DWLBC REPORT

Berri, Loxton and Renmark Irrigation Area CDS Irrigation Drainage Water: Implications of Flow and Quality Data

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Government of South Australia
Department of Water, Land and Biodiversity Conservation

Berri, Loxton, and Renmark Irrigation Area CDS Water: Implications of Flow and Quality Data

John Rolls

Strategic Policy Division
Department of Water, Land and Biodiversity Conservation

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Report DWLBC 2007/24

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Department of Water, Land and Biodiversity Conservation

25 Grenfell Street, Adelaide

GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au	

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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Operational records related to irrigation drainage from Renmark Irrigation Area (IA), Ral Ral Division of Chaffey IA, Loxton and Berri IAs, as well as recent data from salinity and flow monitoring stations installed for DWLBC, have been examined to assess opportunities for alternative management of regional irrigation drainage waters.

In each district, drainage flows have been falling rapidly over recent years, and it appears likely that they will remain low. In the Loxton IA, they may cease except following intense local rain events. The annual flow of drainage water is considerably less than would be expected on the basis of the volume of irrigation water used and the likely fraction of water draining beneath the plant root zone. In each area, the salinity of the drainage water is affected to varying extents by mixing with local groundwater.

On account of the high salinity and low volume of drainage water from Renmark, Chaffey and Berri IAs, there is no prospect for its use for economic irrigation, and current disposal practices with some minor variations, appear to be the most attractive option. The best option for disposal of drainage water from Loxton IA is the irrigation of native vegetation on Katarapko Island, but that needs to be assessed by Department of Environment and Heritage on account of declining flows and likely increasing salinity.

An effective Salt Interception Scheme could be constructed in the Renmark IA and Ral Ral Division of Chaffey IA using the existing drainage infrastructure to convey saline groundwater, but a similar scheme in Berri IA would be ineffective in reducing the salt load to the River.

Current levels of monitoring by the Irrigation Trusts are inadequate, especially considering their duty of care relating to discharges to the environment. Recommendations based on the report’s conclusions, relating to drainage flow and salinity monitoring programs, and drainage water management are being considered by DWLBC.

1. INTRODUCTION

Currently, irrigation drainage water in the South Australian Riverland is disposed of partly by evaporation in floodplain disposal basins, partly to the River Murray under controlled conditions of river flow and salinity, and partly to disposal basins located some distance from the river. Some of these practices result in salinity impacts to the river and its floodplain.

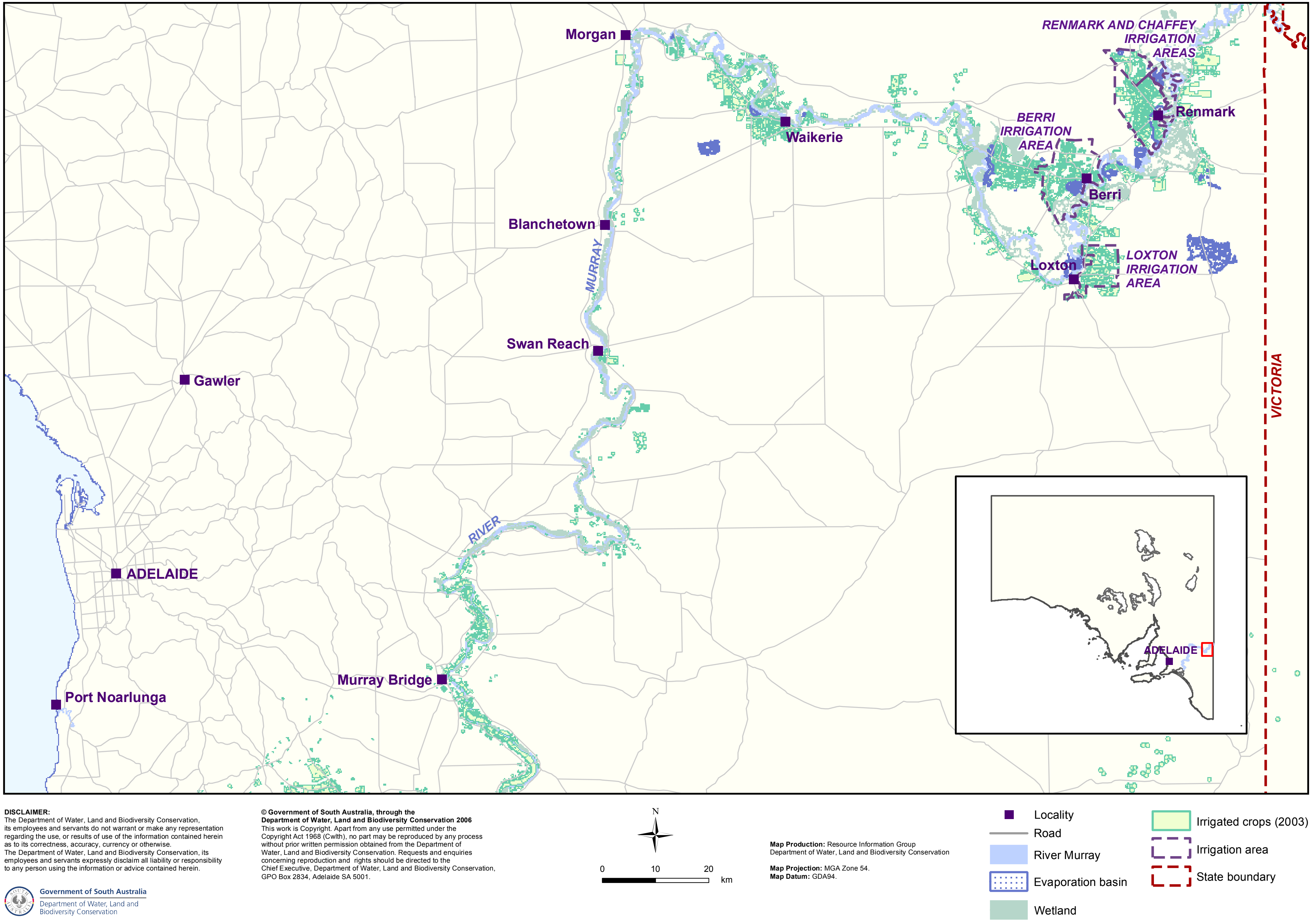
This project has two objectives. One is to assess the potential of alternative management practices for the disposal of drainage waters from the Renmark/Chaffey, Berri and Loxton irrigation areas (Fig. 1). The other is to assess the potential for lowering the watertable mound beneath irrigation areas (and consequently, discharge to the River Murray), by pumping saline groundwater from wells into the existing irrigation drainage infrastructure for discharge to the Noora Disposal Basin.

1.1 BACKGROUND

Irrigation was first developed in the Riverland in large Government Irrigation Areas (GIAs), including the Berri, Cobdogla, Loxton, Renmark and Chaffey districts, over a period from the 1880s (Renmark) to the 1950s (Loxton). Since then, significant private irrigation developments have occurred. Early irrigation water supply infrastructure and irrigation practices in the former GIAs were inefficient, resulting in a large proportion of applied water being lost to drainage, causing perched water tables, inundation of low-lying areas, and reductions in crop yield.

Following the realisation in the early 1920s that continued irrigation required sub-surface drainage to remove excess water, tile drains were installed at a depth of between 1.2 and 1.8 m beneath the ground surface (Andrew Jessup, Renmark Irrigation Trust, and Reg. Bristow, Central Irrigation Trust, pers. comm.). The intercepted water flows by gravity to caissons, from where it is pumped via a pipeline and channel system to floodplain disposal basins. These schemes to intercept and dispose of irrigation drainage water are referred to as Comprehensive Drainage Schemes (CDS). Drainage from the Berri area is disposed to the Berri and K Country Basins, and that from Loxton to Katarapko Island Basin (on the opposite side of the River Murray). Drainage from the Renmark and Ral Ral areas is disposed of to the Disher Creek Basin via the Renmark Area Drainage Scheme (RADDS), which was constructed in the 1960s (Woodward Clyde, 1999).

Most of the disposal/holding basins are on the floodplain. Much of the water is lost by evaporation, with the balance being disposed of by pumping to Noora Disposal Basin (Berri and Renmark) or by discharge to the river under specified conditions of river flow and salinity. Because the basins were historically held at above river level, existing saline groundwater beneath the floodplain can be displaced into the river, which may result in greater salt loads than would occur if drainage waters were discharged to it directly. Direct discharge from the basins results in additional salt loads to the river, though under conditions when the salinity impact is negligible. The operation of the floodplain basins has degraded their environment, specifically through the drowning the fringing Red gums, and the retention of saline water which restricts the range of plants and animals that can survive there.



Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54.
Map Datum: GDA94.

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Figure 1. Location of Berri, Loxton, Renmark and Chaffey Irrigation Areas

The Central Irrigation Trust (CIT) manages the water supply and drainage infrastructure for the Berri, Cobdogla, Chaffey and Loxton irrigation districts. Renmark Irrigation Trust (RIT) performs similar functions for the Renmark irrigation district. DWLBC is responsible for operating the Berri and Disher Creek Disposal Basins.

1.2 ASSESSMENT OF ALTERNATIVE MANAGEMENT OF CDS WATERS

There are a number of potential alternatives to the current management of CDS water, including: irrigation of salt tolerant crops, mixing with raw irrigation water, watering floodplain native vegetation, and direct discharge to the Murray.

Under current conditions, recharge to groundwater varies spatially, and over time within each irrigated area. Following each irrigation and rainfall event, water passes down through the soil profile, with part being transpired by the crop plants or lost by evaporation. The remainder is either collected by tile drains and flows thence to the CDS, or drains to the underlying groundwater. This irrigation drainage initially builds up a watertable mound in the aquifer beneath the irrigation districts, with its shape dependent on the pattern of irrigation, the location of the water supply channels and the aquifer characteristics. Due to the recent rehabilitation of water supply infrastructure and the significant improvement in irrigation management, these mounds have generally reduced in size and changed shape reflecting changes to the sources of recharge.

In areas of higher topographic elevation, the top of the groundwater mound is likely to be below the tile drainage system. Perched groundwater (on underlying low permeability clay layers) may rise above the tile drainage level following an irrigation event, then fall as water enters the tile drains and is used by the crop roots. In view of the long period since establishment of the irrigation areas, the soil profile should be essentially free of soluble salts apart from that delivered with the irrigation water. In elevated areas, the salinity of the drainage water should essentially be determined by the drainage fraction: which is the fraction, or percentage, of the applied irrigation water not used by the plant, and passing beneath the root zone. If the fraction flowing to drainage is 10%, the salinity of the drainage water will be 10 times that of the irrigation water. When a caisson fed by the drains is also located in an elevated area, the salinity of the water pumped from the caisson will be similar to that collected by the drains.

In areas of lower elevation, the tile drainage systems may intersect regional groundwater. The drainage water entering the tile drains will partially mix with the native highly saline regional groundwater, and its salinity will be higher than that predicted from the drainage fraction and irrigation water salinity. Because the drainage infrastructure mixes water from caissons of varying elevation, and therefore varying salinity, any proposal to use the drainage water to irrigate other crops or manage the water in other ways must take this issue into consideration, as salinity of drainage waters may be much higher than predicted from a simple salt balance analysis.

2. METHODOLOGY

Decisions regarding the future management of the irrigation drainage water require knowledge of its volume and salinity, and how they vary seasonally and over longer time frames.

Records of drainage water salinity and flow volumes, hours run records for the CDS caisson pumps, groundwater level, and irrigation water use data held by RIT, CIT and DWLBC were identified, collated and analysed. In addition, gauging stations were established on the drainage outfalls from the RADDS, and the Loxton and Berri Irrigation Areas to provide reliable and current salinity and flow data.

Samples of water were taken from Renmark, Chaffey, Loxton and Berri IA caissons in February 2005 and analysed for boron (high boron levels might influence recommendations regarding use of drainage water for irrigation). Using a portable meter, the salinity and pH of water in caissons serving Chaffey, Loxton and Berri IAs were measured between February 2005 and February 2006. This was intended to provide insight into the variation of drainage water quality spatially within Irrigation Areas, and over time.

Another essential requirements of the project was to develop a groundwater model for the Berri-Cobdogla and Renmark-Chaffey Irrigation Areas (based on the history of vegetation clearance and irrigation development), to estimate the resultant history of groundwater salt load to the River, and to model the salinity impact of conceptual salt interception schemes using the existing drainage infrastructure to convey the intercepted groundwater.

2.1 ESTABLISHMENT OF CDS MONITORING STATIONS

Historically, the flow and salinity of irrigation drainage waters has been monitored by a number of agencies, notably the former Engineering and Water Supply Department (EW&S), the Renmark Irrigation Trust (RIT) and the Central Irrigation Trust (CIT). When responsibility for management of the GIAs was transferred to CIT in 1997, the responsibility for monitoring flow and quality of the drainage waters was not well specified. CIT did not establish formal flow monitoring systems, and the existing flow gauging stations for Berri, Cobdogla and Loveday basins were allowed to fall into disrepair. RIT installed flow gauges on the pipelines from only three of its six major caissons.

Both Trusts record the time of operation of the caisson pumps ('pump hours run'). CIT's pump hours run records and the nominal pump flow curves have been used to estimate flow from each caisson. Smith (1999) has estimated that volumes computed by this method for the Riverland drainage waters may be in error by up to 42%. Estimating the total volume of water delivered to the disposal basins by summing the caisson flow figures requires the assumption that there is no leakage from the pipe system, or the use of an estimated leakage rate. Installation of modern flow monitoring stations on the outfalls to the basins would provide a continuous, reliable and accurate estimate of flows to the basins.

RIT has monitored the salinity (EC) at the caissons of the Renmark Area Drainage Disposal Scheme (RADDS) since late 1978. CIT was not monitoring drainage water salinity prior to the commencement of this project.

Because of the limited up-to-date flow and salinity data, and the likely ongoing need for such information, it was considered necessary to install flow and EC monitoring stations. The major focus of this project was on the Berri, Renmark and Chaffey Irrigation Areas, the drainage water from which is disposed to basins connected to the Noora Disposal Basin, and the Loxton Irrigation Area, for which there is local expectation for future disposal there. However, another project ("Adaptive Wetland Management Demonstration Site – Loveday Basin") is investigating the potential for alternative management of the Loveday and Cobdogla Basins, and tenders for similar installations for the outfalls to those basins were sought at the same time.

