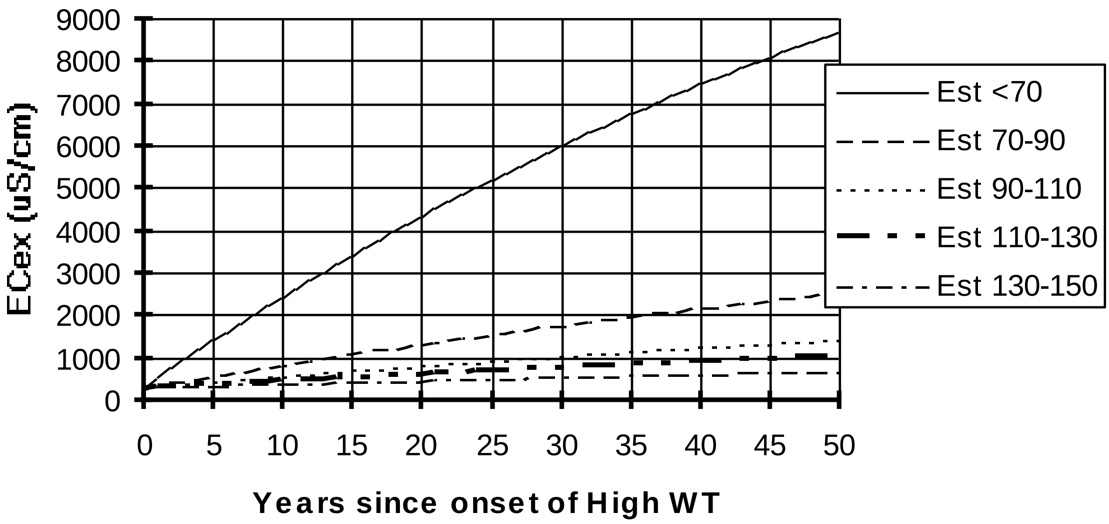

Figure 4-2: Curves for prediction of soil salinity in various watertable categories

The availability of the curves means that if the age of high watertable in a part of the district is known, then an estimate of soil salinity may be made for

a) the current conditions, and
b) the future conditions.

For the assessment for a particular part of a district to be possible the following information is needed:

- the area with high watertables
- the average watertable level in this area
- the distribution of watertables around the mean, giving the proportion of land within each watertable category
- the duration that the high watertable conditions have existed.

The first and fourth of these is derived from maps, the second from the relative recharge and discharge factors in the groundwater balance used in the soil salinity assessment model (see below), and the third is based on watertable statistics.

A complication is that with the prediction for a district, where all areas are lumped together, it is difficult to estimate the average age of the high watertable condition. Some parts have existed for several decades already, other parts may have had high watertables for a short time only. For instance, in the year 2023 some areas will have a short watertable history in that year and other areas a very long history. This issue is addressed by the Soil Salinity Assessment Model, see next section

4.2.3. Soil Salinity Assessment Model

The report "Soil Salinity Assessment using Water Balance Data" (van der Lely, June 1994) the above salinity prediction functions and addresses the problems just discussed. For each five year interval each part of the district with a different watertable history is identified first, after which the soil salinity assessment based on the salinity prediction curves of section 4.2.2 is carried out separately. Finally the areas with salinity within the same class are added up together for the whole district.

Specifically, the steps followed in the Soil Salinity Assessment Model are as follows:

1 Determine Recharge and Discharge factors in groundwater balance.
2. Derive average watertable depth in the high watertable area from step 1.
3. Determine capillary rise from average watertable depth and multiply with high watertable area.
4. Determine the balance as Recharge - Discharge -Capillary Rise, which is the volume contributing to watertable height increases over time. Calculate the high watertable area increase using calibration factors.
5. Carry out steps 1-4 for the full period of 30 years in five year steps.
6. Calibrate the outcomes of 4 against the predicted high watertable areas predicted from hydrograph analysis and maps.
7. Insert the appropriate value for average groundwater salinity for the area considered and insert the age of the high watertable condition that already exists.

8. Identify for each year considered (1994, 1999, 2004, etc) the ages of the incremental watertable areas
9. Calculate for each of the incremental watertable areas the component areas of each watertable category <0.7, 0.7-0.9, 0.9-1.1, 1.1-1.3, 1.3-1.5 metres. This is based on the average watertable height calculated for the year considered and the assumed watertable distribution..
10. Apply soil salinity prediction curves for each area of step 8. Derive the soil salinity for year "t".

11. Categorise all sub-areas according to soil salinity values found and add up the areas for each salinity classes 2-3 dS/m, 3-4 dS/m, 4-6 dS/m, 6-8 dS/m and >8 dS/m.
12. Apply smoothing function before printing salinity table.

Steps 8-11 are automatic in the model, but steps 1-7 require insertion of data and calibration coefficients.

The main feature of the Soil Salinity Assessment Model is that it is linked on water and groundwater balance data, such as described at section 2 of this report. The various values for the groundwater balance are entered in the model. From this the total accessions are assessed as well as the discharge factors. These two are in equilibrium and produce an average watertable depth for the high watertable part of the district. This depth is assessed from available research regressions and corrected for factors such as seepage from channels, deep leakage and groundwater pumping.

The assessment of the average watertable height in the high watertable area allows the assessment of the capillary rise volume. The assessment of capillary rise is based on scientific research for Self-Mulching Clays Soils and Transitional Red Brown Earth. The curves found were converted to exponential equations for the Wakool Irrigation District groundwater models (van der Lely, 1988).

Various parts of the groundwater balance are matched and the differences calculated. The difference in volume between total recharge and discharge (including capillary rise) for the district represents watertable rise and the expansion of the high watertable area with time. A multiplier is used to convert the net recharge to an estimated high watertable expansion. This is then compared with the predicted increase in high watertable areas based on groundwater mapping procedures and hydrograph extrapolation.

The calibration process involves the use of about five coefficients. This requires judgement, , which increases the likelyhood of bias being introduced. In practice fortunately the coefficients are not dissimilar between sub-districts, and some of the variation can be explained in terms of different hydrogeology and soils. Nevertheless this aspect causes the model to be less than ideal, despite of its competitive edge over some other models. Sensitivity testing and caution when making decisions regarding the adoption of the more expensive LWMP options are recommended when using the model for LWMP optimisation.

Whilst shortcomings in the model are readily admitted by the author, it is also claimed that there are no known other available procedures based on scientific know how that are likely to produce a better result.

Once calibration is achieved the model uses the calculated average watertable level in the high watertable area to assess soil salinity for the district. The output is a table giving soil salinity categories and proportions or hectares of land affected.

The soil salinity assessment model can be used to identify the changes in district soil salinity status that may occur as a result of the adoption of a particular LWMP option. This occurs when the water balance for the district or part of the district changes when an option is implemented, resulting in less recharge or more discharge. The changed water balance results in a different average watertable level, which in turn gives less area in the very high watertable category, hence a lesser area with rapidly increasing salinity. The changed salinity status for the district in turn can be used to evaluate agronomic and economic impacts and benefits of the option considered, or a combination of options.

In previous models (eg the MDBC Drainage Evaluation Spreadsheet Model, MDBC, 1994) the benefits for most options were evaluated using coefficients describing the proportion of salinity (and waterlogging) loss that may be mitigated or prevented using the option. These coefficients are rather arbitrary and often decided upon as a compromise between different views of those present at a specially convened inter-agency meeting. The Soil Salinity Assessment Model provides a better technique of providing estimates of benefits of various options. The evaluation of combinations of options is more soundly based.

The outcome for the various options are described in the respective sections.