In Loxton as elsewhere, the CDS system was designed to carry drainage volumes produced when water was supplied in open channels, and when irrigation techniques and practices were far less efficient than now. However, drainage rates are now far less as a result of rehabilitation of the water supply and improvement in irrigation methods and practices. Hydro Tasmania evaluated a large number of possible options for measuring flow in the outfall pipes, but none offered satisfactory accuracy at reasonable cost for the very low linear velocities of the much-reduced flows in the large diameter pipes. The possibility of introducing a reduced diameter pipe section was rejected by CIT because the system has to accommodate very large flows in occasional summer storms.

2.2 GROUNDWATER MODELLING

In order to assess the impacts of irrigation and disposal basin operation on the river and floodplain salinity, it was necessary to undertake modelling of the groundwater systems beneath the project areas. After examining the bids from consultants for the competitive tender, an arrangement representing the best distribution of roles in relation to capabilities was agreed to. This involved Resource and Environment Management (REM) and Australian Water Environments (AWE) compiling the groundwater and irrigation history information for the Renmark-Chaffey and the Berri-Cobdogla Irrigation Areas respectively, with Aquaterra Simulations being lead consultant and responsible for the groundwater modelling.

Conceptual Salt Interception Schemes were also designed. In the Berri-Cobdogla Irrigation Area, one bore was located close to the western extremity of the Cobdogla IA (operated to bring groundwater level to down to river level), with 26 bores located along the alignment of the major CDS infrastructure to lower the watertable mound. In the Renmark Chaffey IA, the concept design included 26 bores above Lock 5 and 9 below, all located between the irrigated area and the river.

3. RENMARK – CHAFFEY IRRIGATION AREAS

3.1 IRRIGATION DRAINAGE WATER MANAGEMENT

The layout of the Renmark Irrigation District, drainage interception pipelines and caissons is shown in Figure 2. The Chaffey Irrigation District lies to the north of, and adjacent to the RIT area, and its water supply and drainage are managed by the CIT. The Chaffey district consists of two sections; the Ral Ral and Cooltong Divisions. Drainage water from the Cooltong Division is pumped via two caissons to the Cooltong Disposal Basin. Drainage from Ral Ral division was initially disposed to Bulyong Island.

Within the Renmark Irrigation District, Caissons 1–4 and 6 receive drainage water from the south-western two thirds of the area. Caisson 5 receives drainage directly from a small part of the RIT area to its northwest, from Caissons 7–13, which drain the north-eastern part of the RIT area, and from the Ral Ral Division of Chaffey Irrigation District.

Caissons 1–6 have open bottoms, allowing direct discharge to, or interception of the regional groundwater. Caissons 7–13 have sealed bases. Drainage from Caissons 7–12 was formerly discharged to Bulyong Island Basin, a practice now confined to periods of high flow in Ral Ral Creek. In normal (low flow) conditions, water is now pumped to Caisson 5. In 1983, Bulyong Island Basin was de-commissioned and drainage from Ral Ral division was diverted to Caisson 5.

CIT does not maintain records of drainage flows. It records the pump hours run by caisson pumps, from which drainage flows are estimated. RIT has used ultrasonic flow-meters to measure flows from Caissons 4 and 5 since late 1986, and from Caisson 3 since late 2002. The records for Caisson 5 are not regarded as reliable. Since 1972, RIT has also recorded power consumption by caisson pumps, from which flows were estimated for 2004.

3.2 SALINITY OF IRRIGATION DRAINAGE WATER

RIT has monitored the salinity of drainage waters at caissons since 1979. As shown in Figure 3, annual average salinities in closed bottom caissons ranged between about 4000 and 13 000 EC until 2001. Salinities of Caissons 9, 10 and 13 waters slowly increased over most of this period.

Salinity of drainage water passing through the other caissons rose through the 1980s, passing through a maximum in 1989, but exhibited no consistent trend from the late 1980s to 2001. Following 2001, salinities in all caissons fell rapidly to between about 1000 EC and 3000 EC. Salinities appear to be stabilising at these lower levels. Assuming a drainage fraction of 10%, and that the root zone was not affected by high salinity native groundwater, the average salinity of the drainage water would be expected to have been about 10 times that of the irrigation water.

The thick blue line in Figure 3 (WS ECX10) plots the salinity of irrigation water multiplied by 10. For most of the period, the salinity of drainage water from all caissons has been slightly more than 10 times irrigation water salinity, suggesting that water intercepted by the drainage

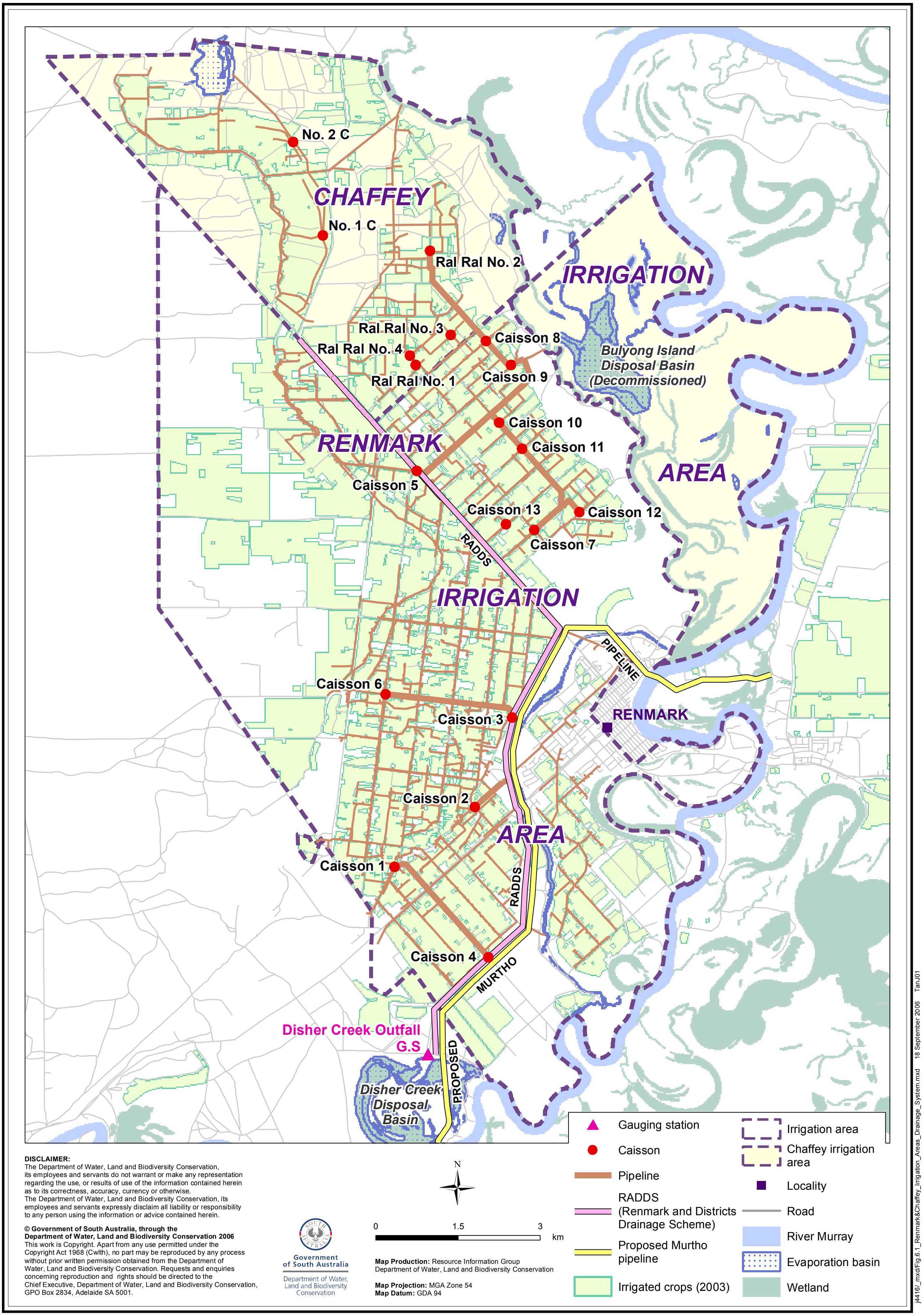


Figure 2. Renmark and Chaffey Irrigation Areas Drainage System

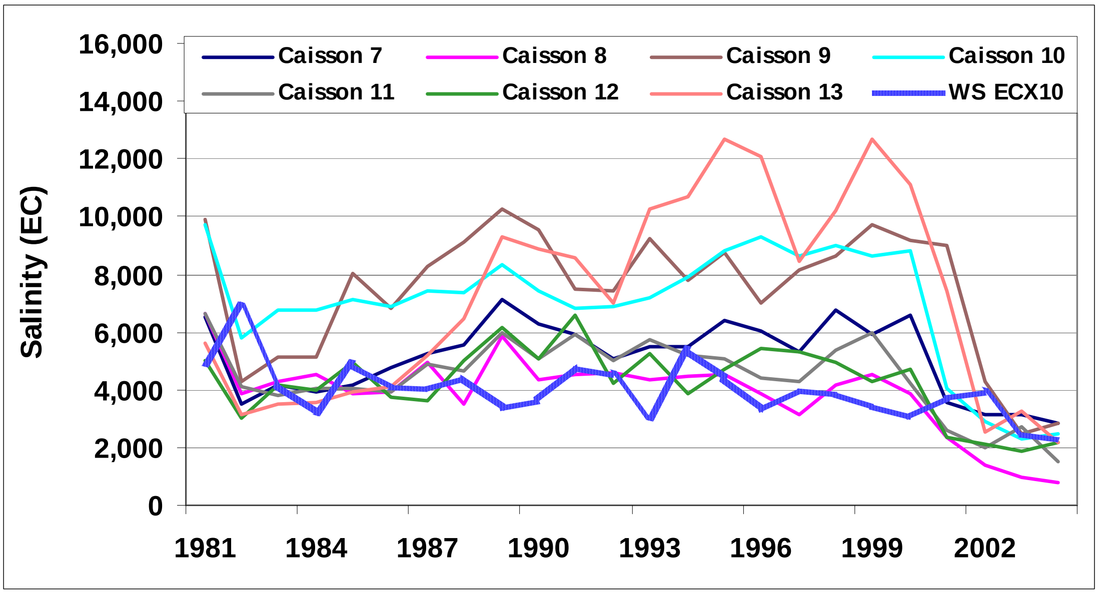


Figure 3. Salinity of RIT drainage water in sealed bottom caissons – 1981 to 2004.

system was affected by saline groundwater. The impact of groundwater appears to be greatest for the catchments of Caissons 9, 10 and 13. Note that had the drainage fraction been greater than 10 (as was probably true for much of the period), the salinity of the drainage water should have been lower. Drainage water salinities since about 2002, have been close to or less than 10 times the irrigation water salinity, which suggests that drainage fractions are in fact, slightly greater than 10%.

Figure 4 shows that annual average salinities in most open bottom caissons have ranged between 2500 and 7000 EC since 1979. In contrast with the situation for closed bottom caissons, only Caisson 4 shows a fall in salinity since 2000.

The red line (WS ECX6.67) and blue line (WS ECX10) plot the salinity of irrigation water multiplied by 6.67 and 10, reflecting water use efficiencies of 85% and 90% respectively.

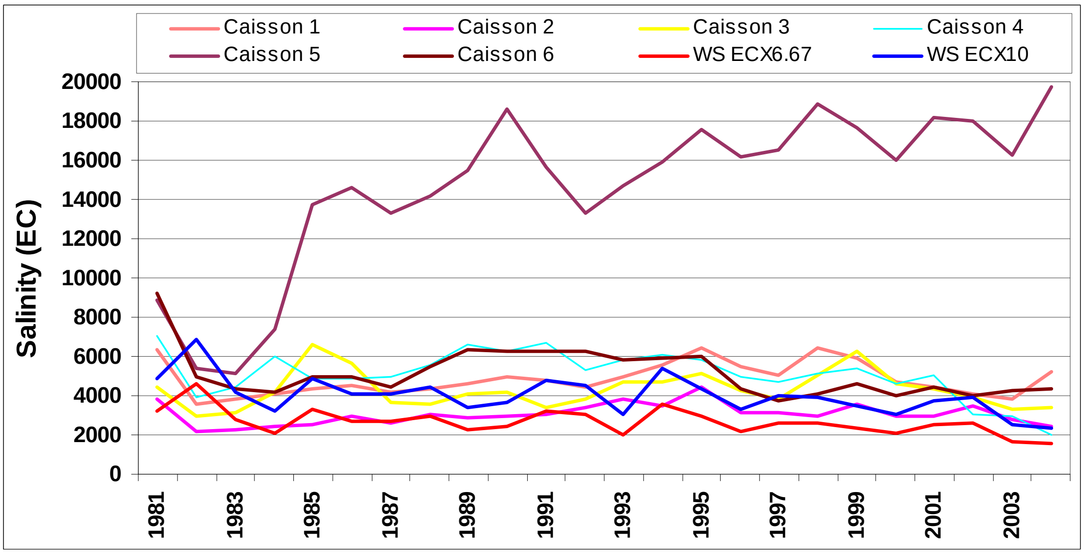


Figure 4. Salinity of RIT drainage water in open bottom caissons – 1979 to 2004.

Before 1983, the salinity of Caisson 5 drainage was only slightly above that of the other open bottom caissons. Drainage from the Ral Ral Division of Chaffey Irrigation Area is of high salinity (20–40 000 EC in 2004), and was discharged to Bulyong Island until 1983, when the disposal basin there was taken out of commission. Drainage was then redirected to Disher Creek Basin. The salinity recorded at Caisson 5 rose rapidly over the next two years and since then, has shown a slow, persistent increasing trend, ranging between 16 000–20 000 EC in recent years. This is probably due to a progressive increase in groundwater level in the vicinity of Caisson 5 and/or the Ral Ral Division caissons, and a resultant increase in the proportion of groundwater passing through Caisson 5.

The fact that the salinity of drainage water passing through Caissons 1, 3, 4 and 6 was a little above both red and blue lines suggests that in their catchments, groundwater had some impact on salinity of drainage water, i.e. that in these catchments groundwater levels were close to or above the irrigation drainage fields and/or the operating range of the caisson pumps. The plot for Caisson 2 lies below the blue line for most of the period, indicating that there was no influence from groundwater (and that the drainage fraction was probably greater than 10%). Since about 1994, Caisson 2 salinity has risen to be approximately equal to WS ECX10, consistent with a fall in drainage fraction in a catchment unaffected by native groundwater. The plot for Caisson 4, lying above WS ECX10 until recently, but falling to WS ECX10 in recent years is consistent with a catchment slightly affected by saline groundwater for most of the period, but where the groundwater level has fallen.

3.3 DRAINAGE FLOWS

As indicated earlier, RIT does not measure most drainage flows, but maintains records of energy consumed by the CDS caisson pumps. This information was used to derive an estimate of 1800 ML/y disposed to Disher Creek Basin over the period 1989–93 (Woodward-Clyde, 1999), when total caisson pump power consumption was about 230 MWhrs annually. The same information was used to estimate a total flow of about 1650 ML in 2004.

Figure 5 shows the total power consumed by pumps serving RIT open bottom Caissons 1–4 and 6 (which have been handling low salinity water), Caisson 5 pumps and the aggregated use by pumps serving the closed base Caissons 7–13. The common feature of each curve is the falling trend since 1995–96.

The first two curves exhibit three maxima, in 1973–74, 1985–86, and the mid 1990s. The 1973–74 peak and subsequent fall are probably due to exceptional rainfall in 1973–74, and also completion in 1973 of the replacement of the earthen channel water supply system by pipes, that presumably resulted in a fall in groundwater levels.

The two later peaks were associated with high river flows, and possibly with elevated groundwater levels as a consequence. The rise in Caisson 5 power use following 1983 coincides with the diversion of Ral Ral drainage to it that year. The further rise after 1990 is most likely related to the 45% expansion of irrigated area in RIT that occurred over the following decade. From 1995–96 to 2005–06, power used by pumps serving Caissons 1–4

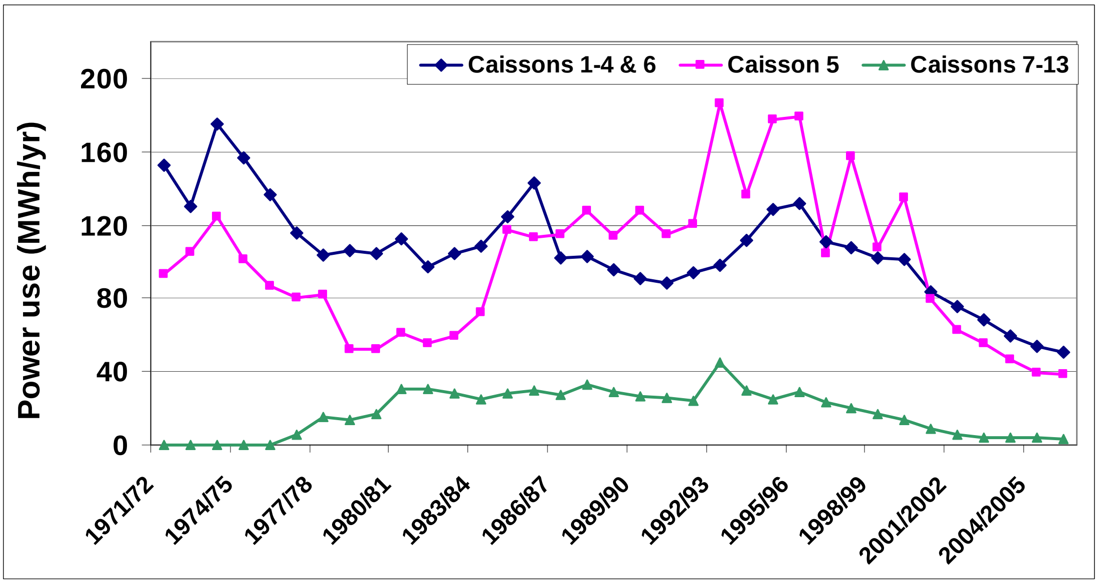


Figure 5. Total annual energy used by RIT caisson pumps.

and 6 fell by over 60%, power use for Caisson 5 fell by over 75% and Caissons 7–13 pumps by 85%, presumably indicating a reduction in volumes of drainage water of similar magnitude.

Figure 5 also shows that prior to 2001, aggregated power use by Caissons 1–4 and 6 was less than that by Caisson 5 pumps, but since then power use has fallen less rapidly and is now greater than for Caisson 5, suggesting that flows from the Caisson 5 catchment have fallen more rapidly.

Figure 6 shows the hours of operation of pumps serving caissons of Chaffey Irrigation Area. Only the Ral Ral caissons, serving the Ral Ral Division, pump to Caisson 5.

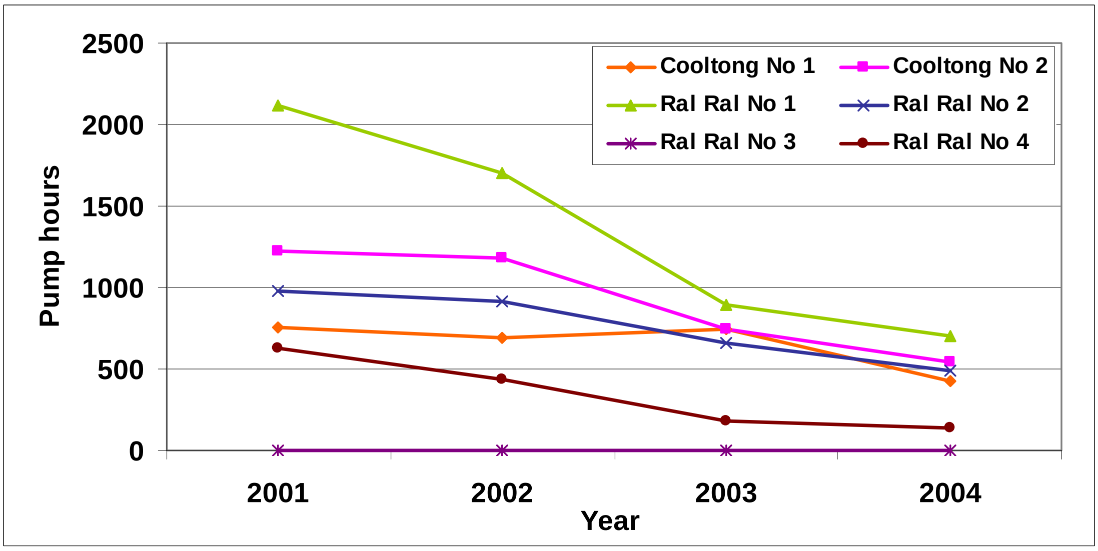


Figure 6. Chaffey IA CDS pump hours of operation.

Water consumption in the Chaffey IA has been declining slowly since 1997, and was about 18% lower in 2005 than 1997 (CIT). This reduction in irrigation applications has been among the factors causing the much more rapid fall in drainage volumes. The total hours operated by Ral Ral division CDS pumps feeding Caisson 5 fell by almost two thirds over the period 2001 to 2004, which suggests a correspondingly large reduction in drainage volume. Over the same period, the power consumption by Caisson 5 pumps fell by less than 40%, suggesting that drainage flows were falling more slowly within the RIT area.

Caissons 7–13 discharge into Caisson 5, and the salinity of water passing through them fell by a factor of over 3 between 2000–04, however Caisson 5 salinity has not decreased (Fig. 4). This is because flows from Caissons 7–13 are only a small proportion of total flow through the caisson and they have been falling at a similar rate to Caisson 5 flows. An additional factor maintaining high salinities in Caisson 5 water may be that it contains a larger proportion of native groundwater than in the past. The pump-hours-run-weighted salinity of Ral Ral Division drainage for 2005 was 9300 EC, compared with 19 800 EC for Caisson 5 in 2004, strongly suggesting that Caisson 5 is intercepting groundwater of high salinity.

Figure 7 plots the volume pumped from Disher Creek Basin to Noora, together with the combined power consumption by Caissons 1–6 (representing flows into Disher Creek Basin). It indicates that volumed pumped from Disher Creek to Noora has followed the same trend as flows into the Basin, as would be expected, and both have been falling since 2000. The rates of fall appear to be decreasing. Since 2002–03, the volume pumped to Noora has averaged 662 ML/y, corresponding to a continuous flow of 22 L/s.

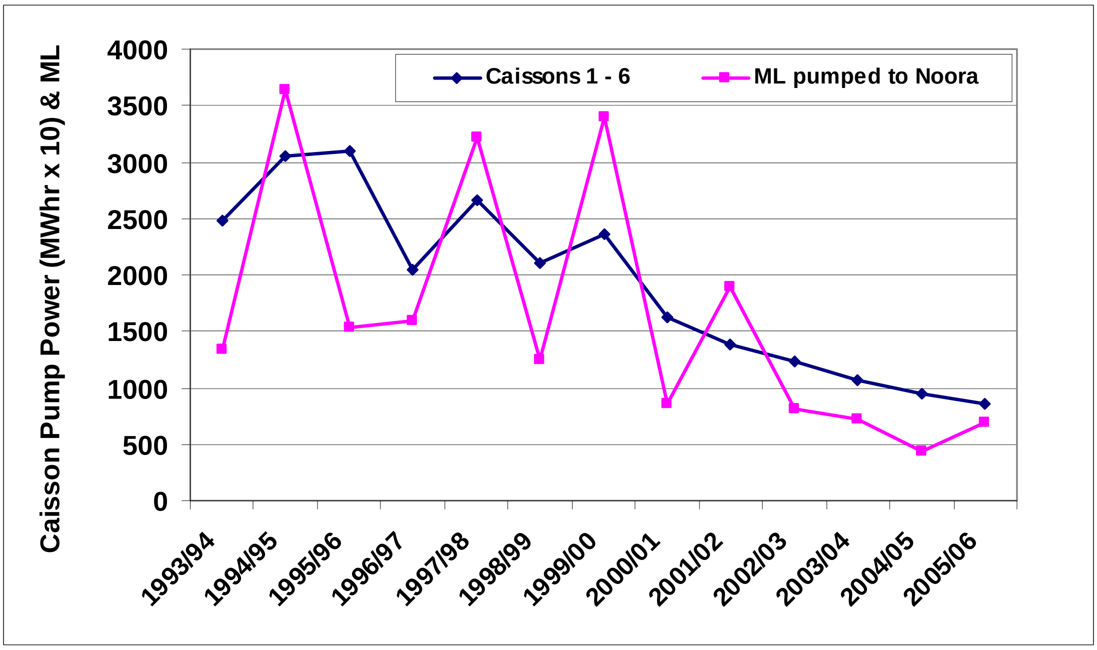


Figure 7. RIT Caisson Pump Power and volumes pumped to Noora

3.4 WATER BALANCE FOR RIT AND RAL RAL

Woodward Clyde (1999) reported that in 1995, 40 400 ML was used for irrigation in the RIT area and 3872 ML was used in the Ral Ral Division of the Chaffey IA. Private diverters accounted for a further 960 ML. CIT figures for the Ral Ral Division for 2000–01 to 2005–06 averaged 3436 ML/y. RIT records for Renmark IA show an average demand of 35 803 ML/y for 2000–05. The slightly lower recent figures presumably represent the impact of drought and associated water restrictions, as well as changes in crops and irrigation practice. Combined current water use for the RIT and Ral Ral Division is thus estimated at 40 200 ML/y.

Assuming the average drainage fraction is 10%, the total drainage beneath the root zone would be 4000 ML/y. Noting that only about 60% of the RIT area is drained, and neglecting groundwater intercepted by the caissons, the volume likely to be collected by the drainage system would be about 2400 ML/y.

Over the 12 months of monitoring RADDS flow and salinity at the Dishers Creek gauging station from October 2005, the total flow was 1106 ML. The total flow in 2004 estimated from RIT pump records was 1600 ML, suggesting that annual drainage flows are still falling. However, pump hours run do not provide reliable flow estimates, and the RIT estimate for 2004 is probably inflated perhaps by as much as 50%. The current gauged drainage flow represents about 28% of the estimated drainage from irrigation, implying that the remainder (72%) is passing down to the regional groundwater. The evidence that the Ral Ral caissons and Caisson 5 are drawing on the groundwater suggests that in the rest of the RIT area, more than 72% of the drainage is passing to groundwater. Given that only about 60% of the area is drained, and given the recent rapid falls in groundwater level, this appears to be a credible estimate. The estimated volume of drainage water passing to groundwater, say 2–3000 ML/y, is consistent with the current salt load to the River (140 t/d) assuming a groundwater salinity of 20 000 mg/L.

3.5 SALT BALANCE FOR RIT AND RAL RAL

Over the 12 months (11/10/2005 to 10/10/2006) of monitoring flow and EC at the Dishers Creek gauging station, mean daily salinity varied between 9764–30 730 EC, averaging 24 473 EC. The total flow was 1106 ML. This corresponds to an estimated salt load of 16 240 t/y.

Over the same period, the salinity in the River Murray upstream of Renmark ranged between 144–237 EC, with a mean of 196 EC. The mass of salt imported into the area annually was thus 5290 tonnes over this period.

Table 1 summarises the information on flow and salinity of drainage waters, comparing the 2004 estimates from pump hours run data with the 2005–06 data from the DWLBC Dishers Creek gauging station. The lower flow recorded for 2005–06 is consistent with the trend of decreasing flow discussed earlier, but the fall in flow from one year to the next is greater than shown in the pump hours run record, and it may be that flows based on that record are higher than the true flow. However the salt loads derived from the two sources are similar.

Table 1. Salt loads associated with RADDS drainage waters.