4.2.4 Crop Salinity Loss Assessment

The Soil Salinity Assessment model outcome is a table showing areas with salinity of different categories for five year intervals over the period considered. This table may be used to assess the crop salinity losses in a variety of ways. The main difference relate to the assumptions of farmers adjustment to the salinity process.

The features of the traditional approach, also used for Benerembah were as follows:

- Maas and Hoffman salinity loss factors are used, but modified wherever Australian values are available.
- There is some consideration of watertable induced waterlogging loss (eg for rice).
- It is assumed that that only a proportion of the area with salinity above 8 dS/m is used for farming. This proportion can be modified if necessary.
- It is assumed that all crops will be grown in an even proportion on all land, except for the proportion of saline land nominated to be not used for irrigation farming.
- The salinity loss relates to total crop yield value, not the gross margin reduction after correction of inputs by the landholder.

This type of model has been used to evaluate the Benerembah Drainage project but presently is superseded. Nevertheless the above type assessment has been developed and would be readily available should this be considered desirable.

The method adopted for the MIA and CIA LWMP's is based on the NSW Agriculture approach including the assumption that farmers will make a choice in avoiding more saline land and adjust production of higher value crops to the better parts of the District. The agricultural loss assessment is based on reductions in gross margin, not total crop value (C. Curthoys and G. Marshall, 1994).

The MDBC Drainage Evaluation Spreadsheet Model uses gross margins, and also allows for a mechanism whereby the loss is attributed to a higher or lesser degree to the least productive crops. The degree may be varied by the user, dependent on his perception of the adjustment the farmer may have made to the salinity process. For instance, in the Berriquin Area high value crops are unlikely to be grown on saline land because land is a resource less limiting than water. In the MIA or CIA on the other hand land may be considered more scarce than water and there may be more tendency to use salt affected land for high value crops.

4.3. PREDICTED FUTURE SOIL SALINITY

Having discussed the methodology of how the present and future soil salinity may be estimated this may now be applied to the selected sub-districts of the MIA. The first step is to collate the necesary data. These are inserted into the model and the calibration procedure carried out by means of a range of factors. This procedure aims at matching the capilary rise volumes with other components of the groundwater balance, and matches the extent of high watertable areas over time between the model calculated values and the values obtained from hydrograph extrapolation over the next 30 years.

To calculate the soil salinity matrix for the sub-district area for five year intervals over the next 30 years and for different salinity classes 2-3 dS/m, 3-4 dS/m, 4-6 dS/m, 6-8 dS/m and over 8 dS/m two more factors need to be inserted in the model. The first of these is the age of the 1994 area with high watertable conditions and the second is the aquifer activity factor. The latter reduces the rate of salting between sub-districts from the standard soil salinity prediction graph (Figure 4.2) where aquifer activit is less than the norm set. The value is typically 1.0 for areas such as Kooba, Gogeldrie and south Benerembah, but less for areas where shallow aquifers have a much lower transmissivity, such as in the Yenda area or parts of Koonadan.

Appendix 2 reveals that the 1994 soil salinity survey has recorded lower actual salinity levels than for 1991 and 1992. It appears that soil salinity surveys following wet winters show higher salinity values than surveys after dry winters. The aquifer activity factor was used to lower the soil survey prediction curve to more realistic levels for all districts by some 10-20%. Less salinity is likely to occur than predicted from the 1991 and 1992 surveys on which the salinity curves are based, and this has now been accounted for.

Lack of time has prevented a review of the soil salinity prediction graphs and this work should be undertaken as part of the review in a couple of years.

The data used and the results of the soil salinity predictions for each sub-district for the current trend (No Plan) scenario are attached as Appendix 3. Table 4.2 summarises the outcomes.

Table 4.2: Areas of the MIA affected by salinity at five year intervals between 1994 and 2024 (*1)

Soil Salinity Areas		**1994**	**1999**	**2004**	**2009**	**2014**	**2019**	**2024**
Area with ECex 2-3 dS/m	ha	4184	5677	6822	7788	8638	9408	10115
Area with ECex 3-4 dS/m	ha	3204	4349	5227	5967	6620	7209	7752
Area with ECex 4-6 dS/m	**ha**	4915	6673	8021	9158	10160	11066	11898
Area with ECex 6-8 dS/m	ha	3815	5184	6236	7122	7902	8608	9257
Area with ECex >8 dS/m	ha	5100	5225	5351	5457	5551	5635	5713
Total	ha	21218	27107	31657	35492	38871	41926	44735
Soil Salinity % of Land		**1994**	**1999**	**2004**	**2009**	**2014**	**2019**	**2024**
Area with ECex 2-3 dS/m	%	0.03	0.04	0.05	0.05	0.06	0.06	0.07
Area with ECex 3-4 dS/m	%	0.02	0.03	0.04	0.04	0.05	0.05	0.05
Area with ECex 4-6 dS/m	%	0.03	0.05	0.05	0.06	0.07	0.08	0.08
Area with ECex 6-8 dS/m	%	0.03	0.04	0.04	0.05	0.05	0.06	0.06
Area with ECex >8 dS/m	%	0.03	0.04	0.04	0.04	0.04	0.04	0.04
Total	%	0.14	0.19	0.22	0.24	0.27	0.29	0.31

Comparison with the 1993 report "Present and Future Salinity Conditions in the MIA" by A. van der Lely shows that the current assessment provides lower estimates, from 25% to 14% for 1994, and from 41% to 31% for 2024. The reason for this reduction is the more careful analysis and weighting for each sub-district, but also the correction in the models for the outcome of the 1994 salinity survey, which suggested that lower salinity levels occurred during the early 1990's than suggested from the 1991 salinity surrvey. Appendix 2 gives the data in this respect.

The data of Table 4.2 are to be used by the NSW Agricultural Economics model, which by linear programming techniques and combination with other data is capable of calculating the agricultural salinity loss, for the No Plan scenario or any other scenario. The difference in salinity cost between runs represents the benefit of the option, or combination of options considered.

Table 4.3 shows the difference in No Plan scenario outcomes for the various sub-districts considered.

Table 4.3 : Predicted total areas affected by salinity in MIA sub-districts.

Area	**1994**	**1999**	**2004**	**2009**	**2014**	**2019**	**2024**
MIA	14	19	22	24	27	29	31
Koonadan	14	18	21	24	26	28	30
Gogeldrie	3	3	4	4	5	5	5
Murrami	27	31	35	37	40	42	44
Yenda	31	34	37	40	42	44	45
Kooba	8	13	18	21	24	27	30
Hanwood	25	33	39	44	49	53	57
North Ben	17	22	27	30	33	36	39
South Ben	6	10	13	15	17	19	21
Warrawidgee	7	12	16	19	22	25	27

The predicted area affected by salinity increases significantly over time. The variation between the southern parts of the MIA and the more northern parts stands out. For more detail on data and results reference is made to Appendix 3

5. DRAINAGE WATER SALINITY

5.1 DRAINAGE WATER SALINITY CONDITIONS.

Drainage water leaving the MIA has a raised salinity compared to the diverted irrigation water, which has a salinity of an average 0.15 dS/m. To understand the increase all the various sources of salt loading within the MIA have to be examined. This was carried out by van der Lely in the "Water and Salt Balance for the MIA and Benerembah" (1992) report. Table 5.1 shows the average volumes and average concentration of the identified sources of salts:

Table 5.1: Average volumes and Salt Loads from various sources in MIA Drainage.