Period	Water source	EC		Flow ML/y	Salt load t/y
		Range	*Mean*		
2004	Caissons 1–4 and 6	2 500–5 300	3 502	817	1 716
	Caisson 5	–	19 800	828	9 837
	Total to Dishers Creek	–	–	1 645	11 553
2005–06	RADDS gauging station	9 764–30 730	24 473	1 106	16 240

On the basis of the above very limited period of monitoring, it appears that the RADDS is functioning as a salt interception scheme, exporting 6000–11 000 tonnes per year more salt than is present in the applied irrigation water. Of the salt in the combined RIT and Ral Ral drainage waters, about 85% is derived from Caisson 5. The hrs-run-weighted average salinity of the Ral Ral Division drainage is estimated at 9300 EC units for 2005, but the actual contribution to the salt load has not been estimated. Noting that drainage flows have fallen sharply in the recent past, until recently the RADDS would have been exporting a greater quantity of groundwater salt. However the salt load exported by the RADDS is much smaller than the salt load to the river induced by operation of the irrigation area, because of the large volume of drainage water passing to groundwater.

3.6 FUTURE DRAINAGE FLOW VOLUMES

Rehabilitation of the water supply system in Renmark was completed in 1973, and the groundwater system has had adequate time to adjust to that change. The factors driving the more recent observed reduction in drainage volumes are likely to be associated with changes in crops and irrigation methods and to some extent to recent reduced rainfall.

Over the period 1995–2003, there was a substantial change in types of crop in the RIT area. Abbott et al (2003) note that the area devoted to pasture has reduced by 100 ha, citrus by 200 ha, and stone-fruit by over 600 ha. These crops have been replaced by nuts (an increase of 100 ha), and vines (1000 ha increase).

Over the same period, total water use in the area has not changed greatly, but as Table 2 indicates, the change in crops was associated with substantial change in irrigation methods (eg furrow to drip). The large change from furrow irrigation to dripper and under canopy irrigation methods would almost certainly have resulted in an increase in irrigation efficiency and a reduction in the volume of water passing to drainage. The change in crops irrigated in the Chaffey IA between 2000 and 2005–06 was similar in nature, but much less marked.

Table 2. Changes in RIT irrigation systems 1995–2002 (Abbott et al, 2003)

Irrigation method	**1995** (ha)	**2002** (ha)	**Change in area** (ha)
Drippers	419	1 128	709
Furrow	1 966	803	-1 163
Under canopy	1 572	2 284	712
Overhead	97	77	-20
Micro-jet	25	10	15
Total	4 079	4 302	223

As illustrated in Figure 8, groundwater levels in the Renmark/Chaffey area have fallen by between 1.0–1.5 m since 1998 (Aquaterra, 2006).

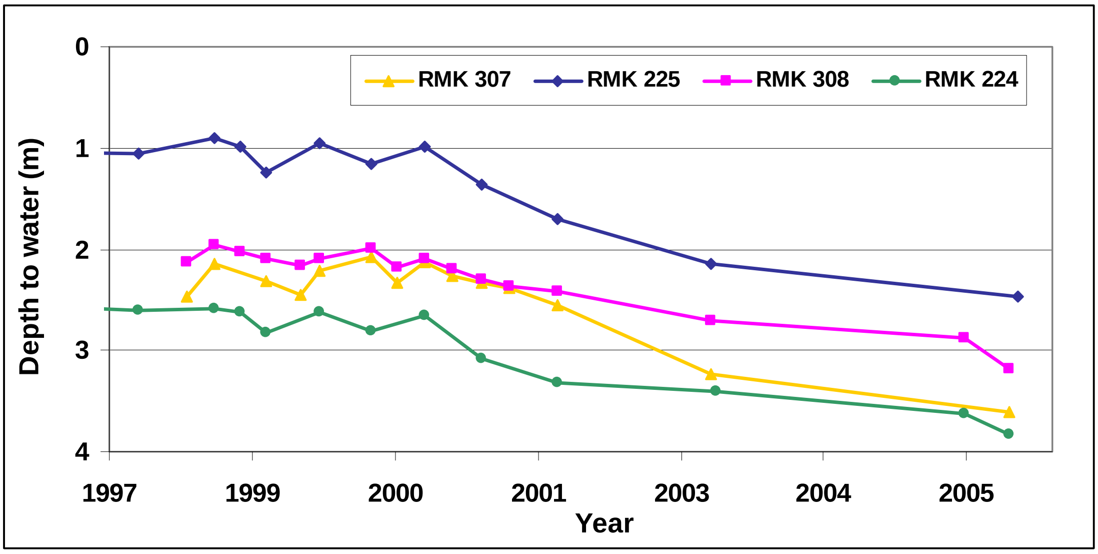


Figure 8. Groundwater levels in the RIT area.

Thus in the vicinity of these bores, groundwater levels have fallen from well above the depth of the tile drainage system, to well below it. This would result in reduced flows of saline groundwater into the tile drainage system. This is the probable cause of the recent rapid falls in salinity of the drainage water pumped from sealed-base caissons, and the more muted reduction in salinity of water passing through most of the open bottom caissons over the same period.

One factor contributing to the fall in groundwater levels could be the recent drought. Figure 9 shows the cumulative difference between the actual measured monthly rainfall at Renmark, and the long term average. An upward trend in this line indicates above average rainfall, while a downward trend shows below average rainfall. It can be seen that below average rainfall persisted from Jan 2002 until Dec 2004.

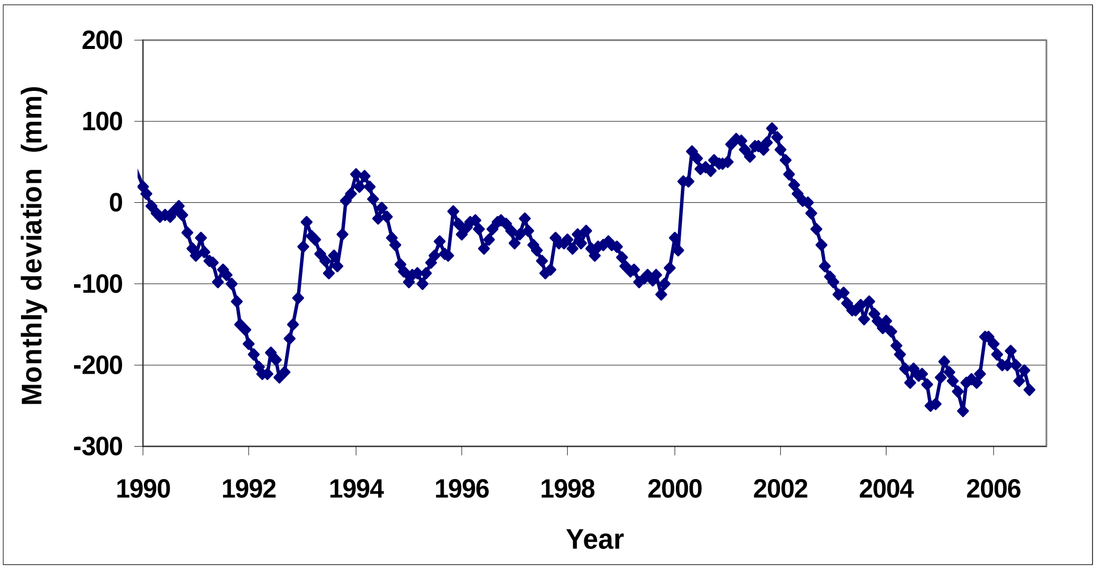


Figure 9. Cumulative monthly deviation from long term average rainfall at Renmark.

If drought had been associated with lower use of water by irrigators, this might explain part of the recent fall in drainage volumes. However, reduced rainfall cannot be the primary factor, since the fall in groundwater levels started in 2000, prior to the fall in rainfall, and has persisted.

To assess the impacts on drainage rates of any changes in the combined water inputs, an estimate of the drainage flow was made based on the history of area irrigated, volume of water used by RIT, and rainfall in Renmark. The volume of drainage was modelled by adding the irrigation water applied and the rainfall, using a constant drainage fraction of 10%, and a factor of 0.6 to represent the fact that only 60% of RIT is served by the CDS. This approach ignores the improvement in water supply infrastructure and irrigation efficiency discussed earlier. The results are plotted in Figure 10.

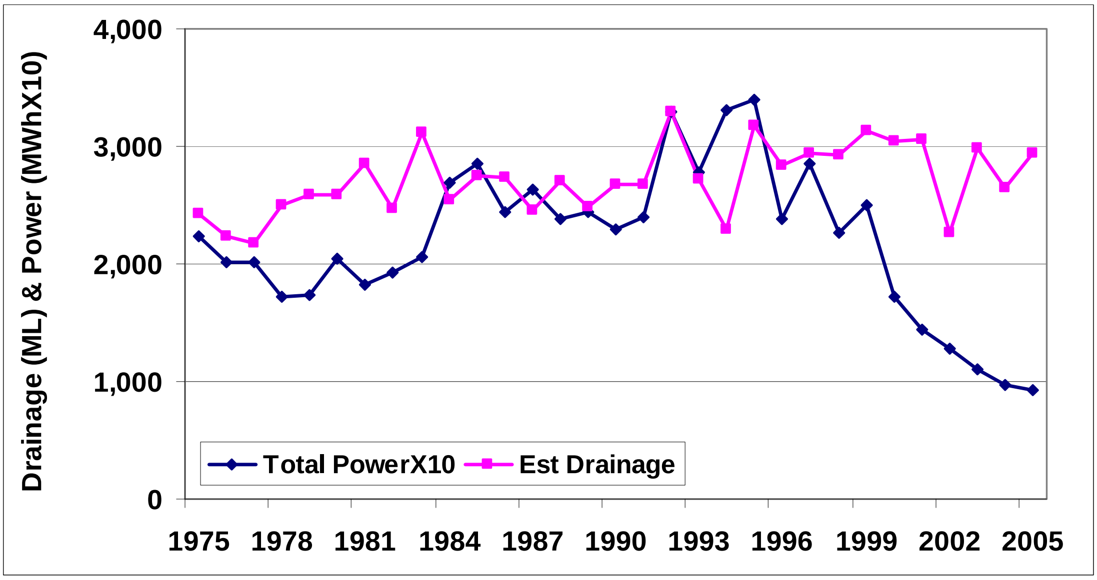


Figure 10. RIT total caisson pump power and modelled drainage

The two plots show a similar trend during the period of increasing irrigated area from the mid 1980s to the mid 1990s, but diverge sharply thereafter during the recent period of change in crops and irrigation methods. Total power consumed by drainage pumps fell by 73% between 1995–96 and 2005–06, and total drainage water volume presumably fell by a similar factor. Clearly, changes in total water inputs, including rainfall, do not explain recent falls in the volume of irrigation drainage with the drainage in open bottom caissons.

In summary, changes in crop type and irrigation technology and practice appear to be the major influences in reducing drainage rates. These changes have lead to reduced groundwater levels, reduced accession of saline groundwater by the tile drains, and corresponding reduction in the salinity and volume of CDS drainage waters. The main factor driving the reduction in drainage flows is the economics of irrigated agriculture, which is likely to remain relevant. Drainage flows (and salinity of drainage water from closed bottom caissons) are therefore likely to remain low. Although it is inevitable that crops will change in future in response to market forces, it is likely that efficient irrigation technology will continue to be used and that the continuing shortage of water will drive efficient irrigation practice.

As noted earlier, in an area where the drainage fraction is 10% of the irrigation water, and where there is no contribution from saline groundwater, the salinity of the drainage would be expected to be 10 times that of the irrigation water. In recent years, river water sampled daily at the Renmark pumping station and used in irrigation has had an average salinity of approximately 250 EC (2003) and 232 EC (2004) and consequently, the salinity of the drainage water should now be about 2400 EC. The unweighted average salinities of the closed bottom caisson waters for those years were 2379 EC (2003) and 2117 EC (2004). These figures are consistent with a drainage fraction of about 9%, and suggest that the irrigation drainage water intercepted by the tile drains is not mixing with the local groundwater – i.e. that the top of the groundwater under the RIT area served by the closed bottom caissons has fallen below the level of the tile drains, as was inferred from the change in water levels discussed earlier.

Figure 4 and the discussion of salinity of open bottom caisson water, suggest that drainage fractions are similar throughout the RIT area, but the regional groundwater mixes to some extent with the drainage in open bottom caissons.

Thus it appears that in recent years, irrigators have been operating at around the appropriate efficiency level. Assuming that on average irrigators in RIT and the Ral Ral Division of Chaffey IA continue to use the same quantity of water as they have since 2000, the long term drainage volume can be estimated at 10% of their combined recent water use. The worst case scenario is to use an allocation of 4800 ML/y for Ral Ral and 45 500 ML/y for RIT, making a total of 50 000 ML/y, which would yield a drainage volume of 5000 ML/y.

However as discussed previously, most of the irrigation drainage is apparently not reporting to the drainage system. The most robust estimate of future surface drainage via the RADDS is the current volume measured by the Disher Creek gauging station, ie 1100 ML/y, and the knowledge that the combination of forces operating to change that are more likely to reduce that volume in the future.

There are two issues that may result in an increase in drainage flows in future. One is the possibility that market factors may result in a change to crops with a higher water demand. The recent acknowledgement by both State and Federal governments that Murray Darling Basin water is significantly over-allocated, and the recognition of the need for a greater allocation to the environment, will reduce the volume available for irrigation and increase the price of water, making high water demand crops less attractive for irrigators. The recognition of major drought as an issue will also tend to make irrigators more wary of high water demand crops. However the issue determining what crops are planted will not be the price of water, but whether it is financially more attractive to use more water on the crop. A higher price will drive efficiency, regardless of the crop irrigated, rather than choice of crop.

A second issue is that a drainage fraction of 10% may be found to be inadequate to maintain the crop root zone sufficiently free from salt, particularly for drip-irrigated crops. This issue is under investigation, and may emerge from soil monitoring by irrigators. However, it should be noted that a lysimeter in Bookpurnong showed no salt accumulation in the root zone after 10 years of drip irrigation at 99% efficiency. Also it is likely that salt accumulation could be managed by a single high intensity irrigation in any irrigated area, and that this would not need to occur frequently. The effect on annual average drainage volumes is thus not likely to be great. Also, it may be found that the occasional high intensity summer storms characteristic of the area, are sufficient to maintain soil salt concentrations below levels of concern. In summary, the likelihood of drainage flows increasing in future appears low.

As noted earlier, the salinity of some of the drainage water pumped from closed base caissons is as low as 1000 EC. This would require a drainage fraction of about 30%. The most obvious explanation is that high water demand crops are being grown and/or inefficient irrigation techniques and technology are still being used in these catchments. This should be investigated by RIT.