	WDvol	EC	WDsl	BDvol	BDsl	WD netvol	WD netsl
LAF runoff	79360	na	18270	22000	4000	57360	14270
Escapes	110000	150	9900	21000	1890	89000	8010
Hort TD	10000	3000	18000	500	900	9500	17100
Hort Runoff	18000	160	1728	1000	96	17000	1632
Dry Area Runoff	0	150	0	0	0	0	0
Town Drainage	4000	300	720	1500	270	2500	450
Tubewell Drainage	4590	5000	13770	2500	7500	2090	6270
Lake Wyangan Pumps	4000	1100	2640	0	0	4000	2640
Seepage into Drains	100	7500	450	0	0	100	450
BID Pumps	-12000	400	-2880	0	0	-12000	-2880
Total	218050	17760	62597	48500	14656	169550	47941
Ave Salinity			478		504		471

The average concentration calculated of 471 uS/cm is weighted for volumes, which produces different results compared to the salinity values reported in the report "MIA Surface Water Quality Project", by Mark Shepheard (1994). The latter report merely took all the salinity values over a fourteen year period and calculated averages of these numbers, without regard to the accompanying volumes of flow. The Information of the key sites for drainage in the MIA are shown at Table 5.2.

Table 5.2. Statistics of salinity data at key sites in the MIA

Site	Mean (1)	St. Dev.	25%	Median	75%	Ave Flow	N
Main Canal	151	62	99	145	186	NA	141
Gogeldrie Main Drain	538	304	307	429	717	52	143
Yanco Main drain	1049	630	579	790	1475	25	171
Little Mirrool Creek	1093	1116	433	590	1283	155	134
Main Drain J	702	549	371	470	739	288	165
Willow Dam	645	511	365	444	628	519	151
BBO Outfall	707	183	602	683	763	337	126

(*1) EC as uS/cm, Flow as ML/day (averages for sampling days, not full hydrology)

A seasonal variation in concentration and salt load exists, as reported in the Water and Salt Balance study. The monthly values for the Willow Dam and Barren Box Outfall sites found in that study are shown at Table 5.3.

Table 5.3: Observed Willow Dam and Barren Box Outfall salinity (mg/L)

Month	Willow Dam	Barren Box Outfall
July	955	446
August	693	465
September	541	476
October	284	484
November	276	476
December	246	469
January	244	459
February	216	424
March	214	412
April	238	406
May	270	410
June	528	404
Mean for Year	392	444
Volume weighted mean	280	NA

Table 5.3 shows the water salinity in Mirrool Creek is above 420 mg/L (700 EC) from June till September. The actual values in September depend on the opening date of the irrigation season. The present procedure is to dilute flows in Mirrool Creek from the river when the salinity at Willow Dam is above 700 EC and a demand for irrigation exists downstream.

The various sources of salt identified at Table 5.1 may change with time. The prediction of future trends of salinity in the drainage system is discussed next.

5.2 MODEL TO EVALUATE TRENDS.

The methodology of Section 4.2 was used to assess present and future salt loads from runoff and the resultant salinity in the drainage system. The following data was used (next page):

Area considered	128,000 ha
Average runoff volume	0.62 ML/ha
Calibration coefficient	0.3
Runoff salinity Non Saline Soils	240 uS/cm
Escape drainage salinity	160 uS/cm
Volume of escapes	110,000 ML

The area considered covers the irrigated areas upstream of Willow Dam, but not the dry areas, or irrigated areas not having drainage. The total large farm area upstream of Willow Dam is 158,000 ha, including 10,000 ha of horticulture (Section 2.1).

From this it follows that the runoff volume would be 0.62 x 128,000 = 79,400 ML. The assessment of the water balance in section 2 shows 100,000 ML/yr, however it applies to a 19% larger area. The 0.3 value for the calibration coefficient is higher than recommended by Merrilees (1992), however this value was found the most appropriate when developing the soil salinity prediction graphs.

5.3. PREDICTION OF FUTURE DRAINAGE WATER SALINITY

The prediction of future drainage water salinity in the MIA depends on the estimation of all the components together making up the total salt load. The main factors believed to be subject to significant change over the next 30 years are the salt loads from large area runoff and horticultural tile drainage. These, and the other salt loads are discussed below.

5.3.1. Large Area Runoff Salt Loads

The conclusion of Section 5.2 is that the prediction of the future drainage water salinity depends on the areas of various soil salinity classes within the MIA. These were determined at Section 4.2. Results of Section 4.2 apply for the whole MIA. The results of Table 5.4 are similar, but corrected for that part of the Yanco Area that drains back to the Murrumbidgee River.

Table 5.4. Present and Future Salinised Areas of lands of the Willow Dam Catchment within the MIA. (*1)

Soil Salinity % of Land		1994	1999	2004	2009	2014	2019	2024
Area with ECex 2-3 dS/m	%	0.04	0.05	0.06	0.06	0.07	0.08	0.08
Area with ECex 3-4 dS/m	%	0.02	0.03	0.04	0.04	0.05	0.05	0.06
Area with ECex 4-6 dS/m	%	0.04	0.05	0.06	0.07	0.07	0.08	0.08
Area with ECex 6-8 dS/m	%	0.03	0.04	0.05	0.05	0.06	0.06	0.07
Area with ECex >8 dS/m	%	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Total	%	0.20	0.25	0.29	0.32	0.35	0.37	0.40

(*1) The area u/s of Willow Dam considered for the assessment is 108,000 ha.

It may be noticed that the proportions affected by salinity are higher if the Gogeldrie and Warrawidgee Areas are excluded (compare: Table 4.2).

Multiplying the areas of Table 5.4 with the volume of farm runoff and a runoff calibration coeffcient gives the estimated salt load. The runoff volume from large area farm land in the MIA has been estimated by Arun Tiwari (1993) to be 0.47 ML/ha, whilst van der Lely (1992) estimated a volume of 0.78 ML/ha. The latter value was an average including horticultural runoff. A average value of 0.62 ML/ha has been chosen for this excercise to achieve a match between areas drained and total volume of farm runoff as per Figure 2.1 (section 2.2). The runoff calibration coefficient proposed by the MDBC (1992) is 0.2, but during calibration of the salinity prediction curves for the MIA it was found that higher value of 0.3 is more appropriate. The result after multiplying all the sub-areas for all five year intervals is shown at Table 5.5.

Table 5.5 : Predicted Runoff Salt Load from the MIA over time.(*1)

Source	1994	1999	2004	2009	2014	2019	2024
Runoff Salt Load (tns)	18270	19404	20274	21008	21655	22239	22776

(*1) Willow Dam Catchment only.

It is shown that over thirty years the estimated salt load in the runoff would increase from about 18,200 T/yr to 22,800 T/yr, or by 4,600 T/yr.

5.3.2. Horticultural Tile Drainage Salt Load.

The tile drainage salt load is known to decrease with time. Studies by DWR during the early 1970's (van der Lely and Ellis, 1971), and early 1980's (Hoey, 1981) provided estimates of the decline. Monitoring during 1990 of the same farms as for the 1980 survey concluded a decrease from an average of 3.9 dS/m to 3.0 dS/m. The initial salinity from regression analysis was found to be about 6.0 dS/m. The volumes involved were estimated to be about 1.7 ML/ha during the 1970's and 1980's, however these may now have decreased due to the handing over of tile drainage pumps to the landholders, providing an incentive to become less wasteful.

NSW Agriculture, for the Land and Water Management Plan, summarised these results and reviewed the decline over time (Sue McAlpine, 1994). She combined all the data and came to the conclusion that the decline would be over 60 years, not 25 years as believed during the early 1970's. Her work also resulted in predictions for salt load increases of potential horticultural expansion into large area farm land and discharge of drainage to the MIA system.

The work by McAlpine highlighted that the decrease of average tile drainage salinity of any particular installation over time is following a more exponential decrease, rather than a linear decrease, however such analysis was not submitted, the reason being that the data were too scattered to justify such analysis. Nevertheless it is clear that improvements in the prediction are necessary.

This report suggests a further alternative approach to estimate the salinity decrease over time.

Firstly the salt load of an installation should be split between a base salt load and a leaching salt load. The base salt load relates to the constant inputs of salt into the soil profile drained by the system. This is the salt from the irrigation water and any salt derived from seepage processed into the farm. The latter is small for most farms but not insignificant for some. At 7 ML/ha water application and 160 dS/m water salinity this quantity is about 0.8 T/ha.

Secondly the remaining leaching salt load decreases by a proportion each year. This proportion may be estimated from the slope of the regression function during the earlier years after installation. The salinity decrease is applied and the same proportional decrease applied to the remainder, thereby effectively creating an exponential type decrease function. The outcome is shown at Figure 5.1.

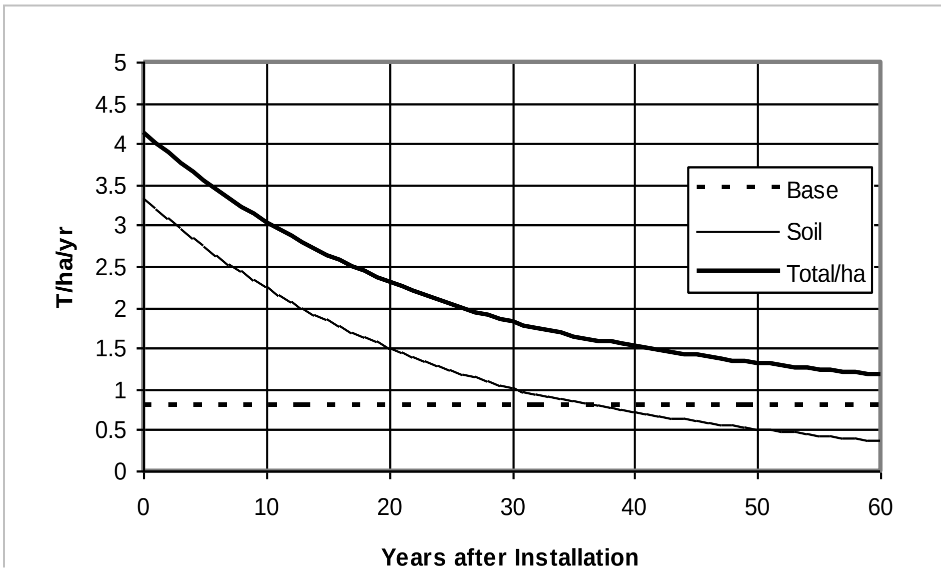

Figure 5.1: Estimated Average Decrease of Hoticultural Salt Load with Time

The next step is to apply this curve for all years in which tile drainage installation were made since 1956 and also make an allowance for future installations in the gazetted horticultural areas. The results are added up resulting in the behaviour of salt loads from tile drainage from the MIA horticultural areas. This is shown at Figure 5.2.

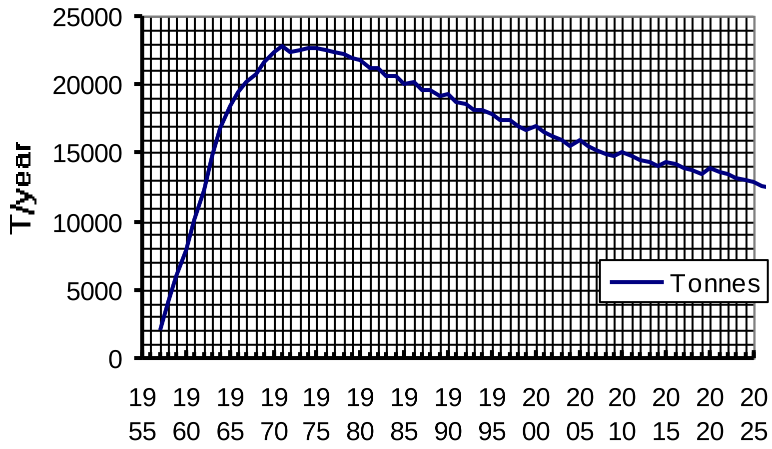

Figure 5.2 : Total Annual Salt Load from Horticultural Tile over Time

From this it would appear that the salt load peaked during about the mid 1970's, that at present the salt load is in the order of 18,000 tonnes, and that salt load in 30 years from now would be in the order of 13,000 T/year.

Tile drainage salt loads vary with seasons and between years. DWR Statistical Hydrology has estimated that the salt load frequency distribution between years, for the winter season and for the October to end April season. This is shown at Table 5.6

Table 5.6: Percentile distribution of winter and summer total tile drainage salt loads

Percentile %	10	20	30	40	50	60	70	80	90
June-August	6000	5600	5100	4700	4200	3800	3500	3100	2500
Oct-April									

The effect of a higher salt load in a specific year does not necessarily translate into a higher salinity at Willow Dam in Mirrool Creek. This effect has not ben assessed at this stage.

5.3.3. Other Salt Loads.

The other sources of salt loads are likely to remain more or less the same over time. The initial values are all based on the values in the Water and Salt Balance report (1992).

Escape salt loads behave with volumes and the river salinity. The latter is expected to increase by about 1% per year, this being the order of increase over the last 25 years. The reaon for the increase relates to river salinity which because of dry land salinity processes is slowly increasing.

Seepage into drains may increase somewhat as the areas of high watertables increase further. An increase from 400 T/yr to 600 T/yr over 30 years is expected.

The salt load from the Lake Wyangan basin may decline initially because of the use of the new pumps, but for sustainability within the basin it is necessary to maintain a salt export strategy. A constant salt load of 4,000 T/yr is proposed. A reduction could only be considered if strategies in tile drainage runoff within the Lake Wyangan catchment were successful.

Town Drainage salt loads are not expected to change over the next 30 years.

The Benerembah pumps will extract salt loads from Mirrool Creek. The increase depends on the increase of salinity in Mirrool Creek, which therefore has to be entered here after the preliminary results are known. As will be shown, Mirrool Creek salinity is not expected to change much, hence the salt load to Benerembah will remain about the same.

The salt loads from dry area runoff in the MIA is not expected to increase in salinity since these areas are essentially non-saline.

5.3.4. Summary of Future salt Loads.

Table 5.7 shows the combined effect of all the salt sources in the MIA.

Table 5.7 : Combined salt loads in the drainage system of the MIA (*1)

Source	1994	1999	2004	2009	2014	2019	2024
Runoff Salt Load (tns)	18270	19404	20274	21008	21655	22239	22776
Escape flow SL (tns)	9900	9999	10099	10200	10302	10405	10509
Tile Drainage GRFT	18000	16800	16000	15000	14200	13700	13000
L Wyangan	2640	2640	2640	2640	2640	2640	2640
Grw Seepage	450	500	550	600	650	700	750
Tubewells	13770	13770	13770	13770	13770	13770	13770
Town Drainage	720	720	720	720	720	720	720
Hort Runoff	1728	1728	1728	1728	1728	1728	1728
DryLand Runoff	0	0	0	0	0	0	0
BID pumps	-2880	-2880	-2880	-2880	-2880	-2880	-2880
Total	62598	62681	62901	62786	62785	63022	63014

(*1) Applying for area draining towards Willow Dam

It is shown whilst there is an increase in large area farm runoff salt load and a decrease in tile drainage salt load, the overall effect is that the combined salt load stays virtually the same. The salt load may be converted to an average salinity at Willow Dam after correction for the flows diverted to Benerembah at Brays Dam. This is shown at Table 5.8.