3.7 ENVIRONMENTAL IMPACTS OF DISPOSAL TO DISHER CREEK

Figure 11 shows that over recent years, the salinity in Disher Creek Disposal Basin has been increasing to levels not previously recorded, presumably because of the lack of high river flows to flush to basin, and declining volumes of drainage water entering the basin.

It is also possible that there is an increased proportion of direct groundwater inflow through the floor of the basin.

Despite the rising salinities, the section of Disher Creek basin affected by drainage water is in a healthier condition than parts of the basin not provided with water (Mike Harper, DEH, pers. comm.). Disher Creek provides habitat for the largest population of the Murray Hardyhead in the River Murray in South Australia (Mike Harper, ibid). The Hardyhead prefers a highly saline environment, which has been created in Disher Creek Basin under its management over recent decades. This species is listed as vulnerable in South Australia.

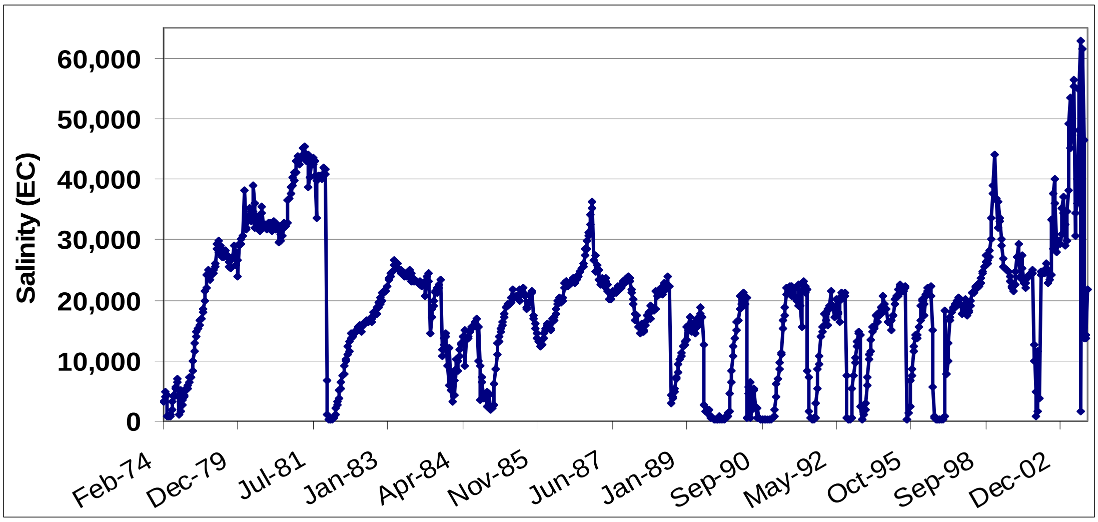


Figure 11. Salinity in Disher Creek Disposal Basin

3.8 BORON

Irrigation drainage waters commonly contain boron, which is toxic to some crops, eg citrus, at quite low concentrations. As one option under consideration was for the drainage waters to be used for irrigation of other crops, samples of drainage waters were collected in January 2005 from caissons in all the project areas and analysed for boron.

Results of the analyses are shown in Appendix B. Concentrations found in RIT caissons range between 0.39–4.5 mg/L. Concentrations observed in the Ral Ral Division of Chaffey IA range between 0.17–1.45 mg/L. The upper ranges of concentrations observed would be of concern in relation to irrigation of boron-sensitive crops. However, other factors suggest that re-use for irrigation is in any case an unlikely option for the RIT/Ral Ral system drainage water.

3.9 ALTERNATIVE MANAGEMENT OF DRAINAGE WATER

A number of alternative strategies for managing the drainage water are available.

Option 1

This option would continue current practice, ie the residual flow from Disher Creek after evaporation being disposed to Noora. This option has the advantage of low capital cost, retains the current benefit to Disher Creek vegetation, and avoids any complications arising over the Murray Hardyhead population. This option retains the current capacity to deal with stormwater from high intensity rainfall events.

Option 2

Option 2 is a variant of Option 1 in which a number of salt interception wells would be constructed in the vicinity of Caisson 5, with the groundwater pumped to the RADDS. This would reduce the river salinity impact of irrigation, and increase the volume and possibly also the salinity of water flowing to Disher Creek Basin. This option would presumably increase the benefit to Disher Creek vegetation and retain the capacity to manage stormwater by disposal to the basin. The increased volume of high salinity water may also suit the Murray Hardyhead population.

Option 3

Another option would be the diversion of the highly saline drainage water from Caisson 5 (from the RADDS pipeline between Caisson 5 and Caisson 3), to the pipeline proposed to convey saline groundwater from the Murtho SIS to Noora (requiring extra capacity for about 20 L/s). The balance of RIT drainage would continue to flow to Disher Creek. This option would retain the capacity to manage stormwater by disposal to Disher Creek, but would reduce the total volume of water flowing to Dishers Creek Basin and possibly reduce the benefit to the Basin vegetation. The smaller volume of lower salinity water may not suit the Murray Hardyhead population.

The justification for Option 3 would not be in reduced operating costs for salinity management, because under current management, the volume of water needing to be disposed to Noora is substantially reduced by evaporation in the basin. The reason for adopting it would have to lie in an improved environmental outcome, and in view of the population of Hardyhead, it is not clear that there would be any such benefit.

Option 4

This option would be a variation of the Option 3, in which a number of salt interception wells would be constructed in the vicinity of Caisson 5 and connected to the proposed Murtho SIS. As with Option 2, the objective would be to reduce the flow of saline groundwater to the river resulting from the current loss of irrigation drainage to groundwater.

Stormwater in the catchment of Caissons 1–4 and 6 would continue to be handled as at present. If found to be necessary, stormwater in the catchment of Caisson 5 could be handled by turning off any RIT SIS pumps, and diverting the water from the catchment to the existing RADDS for disposal to Disher Creek Basin.

Option 4 may be a cost-effective way of reducing salt loads to the river. It would be more costly than Option 2, and as with Option 3, it is not clear that there would be environmental benefits.

4. LOXTON IRRIGATION AREA

4.1 IRRIGATION DRAINAGE WATER MANAGEMENT

The Loxton Irrigation Area is on highland adjacent to the River Murray floodplain. Irrigation commenced in 1948 and within four years, salinisation and waterlogging of the plant root zone emerged (Smith, 1997). Tile drains were installed, with the excess water being disposed to seepage shafts and drainage bores. Disposal to the groundwater via seepage shafts achieved limited success, and a Comprehensive Drainage Scheme was completed in 1964. This comprised gravity main drain pipelines receiving water from the tile drain or agricultural drain systems on each property and delivering the drainage water to open bottom caissons. As indicated in Figure 12, drainage water from Caissons 1–8 is pumped by a northern pipeline, and that from Caissons 9–14 is pumped via a southern pipeline. Both pipelines pump to Katarapko Island Disposal Basin on the floodplain on the opposite side of the river for disposal. Bypasses allow water from both pipelines to be discharged directly to the river under suitable conditions of salinity and flow in the river.

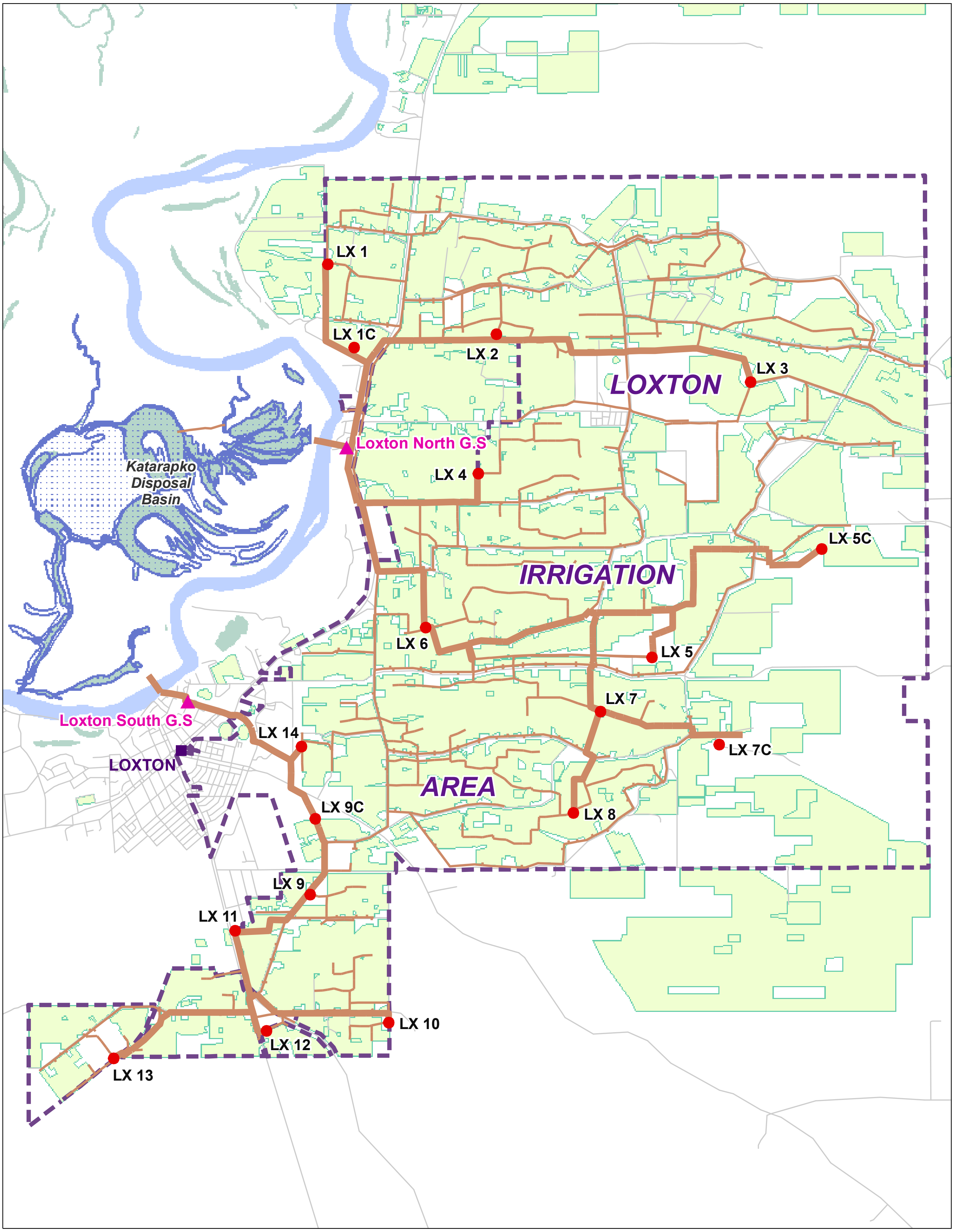
Smith (ibid) reported that 48% of the area was served by drainage in 1972. Watkins (1992) reported that 53% of the area was drained in 1992. Smith (ibid) estimated that by 1997 the proportion had climbed to 58%. He estimated that apart from Caisson LX3, water from all caissons had been discharging to the groundwater. Of these, he estimated that half were still discharging to groundwater in 1997. Caissons LX2 to LX7 were reported as drawing from groundwater for varying periods before 1997 (since installation in 1964 for LX3).

Smith (ibid) also reported on investigations of the interaction of two caissons with the local groundwater over the period 1977–78 to 1995–96. Over the period 1986–87 to 1995–96, for which the data is reliable for Caisson LX3, inflow of groundwater through the caisson bottom represented on average 30% of the volume pumped from the caisson. Groundwater levels near LX8, the other caisson investigated, were below the pumping range throughout the period studied. Despite this, it was estimated that over the period of reliable data (1986–87 to 1993–94) an average of 7% of the volume pumped from the caisson was derived from groundwater.

4.2 SALINITY OF DRAINAGE WATER

The Engineering and Water Supply Department (E&WS), and subsequently SA Water monitored the salinity of water in the northern and southern pipelines at approximately monthly intervals from 1974–96. For most of this time, the salinity ranged between 2500–5000 EC in the northern pipeline. Between 1985–96, average salinity in the southern pipeline was 1970 EC.

Monitoring by CIT between February 2005 and January 2006 (Fig. 13) indicated a variation in salinity of between 600–8600 EC among the caissons feeding the northern pipeline, with an unweighted average salinity of 2600 EC. Average salinity over the catchment was highest in June (3300 EC) when there was little irrigation, and lowest in December (2023 EC).



Government of South Australia
Department of Water, Land and Biodiversity Conservation

Map Production: Resource Information Group
Department of Water, Land and Biodiversity Conservation

Map Projection: MGA Zone 54
Map Datum: GDA 94

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Figure 12. Loxton Irrigation Area Drainage System

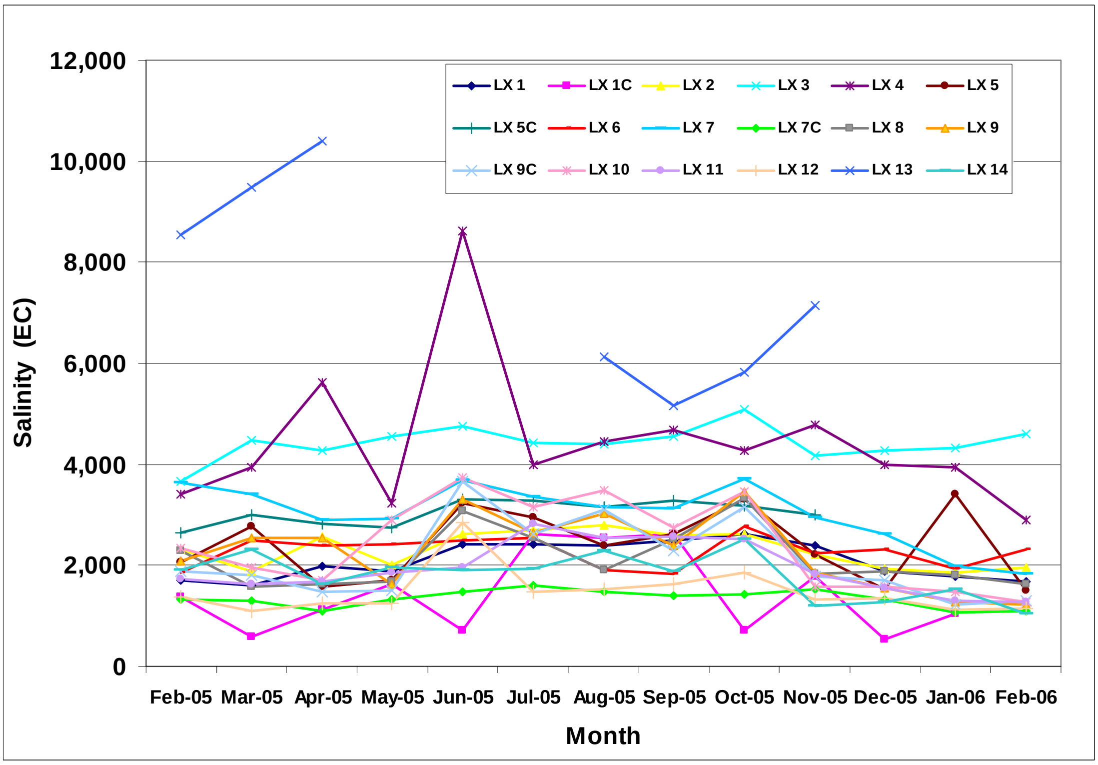

Figure 13. Salinity of Loxton CDS caisson water 2005–06

The salinity of drainage water from caissons in the catchment of the southern pipeline varied between 1100–10 400 EC, with an unweighted average salinity of 2400 EC. Average salinity across the catchment again showed a minimum in the summer irrigation period.