Table 5.8: Predicted Salinity at Willow Dam over next 30 years

Source	1994	1999	2004	2009	2014	2019	2024
Runoff EC	384	408	426	441	455	467	478
Willow Dam EC	471	472	474	473	473	475	475

5.4 IMPACT OF HORTICULTURAL EXPANSION

A key issue at the time of preparing the MIA Land and Water Management Plan is the impact of discharge of tile drainage effluent from horticultural expansion in large area farms. Whilst the actual salt loads from such expansion are yet to be determined, Table 5.9 shows the impact of discharge from an extra 2,800 hectares of tile drained land, for two scenarios:

1. the salt load discharge is controlled to a constant 1.6 T/ha/yr
2. the average discharge rate is 0.8 ML/ha (applicable for efficient irrigation systems) and the initial salinity being 6.0 dS/m, but decreasing over time as discussed at Section 5.3.

Table 5.9. Predicted salinity at Willow Dam for two scenarios of horticultural effluent discharge.

Scenario 1: 1.6 T/yr over 2800 ha (constant)

Year	1993	1998	2003	2008	2013	2018	2023
Tonnes/year	0	4480	4480	4480	4480	4480	4480
New Salt Load	62598	67161	67381	67266	67265	67502	67494
New WD EC	471	516	518	517	517	519	519
Increase	0	44	44	44	44	44	44

Scenario 2: 0.8 ML/year, EC 6 dS/m first year, declining with time, 2,800 ha.

Year	1993	1998	2003	2008	2013	2018	2023
Tonnes/year	0	7630	6600	5767	4613	4068	3627
New Salt Load	62598	70311	69501	68553	67398	67090	66641
New WD EC	471	547	539	530	518	515	511
Increase	0	75	65	57	45	40	36

It is found that the average drainage water salinity at Willow Dam increases by up to 44 EC (=uS/cm) for scenario 1 and 75 EC for scenario 2 The actual increase depends also on the rate of installation, which may be slower than the assumed 5 year time frame..

To obtain the water salinity increase for any particular season it is proposed to increase all values of Table 5.3 by the relevant proportions, which is the ratio of the results at Table 5.9 and 5.8. This may easily be implemented by the reader. It needs to be noted that the final assessment of the number of additional tonnes of salt added to the system has not yet been determined.

6. OPTIONS TO CONTROL FUTURE LAND SALINITY

Land salinity is influenced by watertable conditions, which in turn are influenced by recharge and discharge factors. A sound understanding of the magnitude of each of the factors involved enables the best possible decision making with regard to the options that should be implemented to overcome salinity.

Section 2 discusses the water balance for the MIA. Of this, the groundwater balance of the large area farms is of particular interest. The main factors identified are:

- groundwater recharge from cropped areas
- channel seepage
- capillary rise
- uptake by deep rooted species
- leakage to deeper aquifers
- lateral groundwater outflow
- groundwater pumping

Groundwater recharge from cropped areas represent the highest volume, about 100 GL/year in the MIA. A small reduction in this factor would have significant beneficial effects. The recharge from crops depend on the type of crops (rice, pastures, winter crops, summer crop, vegetables) and the area thereof.

Effective rice growing controls are considered important to minimise recharge. The DWR Rice Growing Policy currently adopted and supported by the Rice Growing Policy Advisory Group aims at achieving sustainability through these policies. At present the policy is to restrict rice growing to 30% of the suitable farm area, or 65 hectares, whichever is the largest. This policy may be reviewed if necessary. The area of rice grown in the MIA is about 40-45,000 hectares per year and the recharge from this is about 60,000 ML, which is a large proportion of all recharge from cropped areas.

Except for the southern fringe areas, where exceedances of the 16 ML/ha rice water use target is not uncommon, most rice fields in the MIA do meet the current policy targets. The only means by which accessions from rice may be further reduced is by rducing the rice areas themeselves, eg from 30% hydraulic loading to 15% of the farm suitable areas.

Recharge from other crops and rainfall also contributes significant amounts to the groundwater system. Significant controls may be effected by appropriate irigation and drainage management on-farm. This is within the sphere of responsibility of NSW Agriculture.

The leakage to deeper aquifers may be influenced by deep aquifer pumping. This option has received prominance in Coleambally and could be useful for the southern MIA, but not in the northern areas, where deep aquifer transmissivity and salinity are less favourable.

The shallow aquifer lateral groundwater outflow provides some protection in the fringe areas of the MIA. The dissipation by this path will diminish once the areas adjacent to the MIA will also have higher ground watertables.

Seepage from channels may be reduced where the rates are high. Much of the 12 GL/year identified as channel seepage however is in the form of low rate seepage and control measures for these small rates are unlikely to make a significant difference.

Trees and deep rooting species may remove significant volumes of groundwater. In the MIA however the estimated areas of remnant tree areas is only about 1000 hectares, or less than 1%. This means that trees are not making a significant contribution to sustainability at this time. Tree planting schemes could be considered, however the option is expensive and possibly of limited effectiveness.

Watertable control options using groundwater pumping is the focus of this report. This option also tends to be expensive. Therefore, in the consideration of this option the design criteria should be determined for conditions whereby all other avenues of reducing recharge are considered as well.

Sections 7 and 8 of this report discusses the groundwater pumping option in isolation from the other options. NSW Agriculture is considering effective and economic on-farm options in parallel. It is proposed to use the model described at Section 4 to determine the relative impact of each of the options just described in terms of reduced salinity, and various or a combinations of options.

7. DESIGN CRITERIA

The objective of this option is to lower the groundwater levels by groundwater pumping, thereby reducing or reversing the salinisation process and reduce the consequent agricultural yield loss. The design criteria used determine the cost and benefits of the schemes proposed. The choice of these criteria will render a scheme effective or ineffective, economic or uneconomic.

7.1. TYPES OF SCHEME

Subsurface drainage has been an effective way of protecting irrigated lands from the effects of soil salinity and watertable induced waterlogging. The methods used include horizontal and vertical drainage systems.

Horizontal pipe drainage, often referred to as tile drainage, collects groundwater from horizontal perforated pipes installed at about 2.0 metres depth, thereby controlling the watertable level. The installation costs are relatively high, which tends to restrict its viability to high value crop enterprises. It is unsuited where the soil permeability at the depth of drainage is very low. This is often the case in the large area farms of the Riverine Plain.

Vertical drainage consists of the installation of specially designed screens into an aquifer at some depth below the surface and pumping of groundwater using various means. Single bores may be used or several closely spaced bores may be hooked up together to form a single system. Single bores may be pumped using submergible pumps, shaft driven pumps, centrifugal pumps or airline systems. Multiple systems may be pumped using centrifugal pumps or airline systems driven by compressors.

Where multiple bores into very shallow sands are installed using jetting techniques they are often called "spearpoints".

The pumped water is either discharged to waste to evaporation areas or the drainage system, if present, or it may be reused in the channel supply. Very saline effluent should always be discharged to evaporation areas. Discharge into on-farm or district supply channels is only considered feasible where the salinity of the effluent is below 5,000 uS/cm. For on-farm systems a 3,000 uS/cm criterion may be more appropriate. The end result depends on the shandying achieved and the resultant salinity of the water supply. Values above 500-700 uS/cm may result in crop yield reduction if there is insufficient soil leaching.

Table 3.2 shows that the average groundwater EC in the MIA is about 8,000 uS/cm, hence there is little choice but to design any future groundwater pumping scheme in the context of using evaporation areas.