The DWLBC continuous EC monitoring station on the southern pipeline recorded a daily average salinity of 2500 EC between mid September and the end of November 2005, 1500 EC from December 2005 to the end of June 2006, and back to about 2400 EC from then until mid September 2006. For the twelve months from 14 September 2005, salinity ranged between 1164–3115 EC, with an average of 1822 EC. The winter salinity maximum found in both the caisson monitoring and continuous monitoring of the southern pipeline is due to dilution of groundwater by irrigation drainage water during the irrigation season.

The results from the continuous monitoring of the northern pipeline appear to be unreliable, with about 40% of readings less than 600 EC. Reported values were low from the middle of January and the beginning of June 2006. The average of the daily readings above 600 EC for the same 12-month period was 2843 EC units. The reason for the unreliable EC readings is being investigated.

Assuming the average salinity of irrigation water supply to Loxton was about 250 EC in 2005, the average salinity of the caisson drainage suggests the drainage fraction was about 10%. The average salinity of drainage in the southern pipeline suggests a drainage fraction of about 14%. However, the average salinities at LX1C, LX7C and LX12 are well below 2000 EC, suggesting that drainage fractions may well be considerably higher, diluting the influence of native groundwater salinity on the flow from the caissons. This should be investigated by CIT.

4.3 VOLUME OF DRAINAGE WATER

Flow of drainage water is not measured directly, but records of caisson pump hours run and pump performance curves have been used by CIT to estimate drainage flows. No data has been retained for the period 1979–89.

Figure 14 shows that drainage volumes grew progressively until 1994. Smith (ibid) attributes the rise from the 1970s to the 1990s to a combination of an increase in the area drained as well as rising groundwater levels. Following rehabilitation of the water supply infrastructure in 1997 and improved irrigation practices, volumes have been steadily falling to about 25% of their peak levels.

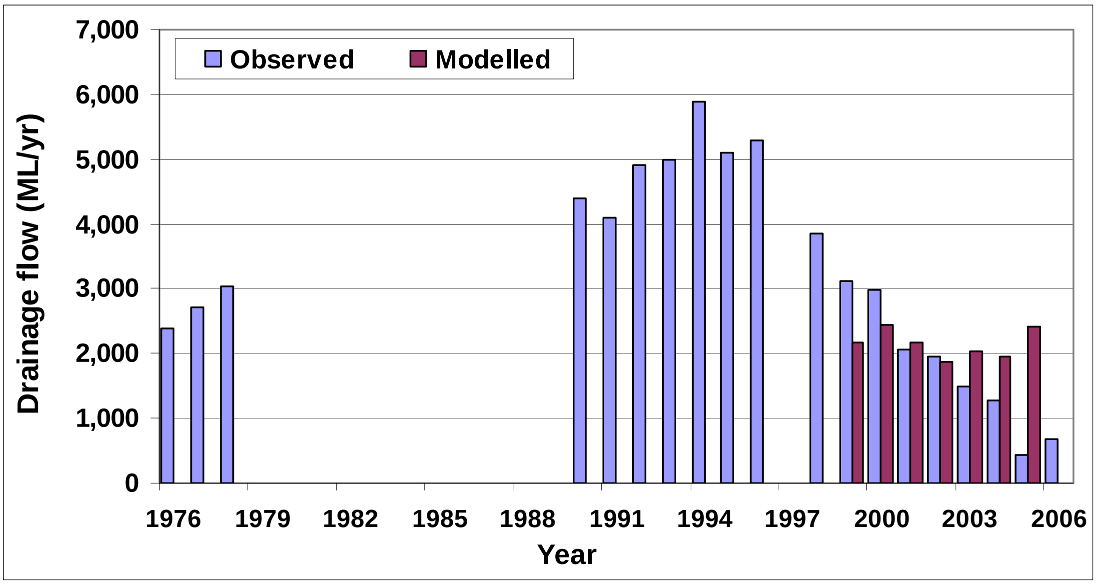

Figure 14. Combined drainage flow from Loxton Irrigation Area

In financial years 2003–04 and 2004–05, the flow of drainage water estimated from caisson pump hours run was about 1300 ML/y, of which about 11% was carried in the southern pipeline.

In Figure 14, the modelled irrigation drainage is estimated from the sum of water supply and rainfall, using a drainage fraction of 10%, and reducing by a factor of 0.6 to reflect that only about 60% of the area is served by drainage. Using these assumptions, it appears that after 2001, the volume of drainage intercepted by the CDS became less than the volume of drainage generated. As for Renmark, the changes in total water inputs to irrigation (including rainfall), do not provide an explanation for the fall in CDS flows.

Adopting a factor of 0.6 to reflect the fact that only 60% of the area is drained allows an estimation of the maximum flow that could be derived from drainage, assuming the groundwater level is above the drain level over the whole irrigated area. Noting that flow from irrigation drains occurs only if the watertable is above the top of the drain, it appears that the watertable is below drain level for much of the area where drains are installed.

4.4 WATER BALANCE

Watkins (1992) estimated that in 1992, 7200 ML/y was going into storage in the groundwater mound, with drainage flow estimated to be 4900 ML/y. Therefore in that year, the total losses from the water supply system and irrigation of 12 100 ML represented between 40–45% of average water use by irrigators. Presumably groundwater accessions continued at a comparable rate until rehabilitation of the water supply in 1997.

Smith (ibid) indicated that most of the caissons contributing most to the total drainage volume were drawing on groundwater before 1997. Hence it is assumed that at least until recently, most of them have been drawing water from the groundwater mound, and that the observed reduction in drainage flows represents the combined effect of reduction in inputs from the water supply system following rehabilitation, improved irrigation practices, and reduced extraction from the groundwater mound.

As illustrated in Figure 15, groundwater levels have been falling since about the time of water supply rehabilitation in 1997. Observation wells GDN007 and GDN041 are more or less in the centre of the northern half of the irrigated area: groundwater level peaked in 1996 at GDN007, and in 1994 at GDN 041. At well GDN 010 to the east of the irrigated area, groundwater level peaked around 2000. At well BKP003 to the south, groundwater levels peaked in 2001, and are falling more slowly than in the centre of the irrigated area.

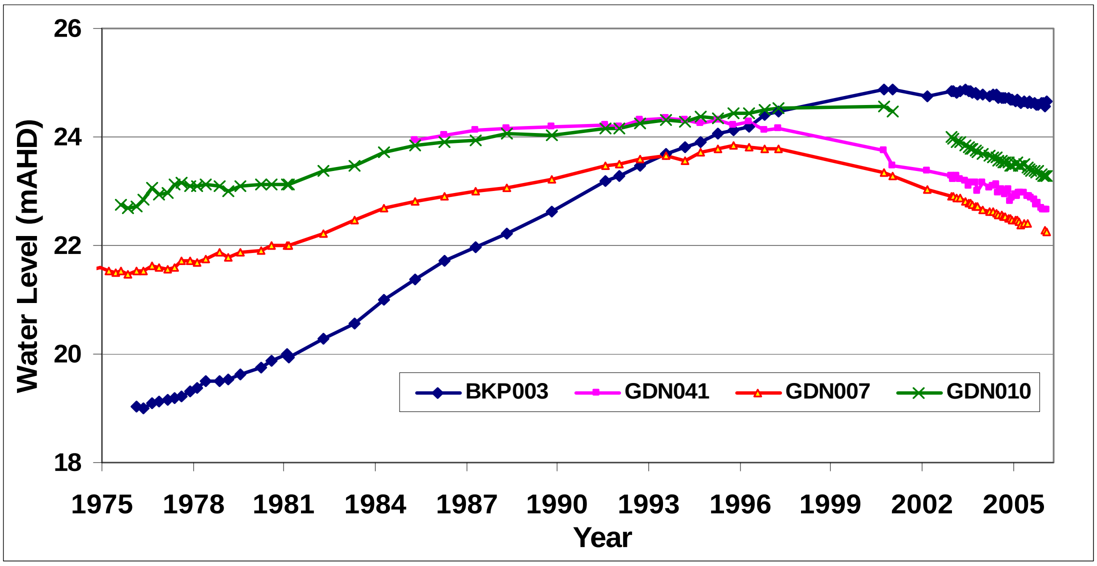

Figure 15. Groundwater level in Loxton Irrigation Area

Of the 23 monitoring wells in the irrigation area, all but two have shown a fall in level of between 0.1 and 1.0 m (average 0.4 m, average annual rate of fall 0.13 m) since 2003. The six monitoring wells established before 1997 show a fall between 0.2 and 1.5 m (average 0.7 m, average annual rate of fall 0.07 m). Over the 21 observation wells, the average rate of fall is about 0.11 m/y. The two wells where a rise of about 0.1 m has been recorded are located close to the river.

Smith (1997) includes information on the Loxton IA water balance at that time. Total water pumped from the River, less water sold to irrigators was 4990 ML, of which part flowed to ponds at the end of distribution lines, and from which an estimated 1500 ML was used for irrigation. Total water received by irrigation (water sold + rainfall) less evapo-transpiration was estimated based on studies of two caisson sub-catchments at 7090 or 5830 ML, an average of 6460 ML. Total sub-surface recharge was therefore 4990 - 1500 + 6460 = 9950, say 10 000 ML. At the same time, CDS flows based on pump hours run were 5000 ML/y, hence accessions to the mound were also about 5000 ML/y.

During this period, groundwater levels were rising at about 0.13 m/y. Assuming that the area in which groundwater was rising was twice as great as the irrigated area of 3200 ha, i.e. 6400 ha, and that the porosity of the aquifer is 10%, then a rise of 0.13 m/y represents 832 ML/y. Thus during the development of the mound, the majority of the water not intercepted by the CDS was being accommodated by lateral expansion of the mound and drainage to the river rather than an increase in groundwater level. Yan et al (2005) modelled the flow of groundwater from the Loxton IA to the river at 5000 ML/y.

Following rehabilitation of the water supply, accessions to the mound would have been greatly reduced, resulting in deflation of the mound as shown in Figure 15, through lateral spread and drainage to the river. This has caused drainage intercepted by the CDS to fall, as shown in Figure 14. During this current phase, drainage from the irrigated area is being progressively transferred from flow to the CDS to groundwater accession. As the groundwater level falls below the level of the tile drainage, CDS flows into the caissons will dry up, but water will continue to be pumped from the caissons till groundwater levels fall beneath the cut-in level of the pumps. Following that, CDS flows will reduce to zero, except following periods of exceptional rainfall.

Most of the drainage installations were designed to intercept watertables perched above the Blanchetown Clay, which is present beneath most of the Loxton Irrigation Area. In topographical depressions where the Blanchetown Clay is absent such as the LX3 area, drains were skimming the water off the top of the groundwater mound but drain flows ceased once the mound receded below drain level. Where Blanchetown Clay is present, drains will flow only if the volume percolating past the root zone exceeds the drainage capacity of the Blanchetown Clay, and the resultant perched watertable rises above drain level.

The fact that the relationship between the groundwater level and the level of base of caissons varies across the irrigation area makes it difficult to predict when the CDS flows will cease, but on the basis of recent records, the time to cessation of flow could only be a few years. Caissons in topographical depressions with higher salinity water, e.g. LX3, LX4, and LX13 are obviously tapping the groundwater mound. Flows from them may persist longer, and the salinity of CDS water may therefore increase.

In the above discussion, no mention has been made of the impact of changes in crop type and irrigation method in the irrigation area, though both have occurred over the same time frame, and presumably have contributed to the decline in groundwater level and CDS flows. However, rehabilitation of the water supply has clearly had a larger impact on the groundwater budget.

Crop type could be an important factor in relation to the volume of accessions e.g. conversion from citrus to wine grapes in a particular area could result in an 18% reduction in accessions from that area for water use efficiencies of 85% - conversely, if there was large scale conversion from wine grapes to crops with a significantly higher crop water requirement in the future, then an increase in accessions could be expected. (K Smith, pers. comm.)

As noted earlier, it was found impractical to measure drainage flows directly, and flow estimates are based on pump performance, with associated uncertainties about accuracy. Pump performance could be calibrated using data loggers at each caisson to log the time of operation and change in caisson water level. This should be done to provide a more robust estimate of CDS flows.

4.5 IMPACT OF DISPOSAL OF DRAINAGE WATER TO KATARAPKO ISLAND

Yan et al (2004) discussed the impact of disposal of drainage water to Katarapko Island Basin (KIB) on the movement of saline groundwater to the river. They noted that prior to 1964 when disposal of drainage water to the KIB started, the watertable was at about 9.8 m AHD (0.2 m below river level at Loxton for entitlement flows), resulting in a small gradient away from the River Murray.