About 7 vertical groundwater pumping schemes exist in the MIA to protect horticultural plantings. Another 6 public and about 4 private vertical drainage bores exist to protect large area farm land. Their use is being restricted to minimise salt loading of the drainage system. In addition to these, about 10 large area private horizontal tile drainage drainage installations exist in the MIA. Four of these were constructed during the early 1980’s for experimental purposes, each protecting about 10-100 hectares of land.

7.2 DESIGN PUMPING RATES

The height of the watertable once equilibrium occurs is dependent on several factors, grouped together into accession factors and discharge factors. The actual watertable levels fluctuates around this equilibrium dependent on seasonal conditions and the proximity of rice fields in any given year. The equilibrium average watertable is a good indicator of the risk that exists. The critical depth in the MIA and CIA is about 1.3 metres. The accession factors include the proportion of land under rice and the type of soils used for rice growing, rainfall (especially winter rainfall), accessions from crops other than rice, channel seepage, and the presence or absence of a surface drainage system to remove unwanted water. The discharge factors include leakage to deeper aquifers, uptake by deep rooting species or trees, capillary rise to the land surface, seepage into deep drains, depressions and gravel pits, and groundwater pumping.

To understand the effects of groundwater pumping the groundwater behaviour in a district needs to be understood. On a district scale most land may not be affected by salinity and only a small proportion requires protection. The groundwater pumping option is concerned with the latter. If a groundwater bore is constructed at a specific location (probably in the vicinity of salting occurring) then the pumping effort will result in a lowering of the pressure level in the aquifer, and by leakage, a lowering of the watertable. The shape of the watertable reduction is a cone of depression, the largest drawdown being close to the bore, and less and less with distance away from the bore.

The groundwater bore is pumping until an equilibrium is reached whereby the pumped volume is equal to the accessions within the so called area of influence, plus any groundwater inflow into this area of influence. Because of the slope in the landscape (about 0.4 m/km in the MIA) the cone of depression will tend to be shaped as an ellipse, with the location of the pumping bore in the more upstream of the two centres. This is important when designing locations of bores in relation to the occurrence of saline areas.

Within the area of influence a combination of non-saline land and salt affected land occurs. The net accessions of both type of lands will need to be removed by the bore. Accessions from non saline lands enter the groundwater system and over time find their way to the discharge areas which are becoming saline. These accessions may be intercepted by deep rooting species, or trees, and a proportion may result in deep leakage. If this happens the pressure towards the discharge areas may be less, and less land is affected by salt. An assessment of the benefits of these processes in terms of reduced areas with salinity may be made with the model described by van der Lely (section 4).

In the absence of other discharge factors the discharge areas would grow and an equilibrium between accessions and capillary rise in the discharge areas would occur. This applies to the Tragowal Plains area. Groundwater pumping bores if installed would replace the capillary rise process and the saline area becomes less.

The volume to be removed by groundwater pumping therefore is a matter on finding the appropriate balance between accessions and discharge factors. On a district scale the volume to be removed could be determined from the groundwater balance, if all factors are accurately known.

These approaches to derive the design pumping rates are fraught with difficulties, because it tends to ignore many of the interactions between watertable depth and accessions from various crops, between watertable depth and uptake by trees or deep rooting crops, between watertable depth and channel seepage, etc. This is a variable and not always linear factor across the landscape.

All other factors being equal, the minimum volume of groundwater that needs to be removed relates to the minimum leaching concept. A certain amount of leaching is necessary to maintain a suitable rootzone salinity, else salts in the irrigation water will accumulate over time. In the MIA this amount is about 0.1 ML/ha. (van der Lely, pers. comm.). Another approach is to look at groundwater flow between rice areas and non rice areas over the period of one season. Under average aquifer conditions this volume has been assessed at 0.35 ML/ha/yr (van der Lely, 1981). The SWAGSIM models of CSIRO calculate similar volumes. This flow may be equated with the theoretical salinity hazard but it is unlikely that all of this flow needs to be intercepted to achieve sustainability.

The CSIRO has estimated from the SWAGSIM groundwater model in the Hanwood area that pumping at an equivalent rate of 0.2-0.25 ML/ha/year over the whole area, with pumps in targeted locations of the landscape would ensure that target watertables can be achieved and net upward capillary rise and salinisation rates in most of the landscape minimised (Prathapar, 1994). Salinisation of some low lying depressions however may need to be accepted.

Where deep leakage is a significant factor the lower end of the 0.2-0.25 ML/ha range is an appropriate starting criterion in the MIA and Coleambally. This initial economic assessment is based on pumping rates of 0.2 ML/ha being sufficient to achieve sustainability.

7.3. DISPOSAL OF EFFLUENT

The MIA Land and Water Management Plan Committee, after consultations made the decision that any future watertable control scheme should not be at the expense of the downstream water users or the environment. Any additional salt loading should be retained within the MIA itself.

The salt loads from various sources in the MIA were discussed at Chapter 5. These include small quantities of salt loads from large area groundwater pumping, mostly in the Murrami and Kooba areas. Before 1984 additional vertical groundwater pumping installations were being constructed, but the assessment of future drainage water salinity at the time led to the view that, if left unchecked, the ultimate consequences of continued installations would eventually have very serious consequences downstream (eg see van der Lely, 1983). Consequently, an embargo was declared on the further construction of additional installations, and the operation of the existing installations was curtailed.

At the time a typical vertical groundwater bore would pump up to 2-3 ML/ha over the area of measurable groundwater drawdown. A sound understanding of required groundwater pumping rates, as discussed in the previous section did not exist as yet.

Consequently, any further sub-surface drainage scheme has to consider evaporation areas as a means for disposal. The design criteria for these ponds has to meet several criteria.

- there needs to be sufficient capacity at all times
- the banks need to be sufficiently resistant to erosion
- any seepage return to the groundwater system has to be sustainable and should not affect productive land.
- access to the site should be possible at all times.
- maintenance should be possible during certain times of the year

The capacity requirements can be met by knowing the design discharge rates of the pumping scheme. In the case of vertical drainage bores these can be more effectively controlled than with horizontal tile drainage schemes. The first can be switched off any time, but the in the latter the groundwater flows to the lower parts of the system and the need to pump these volumes is greater. A safety margin for the occurrence of wet seasons in wet years therefore needs to be included in the capacity in that situation. This should be achieved by an increase in the area of evaporation ponds rather than increasing the height of banks. The latter has the most relevance when considering the relative pumping rates and evaporation rates between seasons.

Erosion protection may be improved by maintaining less depth of water in ponds, by reducing the side slopes to about 1 in 7 and by wide, well compacted banks. The application of erosion control by old tyres or other placements may be necessary. Wide banks which can be used by vehicles also improves access and allows easier maintenance.

As far as the seepage loss is concerned, minimisation of this is critical where groundwater levels are deep and any loss would result in the formation of groundwater accessions and mounds. Where the groundwater levels are already close to the surface the addition of the seepage loss can be controlled by interceptor drainage. These may be vertical or horizontal sub-surface drains, which return the leaked effluent to the ponds. For high efficiency no more than 10% or so of the groundwater volumes pumped should be allowed to leak, and this means that the leakage rate should be kept below about 0.5 mm/day.

Low leakage may be achieved by site selection. The presence of clay soils to depth is a first criterion. If no aquifer system occurs within about 15-20 metres from the surface, or if there is bedrock close to the surface there would be confidence that leakage will be small, controllable by interceptor horizontal drainage. If site investigations indicate higher than acceptable leakage than a liner may need to be applied. Compaction as a sole measure is unlikely to be effective since saline effluents will tend to make these ineffective.

Muirhead and Moll (1994) discuss a range of issues related to evaporation areas and discuss cost aspects.

In the MIA the northern fringe areas are underlain by bedrock not far from the surface, or the thickness of low permeable clays is extensive, and aquifer presence is much less. All these factors contribute to improved chances that no leakage to the regional groundwater system would occur. The local leakage through superficial layers may easily be controlled by interceptor drainage. To the south of the MIA on the other hand the occurrence of shallow aquifer systems at 8-15 metres is quite widespread, and the location of a suitable site where seepage could be controlled is far more difficult.

Consideration of the disposal aspect was a major contributing factor in the selection of the two proposed sub-surface drainage schemes of Chapter 8.

7.4. OTHER DESIGN ASPECTS

Other design aspects of sub-surface drainage systems relates to the siting of bores, depth of installation, pumping tests, the methodology, pumping rates, the materials used, pumps, equipment, pipelines, electricity connection, etc. As far as the current study is concerned, these were considered by Mr Arun Tiwari of DWR Griffith, and are further dealt with at Chapter 8.

8. COST/BENEFIT ANALYSIS OF TWO POSSIBLE GROUNDWATER PUMPING SCHEMES

Two schemes are considered, a vertical groundwater pumping scheme at Murrami and and a horizontal sub-surface drainage scheme at Benerembah. There are other areas in the MIA that are equally worthy of consideration, but these have not been considered as yet. The purpose of the evaluation of these two schemes is to determine typical costs and benefits that may be derived from such schemes. This information may then be used to determine how this watertable control option stacks up against other options, allowing decions to be made. This may include extension of sub-surface drainage to other parts of the MIA.

It is stressed that the evaluation of this Chapter, whilst using actual areas and maps, is for analysis purposes only. At this stage there is no commitment by anyone, including the DWR, the Management Board and the Land and Water Management Plan Committee, to proceed with the of the schemes discussed below. The implementation would depend on firstly the economic viability, and secondly on satisfactory arrangements and cost sharing by all parties concerned.

8.1. SCHEME 1: VERTICAL SUB-SURFACE DRAINAGE SCHEME AT MURRAMI

8.1.1 Description and Costs

The scheme is designed to protect an area of about 20,000 hectares in the Murrami and Kooba sub-districts. The number of drainage bores proposed is 30, pumping an average of 5 L/s (0.43 ML/day). The pumped water will be conveyed by a network of pipelines to evaporation basins. For the location of evaporation areas several possibilities exist, all of which are located near the slopes of the in the Wumbulgal hills and Mount Harris.

Figure 8.1 is a tentative plan used for design purposes and discussion. It shows sites for pumping and the possible evaporation areas.

As far as the design pumping rate is concerned a value of 0.2 ML/ha was used over the whole of the project area (see section 7.1). The decision to use many small capacity drainage bores rather than a fewer number of higher capacity bores was influenced by the agreed concensus between dr Prathapar and the author that the smaller capacity bores would be more effective in targeting the locations in the landscape where groundwater pumping at the smallest possible design rate would be most effective overall.

Appendix 4, prepared by Mr Arun Tiwari of DWR, contains tables with costs and values used for design purposes including the type of pumps proposed to be used and power requirements. It was found that the cost of the scheme, to be constructed over a 15 year time frame adds up to $ 6.19 million million, or about $431 per hectare. Operational costs once fully constructed are about $80,600/year.

The cost of the scheme is highly sensitive to the volumes of groundwater being pumped. This scheme assumes 0.2 ML/ha therefore 4000 ML of effluent needs to be disposed off. This requires an evaporation area of about 400 hectares once the scheme is completed.

Details of the 72 km pipeline design, most of which is 150 and 200 mm diameter and avoids the use of expensive 450 mm pipes, are shown at Appendix 4. Because most pumps are low capacity pumps the cost of three phase power line extensions is also being minimised.

8.1.2 Benefits

The benefits of the project is the lowering of salinity in the landscape and the maintenance of these at sustainable levels. This assessment depends on the assessment of the difference between the No Plan Scenario and the scenario including the implementation of the option. The model described at Chapter 4 was used to make these assessments. Table 8.1 shows the results for the No Plan scenario and Table 8.2 shows the results for the 20,000 hectares, 6.19 million dollar scheme, assuming that implementation is increasing by 1000 ML/yr every five years until year 20 (2014).

Table 8.1: Predicted proportions of land affected by salinity for the No Plan scenario in the Murrami/Kooba area.

Soil Salinity % of Land	1994	1999	2004	2009	2014	2019	2024
Area with ECex 2-3 dS/m	6.3	7.2	7.8	8.4	8.9	9.3	9.7
Area with ECex 3-4 dS/m	4.8	5.5	6.0	6.4	6.8	7.1	7.4
Area with ECex 4-6 dS/m	7.4	8.4	9.2	9.9	10.4	10.9	11.4
Area with ECex 6-8 dS/m	5.8	6.5	7.1	7.7	8.1	8.5	8.9
Area with ECex >8 dS/m	2.6	3.6	4.4	5.1	5.6	6.2	6.6
Total	26.9	31.3	34.6	37.4	39.8	42.1	44.1

Table 8.2. Predicted salinity in the Murrami/Kooba area if a sub-surface drainage scheme is implemented.

Soil Salinity % of Land	**1994**	**1999**	**2004**	**2009**	**2014**	**2019**	**2024**
Area with ECex 2-3 dS/m	6.51	5.55	4.82	4.20	3.65	3.16	2.71
Area with ECex 3-4 dS/m	4.98	4.25	3.69	3.21	2.80	2.42	2.07
Area with ECex 4-6 dS/m	7.64	6.51	5.65	4.93	4.29	3.71	3.17
Area with ECex 6-8 dS/m	4.98	3.66	2.65	1.80	1.05	0.37	0.00
Area with ECex >8 dS/m	2.46	1.64	1.01	0.48	0.02	0.00	0.00
Total	26.56	21.62	17.82	14.62	11.80	9.66	7.95

In general it is believed that a sustainable system has been achieved if the areas with salinity above 2 dS/m can be restricted to below 10-15%, and according to the model outcome this is being achieved with a margin.

Since there is a degree of uncertainty regarding the input numbers into the model and therefore the predicted salinity values, it is recommended that the scheme, if justifiable on economics, environmental and sustainabiltity criteria is implemented over the longer time frame, with expansion of the scheme at all times being subject to review of groundwater and soil salinity trends based on monitoring.

Readers are referred to Appendix 5 for reference of the various data inputs and outputs for the soil salinity assessment.

The Agricultural salinity Loss assessment model of NSW Agriculture (eg Graham Marshall et all, 1994) is proposed to be used to assess the salinity benefits that may be obtained from this scheme. The DWR Economics group may then carry out the full economic evaluation of the option, which includes the consideration of other benefits, eg road benefits.

8.2. SCHEME 2: HORIZONTAL SUB-SURFACE DRAINAGE SCHEME IN NORTH BENEREMBAH

8.2.1. Description and Costs

Around 6,000 ha in the north Benerembah area is affected by soil salinity and productivity is reduced. The only remedy to overcome this situation may be the removal of salts by sub-surface drainage of the watertable perched on denser layers below 2-4 metres. Since aquifers systems from which water may be pumped are generally not present the only means of reclamation is horizontal (tile) drainage.

The conceptualised scheme consists of installing tile drains in about 24 farms, and pipe the effluent to an evaporation area close to Barren Box Swamp.