Although the operational strategies prepared in 1976 recommended restricting the water level in the basin to 11 m AHD, the volume being delivered to the disposal basin in the 1970s and ‘80s resulted in a water level elevation of 11.5 m AHD. The water level was reduced following rehabilitation of the water supply and improved irrigation practices, but two small groundwater mounds remained in 2004, with a potentiometric head of about 1 m above river pool level, driving saline groundwater toward the river. Because no data on the disposal basin water level was available for groundwater modelling by Yan et al (ibid) to estimate the effect of operating the basin, an estimated high water level consistent with the maximum observed historical potentiometric head was used. These conditions occurred when discharge to the basin was as high as 6000 ML/y in 1994, but as discussed above, CDS flow has fallen drastically since then. The modelling indicated that the salt load to the river would be 28 t/d for the August 2001 to July 2002 period.

The impact of disposal to Katarapko Island on floodplain vegetation was discussed with the Department for Environment and Heritage. Vegetation on the island has suffered as a consequence of extended periods of low river flow in recent years, and historical periods of extended inundation following floods and earlier operation of the drainage basin. There were indications the present practice of disposing water to the Island has had a positive outcome for the vegetation affected. Given the likelihood that CDS flows may cease in a few years, these beneficial effects may be short-lived.

4.6 BORON

Results of boron analyses are shown in Appendix B. Concentrations found in Loxton caissons range between 0.63 (LX1C) and 5.89 mg/L (LX13), with 8 of the 18 analyses exceeding 3.0 mg/L. These concentrations would certainly make re-use for horticultural crops risky, and may be of concern in relation to the use of the water for rehabilitation of native vegetation on Katarapko Island.

4.7 ALTERNATIVE MANAGEMENT OF DRAINAGE WATER

Water with a salinity of 2500 EC is of limited use for irrigation of normal commercial crops, most of which would suffer a serious decline in health and yield, except for more salt-tolerant species such as lucerne, olives, pistachios and date palms (if adequate leaching is provided). It could potentially be used mixed with the raw irrigation water, in dilution of say one part in ten, in which case it would add about 250 EC units to the salinity of the irrigation water. However this would require significant pipe-work and control mechanisms and would be difficult to justify in relation to the small volume available. This is particularly true given that in recent year irrigators have used less than 75% of the aggregate allocation of raw water for the Loxton Irrigation District.

It would also be possible to use the water to irrigate a eucalypt woodlot for e.g. firewood production. However this also would require infrastructure, and in view of the potential for satisfactory disposal to natural vegetation on Katarapko Island, this alternative has not been systematically evaluated.

Both transfer pipelines are equipped with by-pass valves, enabling the drainage water to be disposed directly to the river in circumstances of high river flow and low river salinity - when flow at Lock 4 is greater than 4500 ML/d and the salinity at Loxton Irrigation Pumping Station is less than 635 EC. Given the relatively small salt load associated with the drainage waters currently, it would be possible to dispose of them to the river on a continuous basis. In assessing whether to adopt this option, SA would need to determine how to offset the salinity impact on the River.

It may be possible to increase the area of vegetation on Katarapko Island benefiting from the drainage water by installing a relatively short length of pipe and using this to distribute the water over a greater area. The use of Loxton drainage water would represent a much more economical option than diversion of River Murray water to irrigate drought-affected floodplain, which DEH and DWLBC may consider under the South Australian “Environmental Flows for the River Murray 2005–2010” strategy.

As indicated above, drainage volumes are now about one sixth of those when disposal was at the historical maximum levels, and the associated salt loads to the river are likely also to be greatly reduced. The impact on River salt loads of current practice and any proposed vegetation watering strategy should be assessed on the basis of current groundwater level data.

Occasional high intensity rainfall events result in large volumes of water being collected by the CDS. To avoid excessive volumes being collected in the KIB, flows could be directed to the river during such events, when salinity is likely to be lower than average. It would be possible to define a design storm event which would be used as the basis for decisions to dispose the stormwater to the river. However, given the likely continuing fall in CDS flows from irrigation and the value of water in promoting native vegetation health on the Island, the emphasis should be on maximising the disposal of stormwater to the Island.

5. BERRI IRRIGATION AREA

5.1 IRRIGATION DRAINAGE WATER MANAGEMENT

The Berri Irrigation Area was proclaimed in 1910 and by 1914, the irrigable area had increased to ~1200 ha. Following the end of the First World War in 1918, the area was expanded, and by 1925 the area irrigated totalled 3125 ha. The area increased to 3300 ha where it has remained for several decades (Smith, 1999). Most irrigation in the Berri and Cobdogla Irrigation Areas occurs on highland above the river valley.

A groundwater mound began to build up beneath the irrigated area soon after irrigation started, showing initially in topographic lows such as Puddletown and Glossop. Tile drainage installations to overcome waterlogging and salinisation commenced in 1922–23, with the drainage water initially being disposed via gravity mains to the River Murray, backwaters or depressions on the river flats. In areas more distant from the river, disposal was to seepage shafts sunk to reach the Loxton/Parilla Sands aquifer.

Despite these measures the groundwater mound continued to rise, requiring the construction of a CDS, on which work commenced in 1940 and was completed in 1952 (Smith, ibid). Most drainage water intercepted by tile drains flows to open-bottom caissons, from where it is pumped via either Puddletown or Monash outfall to Berri Disposal Basin on the floodplain.

A small proportion of drainage water flows to the South Winke Caisson which pumps to the floodplain, and to Penneys, Grossers and K Country caissons which pump to the K Country Evaporation Basin remote from the river. Drainage from the small Berri East area flows directly to the river. Smith (ibid) estimates that CDS pumped discharges to disposal represent about 90% of total discharges for the Berri area. The balance is made up of gravitational (including discharges to bores) and private pumping scheme discharges. The locations of the caissons and the Puddletown and Monash outfalls are shown in Figure 16.

5.2 IRRIGATION DRAINAGE FLOWS

CIT is responsible for water supply and drainage. It has monitored neither salinity nor volumes of drainage, but maintains records of caisson pump hours run that have been used to estimate flows. GHD (2003) conducted an investigation for the Berri Barmera Local Action Planning Committee (BBLAP) into alternative management of irrigation drainage in the area, and used the caisson pump hours run data to estimate drainage flows to Berri, K Country, Loveday South, Loveday and Cobdogla Disposal Basins. The data for Berri have been updated with recent caisson pump hours run data from CIT, and combined with flow records of pumping from the Berri Basin to Noora in Figure 17.

Figure 17 indicates that pump-hours-run-based drainage flows have been falling since the mid 1990s, and fell rapidly from an estimated 3840 ML/y in 1997–98, to 1550 ML/y in 2000–01. Since then, CDS flows have declined more slowly to 1180 ML/y in 2005–06.

Figure 16. Berri Irrigation Area Drainage System

For the 12 months from 10/10/05, total flow at the DWLBC Puddletown gauging station was 539 ML. Over the same period the DWLBC Monash gauging station recorded 247 ML, hence the total measured flow for this period was 786 ML. The estimate from pump hours run data for 2005–06 is 50% greater.

The pump hours run data for the period from 1/7/05 to 30/10/05 is similar to that for the rest of the 2005–06 year, and hence does not explain the difference between the two figures. Smith (1999) noted that metering of flows at the Monash outfall over the two years prior to 1999 indicated that flows based on pump hours run data could give results as much as 20% too high. It appears that pump hour run data for the Berri Irrigation Area cannot be relied on to provide absolute flow figures, though they presumably provide a good indication of trends over time.

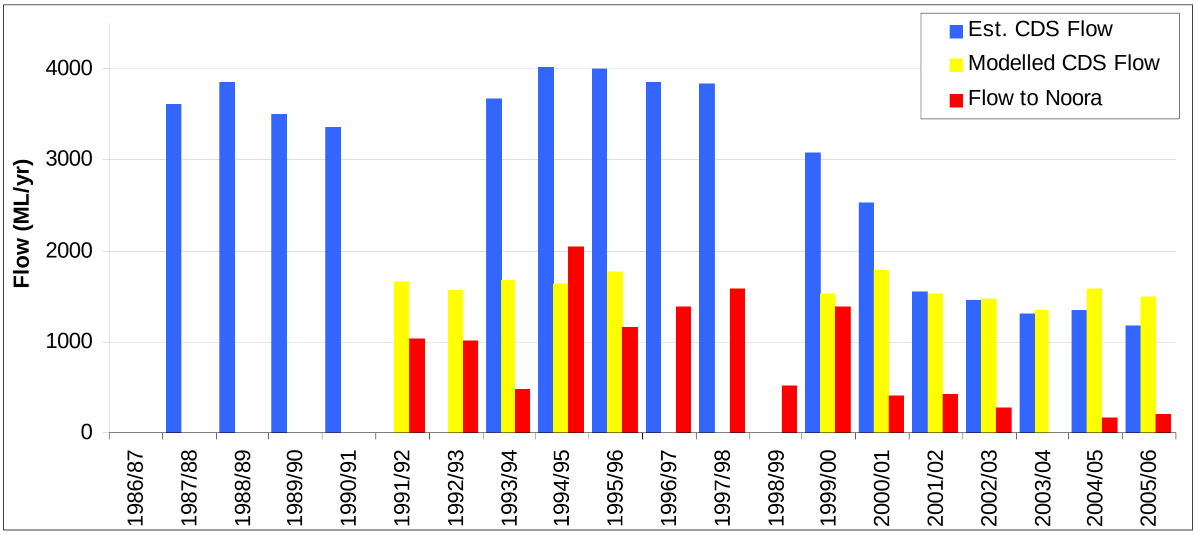

Figure 17. Estimated and modelled drainage flows from Berri Irrigation Area to Berri Disposal Basin, and flows from Berri Basin to Noora Disposal Basin

Reasons for inaccuracies in flow estimates from pump operational data include the need to rely on pump curves, and the progressive reduction in flow from pumps as they wear, and the fact that the pumps are operating against varying heads (i.e. between the cut-in and cut-out level in a caisson).

Figure 17 indicates that for most of the period, the volumes pumped out of the Berri Basin to Noora were about half of the CDS inflows to the Basin, with the balance being lost to evaporation. Since 2002–03, volumes pumped to Noora have declined to less than 20% of estimated CDS inflows, presumably because a larger proportion of the smaller inflows is being lost to evaporation in the Basin.

In Figure 17 the modelled flows have been calculated in the same way as for Loxton, based on total water applied to the irrigated area, except that the flows have been reduced by a factor of 0.45 to reflect that only 45% of the Berri Irrigation District is drained to Berri Basin. CDS flows to Berri Basin, as modelled, have shown little change, but flows estimated from caisson pump operating hours have fallen sharply since 1998. As discussed below, this reduction in drainage flow appears to be due to the same factors as in Loxton and Renmark.

Figure 18 shows groundwater levels at representative wells in the Berri Irrigation Area. In nine of ten wells in the irrigation area, levels have fallen by between 0.23–1.81 m since 1999. In the remaining well located on the edge of the watertable mound, the level increased by 0.38 m. The average change over all wells was a fall of 0.79 m, or 0.11m/y.

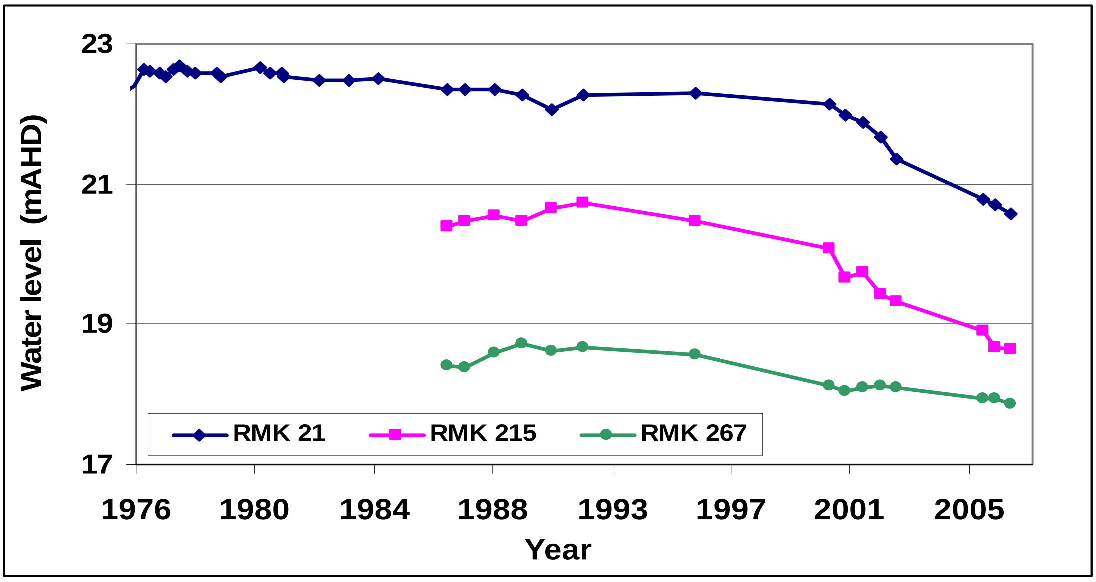

Figure 18. Groundwater levels for representative wells in the Berri Irrigation Area

There are far fewer long term observation well records for Berri than for Loxton, so the history of change in groundwater level and its relationship to changes in water supply infrastructure, irrigation practice and crops is not available. The observed falls in drainage flows are presumed to be due to the same factors as in Loxton and Renmark. Smith (1999) estimated drainage as depth of CDS run-off from the Monash North catchment, based on total water inputs (irrigation water plus rainfall) and crop water requirements for different periods from 1972–73 to 1994–95. This period was characterised by changing water supply and irrigation management. He estimated reductions of 60 mm following introduction of availability of weekly ordering of water (1975–76 to 1982–83), 70 mm following rehabilitation of water supply and introduction of water-on-order (1983–84 to 1988–89), and 62 mm in CDS run-off as a result of improved irrigation methods and management (1989–90 to 1994–95). The continuing decline in groundwater levels shown in Figure 18 illustrates the combined impacts of those influences currently operating on the groundwater budget.

The flows measured by the DWLBC gauging stations provide the most reliable estimate of current drainage volumes, but the pump-hours run data indicated that those flows are declining. As discussed in section 3.6, there are factors that could result in an increase in drainage volumes in future, but they do not appear likely to arise, or will probably have only a minor effect. Thus for the purpose of estimating future flows from the Berri Basin, the use of current DWLBC drainage inflow figures is probably conservative.