In the MIA large area farms often the shallow clay soils within 2 metres from the surface have permeability values too low for the effective removal of sufficient volumes of groundwater. It is desirable to remove a minimum of about 0.2 ML/ha/year. Horizontal pipe drainage should be installed in the most permeable layer, limited only by the trenching machines capacity to dig to certain depths. The machine now available through AussieDrain Pty Ltd is capable to dig to up to 6 metres depth. This increases tremendously the opportunity to use the most permeable layer avilable in the soil profile for installation of drains. From bore logs in the area it is found that In north Benerembah this depth often is about 3-4 metres. Such depths have been used for the design of the scheme, allowing drain spacings of several hundreds of metres.

Appendix 4, prepared by Mr Arun Tiwari of DWR, gives detailed information on design aspects for this project.

The actual design groundwater pumping rates is based on 0.3 ML/ha/year because with horizontal pipe drainage the volumes are less easy to control. This meant that the total volume of the scheme over 6,000 ha is 1,800 ML, and the minimum evaporation area needs to be 180 hectares. An area of 216 hectares has been allowed for to provide a 20% margin (Appendix 4, part 2).

The cost of the scheme as designed is $5.2 million with operating costs of $47,500/year.

The 6,000 hectares of the scheme is located in a 20,000 ha large area of northern Benerembah. The assessment of the No Plan scenario indicated that about 38% of the landscape would be affected by salinity in 30 years time, up from about 17% at present. Not all the land of the scheme is presently salt affected. This means the scheme the scheme should be introduced gradually over a 10-20 year time frame and at present any construction should be targeted towards the more susceptible salinity locations and extended as the need arises.

8.2.2 Benefits.

The sub-surface drainage system would be situated for the most part in the Warrawidgee sub-district and partly in the North Benerembah sub-district. The No Plan scenario results for Warrawidgee are not considered fully representative, because much of Warrawidgee at the present time is not subjected to high watertables, and that would make the assessment invalid. North Benerembah was selected as having the representative No Plan scenario results. These were used and the area scaled up to assess the reduction in salinity for the volumes to be pumped.

In many areas underlain by shallow aquifer systems the effect of horizontal pipe drainage has been that a much larger area than actually targeted for sub-surface drainage actually receives benefits in terms of reduced salinity risk. For instance, with a ten hectare installation in the Kooba area the area protected was about ten times larger. A multiplier effect of this order should not be expected for the Benerembah area, where the horizontal continuity is much less because of the lack of aquifers or shoestring sands. Nevertheless it is reasonable that some areas adjacent to the installations would benefit, hence instead of benefits extending to 6,000 hectares only, a larger proportion of north Benerembah would benefit.

Since there is a degree of uncertainty regarding the input numbers into the model and therefore the predicted salinity values, it is recommended that the scheme, if justifiable on economics, environmental and sustainabiltity criteria is implemented over a longer time frame, with expansion of the scheme at all times being subject to review of groundwater and soil salinity trends based on monitoring. The construction would be carried out as the need arises, and effectively all the land within the 20,000 target area requiring protecting will get benefit.

In general it is believed that a sustainable system has been achieved if the areas with salinity above 2 dS/m can be restricted to below 10-15% and this would be achieved.

The benefits of the project is the lowering of salinity in the landscape and the maintenance of these at sustainable levels. This assessment depends on the assessment of the difference between the No Plan Scenario and the scenario including the implementation of the option. The model described at Chapter 4 was used to make these assessments. The sub-district selected for thTable 8.3 shows the results for the No Plan scenario and Table 8.4 shows the results for the 20,000 hectares, 6.19 million dollar scheme.

Table 8.3 : Predicted soil salinity levels in northern Benerembah for No Plan scenario

Soil Salinity % of Land	1994	1999	2004	2009	2014	2019	2024
Area with ECex 2-3 dS/m	2.6	4.3	5.6	6.6	7.6	8.5	9.3
Area with ECex 3-4 dS/m	2.0	3.3	4.3	5.1	5.8	6.5	7.1
Area with ECex 4-6 dS/m	3.0	5.0	6.5	7.8	8.9	9.9	10.9
Area with ECex 6-8 dS/m	2.4	3.9	5.1	6.1	6.9	7.7	8.5
Area with ECex >8 dS/m	6.7	5.8	5.1	4.5	4.0	3.5	3.0
Total	16.7	22.3	26.5	30.1	33.3	36.1	38.7

Table 8.4 : Predicted Soil salinity levels in northern Benerembah if a horizontal pipe sub-surface drainage scheme is implemented

Category		1994	1999	2004	2009	2014	2019	2024
Area with ECex 2-3 dS/m	%	3.14	3.04	2.97	2.91	2.85	2.81	2.76
Area with ECex 3-4 dS/m	%	2.40	2.33	2.27	2.23	2.18	2.15	2.11
Area with ECex 4-6 dS/m	%	3.69	3.57	3.48	3.41	3.35	3.29	3.23
Area with ECex 6-8 dS/m	%	3.42	2.56	1.89	1.33	0.84	0.39	0.00
Area with ECex >8 dS/m	%	4.32	2.91	1.82	0.91	0.10	0.00	0.00
Total	%	16.96	14.40	12.44	10.78	9.32	8.63	8.10

As with the Murrami scheme the project indicates that the volumes to be pumped are adequate to protect the area, with a safety margin. Readers are referred to Appendix 5 for reference of the various data inputs and outputs for the soil salinity assessment.

The Agricultural salinity Loss assessment model of NSW Agriculture (eg Graham Marshall et all, 1994) is proposed to be used to assess the salinity benefits that may be obtained from this scheme. The DWR Economics group may then carry out the full economic evaluation of the option, which includes the consideration of other benefits, eg road benefits.

9. INTEGRATION WITH OTHER WATERTABLE CONTROL OPTIONS.

If reliance is placed on sub-surface drainage schemes to control watertables and salinity in the MIA then the two schemes just discussed are not sufficient. In fact, by using the model for all sub-districts using the same principles, the following quantities need to be removed from the groundwater system.

Table 9.1: Groundwater volumes to be pumped in MIA sub-districts for two scenarios (*1)

Sub-District	Scenario 1 ML/year	Scenario 2 ML/year
MIA as a whole	18,700	13,400
Koonadan	2,000	2,000
Gogeldrie Yanco Area	NIL	NIL
Murrami Calorofield	4,000	2,000
Yenda Widgelli Area	4,000	1,800
Kooba	1,200	1,200
Hanwood Area	3,000	2,000
North Benerembah	1,800	1,700
South Benerembah	1,200	1,200
Warrawidgee	1,500	1,500

(*1) 1. Full protection, 2. Maintain Status quo

The schemes being evaluated will afford good protection for the areas in question. If the objective is to just maintain the status quo, without future improvements over and above the current salinity status, then the volumes for scenario 2 apply.

At a capital cost of $1500 ML/yr extracted, plus running costs of about $5-10/ML/yr it will always be fruitful to look at alternatives. The main alternatives would be strategies in the area of reduced accessions.

During planning the most appropriate procedure appears to be to first identify the on-farm measures that are practicable and acceptable. The issue of reducing rice areas should also be evaluated, since the proportion of land under rice has a lot of bearing on the average depth to the watertable.

In the MIA unfortunately the leakage to deeper aquifers is restricted in some areas, and this will have the effect that on-farm measures alone may not suffice. After having considered on-farm and institutional (rice policy) options, the use of regional options will be the only remaining option to control future salinity.

Channel seepage should be controlled, but from Chapter 2 it appears the impact of these control measures will not be widespread. The watertable control options by groundwater pumping should be entered into the evaluation after all other means have been explored.

If the on-farm options are likely to be effective to a degree, this would reduce the need for sub-surface drainage schemes.

This report is believed to show the way by which the intergration of the various watertable control and land sustainability options can be integrated into an acceptable package.

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