5.3 SALINITY OF IRRIGATION DRAINAGE WATER

Over most of the 12 months of monitoring by DWLBC from 10/10/05, the average daily salinity at the Monash pumping station was 3721 EC, a daily minimum was 2121 EC, with a daily maximum of 19 568 EC. The fact that the spikes are higher than measured at the caissons is presumed to reflect the fact that the caissons were only sampled monthly by CIT, and that the high salinities occurred over shorter periods.

The average daily salinity at the Puddletown monitoring station varied rapidly from 5471 to over 27 413 EC, the spikes presumably reflecting the pattern of pumping from the two high salinity caissons. The average daily salinity was 19 664 EC.

At the request of DWLBC, CIT monitored salinities at each caisson in Berri Irrigation Area from February 2005 until February 2006. This data is presented in Table 3 and Figures 19 and 20.

Table 3. Average salinities at caissons in the Puddletown and Monash outfall catchments.

Caisson	**Ave. Salinity** (EC)	**Caisson**	**Ave. Salinity** (EC)
MONASH OUTFALL			
Monash North	6 576	Glossop	3 715
Monash Central	3 258	Vineys	28 078
S Lone Gum	2 607	Toorak	3 630
Monash South	3 172	East Toorak	4 901
		Unweighted Ave	**3 980**
PUDDLETOWN OUTFALL			
Mules	2 775	S190-191	2 406
Glossop Town	19 592	S192-193	1 582
Section 490	4 090	S194-197	1 740
North Winkie	2 841	W Winkie	2 801
Puddletown	18 490	S Winkie	4 596
		Unweighted Ave	**11 250**

Figure 19 indicates that salinities in several caissons feeding the Monash outfall channel were much higher than would be expected on the basis of the EC of the irrigation water and the likely drainage fraction. Viney’s Caisson is strongly affected by groundwater throughout the year, but serves a catchment of only about 1 ha, and collects very little water. There are a number of gravity systems discharging to the Monash Outfall (Nos 1, 2, 3, 4 and 10 Main Drain systems – only the last is likely to have any significant flows). Monash North and East Toorak caissons are clearly drawing on groundwater to a significant extent. The winter maxima exhibited by the Monash North and East Toorak plots suggests that in summer, flows to that caisson are dominated by irrigation drainage, but in winter by regional groundwater.

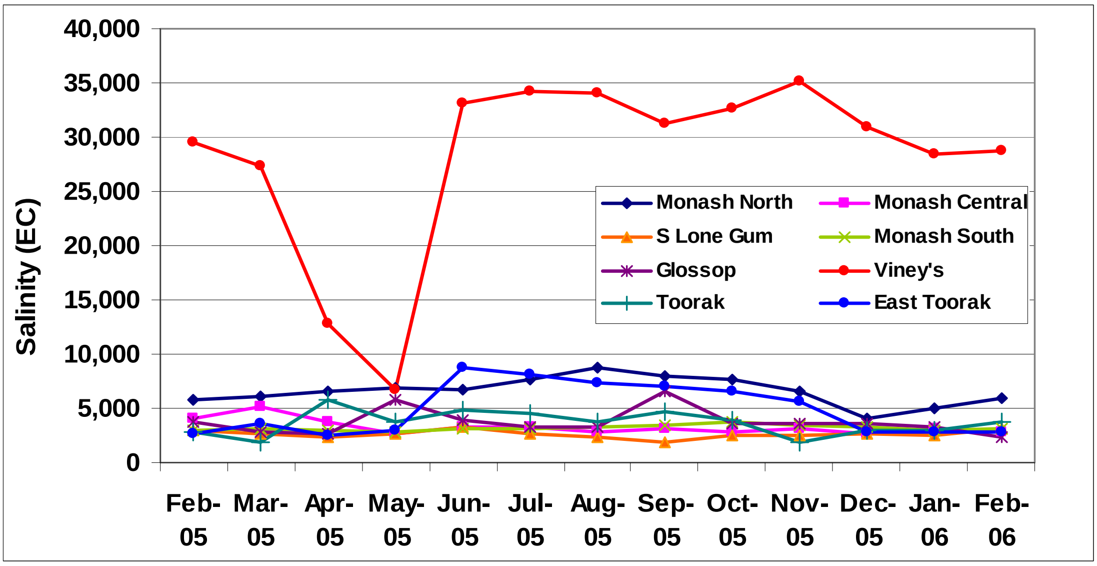

Figure 19. Salinities in caissons of the Monash outfall in Berri IA

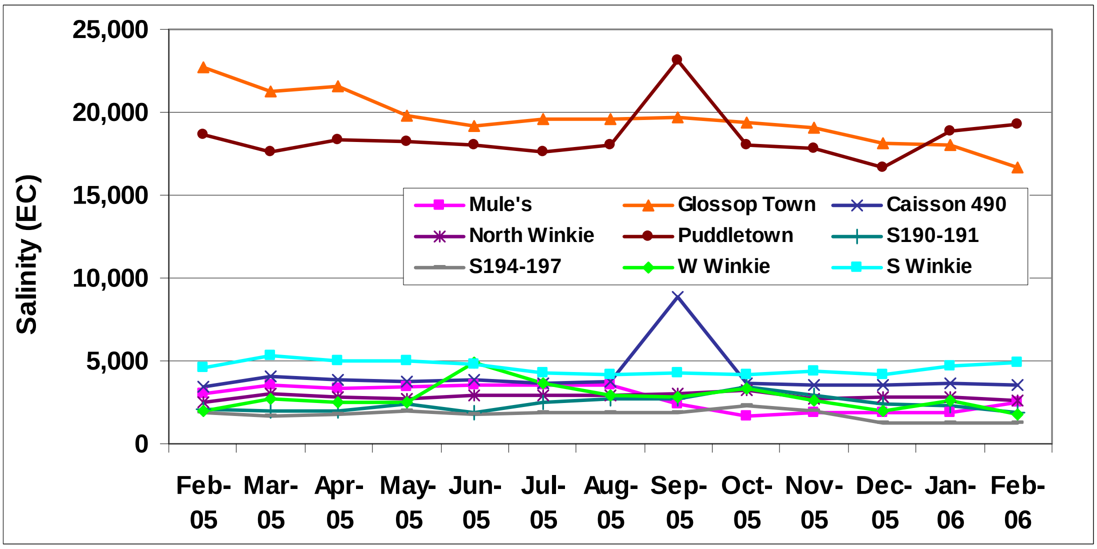

Figure 20. Salinities in caissons of the Puddletown outfall in Berri IA

Figure 20 indicates that salinities in most caissons of Puddletown pipeline were 2000–5000 EC, little above what would be expected on the basis of the salinity of irrigation water. Salinities varied little through the year. Blanchetown Clay is absent in the Glossop Town and Puddletown caisson areas and they were clearly drawing strongly on groundwater throughout the year. Puddletown caisson is in a topographic low and maintains the groundwater level about 5 m below the regional water level. Glossop Town caisson is in an area of groundwater discharge where the top of the groundwater mound is close to natural surface.

5.4 SALT AND WATER BALANCE

Examination of the pump-hours-run data indicates that over the period from 2001–02 to 2005–06, flows from 16 caisson pumps have been falling, eight exhibit no clear trend, and only flow from Monash South is increasing. The two Puddletown Caisson pumps were among those exhibiting no trend. However in 2001–02, they carried 50% of the total flow, but by 2005–06 that proportion had increased to 70%. Thus flow from the low salinity caissons has been falling strongly, while that from the caisson drawing predominantly on the local groundwater has remained steady. This suggests that over the period when groundwater levels have been falling, flow has reduced from those caissons principally handling irrigation drainage water, while those predominantly drawing native groundwater have had a more constant flow. This presumably accounts for the much slower rate of decline in total CDS flows since 2002–03.

The volume of water used for irrigation in Berri in 2005–06 was 23 200 ML. Assuming that 10 % drains below the root zone, and noting that 94% of the area is served by the CDS but only 45% is actually drained (Smith, 1999), the drainage volume should be 1040 ML. Based on the 12 months of flow measurement by DWLBC to 10/10/06, the total flow of CDS drainage was 785.6 ML. Based on the pump hours run record, the high salinity caissons Puddletown, Glossop Town and Vineys collectively carried 70% of total flow in 2005–06, or about 550 ML compared with the theoretical 1040 ML from irrigation drainage. Noting that the salinity of water from most caissons indicates some contribution from groundwater, groundwater accounts for significantly more than 50% of 2005–06 CDS flow. Noting also that only 45% of Berri IA is served by drainage, it can be estimated that more than 75% of Berri IA irrigation drainage water is currently contributing to groundwater. Since groundwater levels are falling regionally, this excess must be accommodated by flow toward the River, some of which is being lost by evaporation from the low-lying land between Berri IA and the River.

Based on the average salinity of water supplied to the Berri IA in 2005–06 of 242 EC, the salt input in irrigation water for 2005–06 was 3370 tonnes. For the twelve months of monitoring to 10/10/06, the average salinity for the Monash outfall was 3721 EC, the total flow 246.7 ML, hence the salt load in the Monash outfall was 550 tonnes. The average salinity for the Puddletown outfall for the same period was 19 664 EC and the total flow 539 ML, hence the Puddletown outfall salt load was 6360 tonnes.

The total CDS salt load was thus 7000 tonnes, about twice the salt load in the raw irrigation water. Hence the CDS appears to be functioning more as a groundwater interception scheme than as a drainage scheme. Smith (1999) found that the salt load for the combined Berri-Cobdogla Irrigation Areas in 1995–96 was about 80% higher than the salt load applied.

5.5 BORON

Results of boron analyses for Berri IA caisson waters taken in February 2005 are shown in Appendix B. Concentrations range between 1.02–5.25 mg/L, with 8 of the 23 analyses exceeding 3.0 mg/L.

5.6 ALTERNATIVE MANAGEMENT OF DRAINAGE WATER

The high salinities and declining annual volumes of the Puddletown drainage waters make them unattractive for alternative uses. The small and decreasing annual flow rates of the lower salinity Monash pipeline make it unlikely that they can be put to economic use, even if mixed with raw irrigation water. The low cost of raw water also makes blending economically unattractive. The high salinities would likewise make the water of no use for watering floodplain vegetation.

About 65% of the CDS drainage flow to Berri Basin has historically been lost to evaporation, and this has risen to 80% since 2001. It is likely that the flow to the Basin will continue to decline because the inputs from irrigation drainage are unlikely to increase, and groundwater levels are falling. Thus an increasing proportion of irrigation drainage is likely to pass to groundwater. In future it is likely that most, if not all the flow to the Basin will be evaporated. The average volume pumped to Noora since 2000 has been 230 ML/y (7 L/s).

One management option is to continue the current method of operations. This will permit stormwater in the catchment to be handled easily, but will result in a progressive build up of salt in Berri Basin.

An alternative is to construct a pipeline to connect the two outfalls directly to the Berri pumping station for pumping to Noora. This would reduce the rate of build up of salt. Provision could be made to divert stormwater to the Basin. Based on 2005–06 flows, it would be necessary to provide for about 750 ML/y (25 L/s) in the Noora pipeline and Disposal Basin if this option were adopted. However, the Basin is necessarily operated below local River level, and especially because of the elevated groundwater level of the adjacent Berri IA, it is operating and will continue to operate as a local groundwater discharge area. Thus prima facie, construction of such a pipeline would merely reduce the rate of build-up of salt in the Basin

Aquaterra (2006) indicated that constructing a SIS within the Berri-Barmera Irrigation Districts to make use of the existing CDS pipeline system was likely to be cost-effective, but would result in only a very small reduction in salt load to the Murray. This is because the scheme would reduce the groundwater mound in the vicinity of the drainage infrastructure, but not impact on a larger scale. Groundwater levels would remain high to the east of the scheme, maintaining steep hydraulic gradients toward the River. As a result EC benefits in the River would be small, about 5 t/d, representing a River benefit at Morgan of 1EC.

6. GROUNDWATER MODELLING

The modelling exercise used an existing five layer numerical groundwater model developed by DWLBC (Yan et al, 2005) which had previously been updated by Aquaterra Simulations on the southern side of the River Murray. The present study entailed updating the model on the northern side of the river.

The following assumptions regarding recharge and drainage rates were made for model inputs:

- Dryland recharge rate under uncleared areas was 0.01 mm/y.
- Dryland recharge rates varied under cleared areas from 0.1 to 10 mm/y, with spatially varying time lags.
- Irrigation drainage rate was 15% of application rates, with spatially varying time lags.
- Drainage features were installed at 1.8 m below the ground surface within the Irrigation Areas to simulate irrigation drainage schemes.
- Drainage features were used to simulate the irrigation drainage basins.

6.1 CALIBRATION

Model calibration was achieved by matching groundwater levels generated by the model with those measured at 22 observation wells with over 20 years of data. Aquaterra (2006) noted that the model performance was good in that the calibration was consistent with MDBC guidelines and that the modelled salt loads to the River were broadly consistent with salt loads estimated from run-of river surveys and surface flow and salinity results. However the report notes a number of limitations of the model, some of which are discussed below.

In two areas, central Berri IA and Chaffey IA, the initial model calibration was poor, with the modelled heads higher than measured water levels. To achieve calibration, recharge rates were halved in these areas. This reduction in recharge rates is consistent with the previous conclusion that volumes of drainage intercepted by the CDS were lower than those estimated from water application rates and the assumed 10% drainage fraction, and that the CDS system is acting as a groundwater interception scheme. Although the implied recharge rates are very low, better correlation between the modelled and actual groundwater levels after 2000 could not be achieved by adjustment of other model parameters.

The salt loads to the river are based on one value of groundwater salinity for each sub-reach of the River, and finer resolution of the salinity information may affect the predicted salt loads.

Generally poorer model performance was found in the Berri IA. This was attributed to the lack of consistency of trends in groundwater level over time, which the model was not able to match.

6.2 SCENARIOS

The following scenarios were modelled:

1. History match: the historical development to 2005.
2. Dryland clearing scenario: salt load predictions for dryland clearing only, simulating the hydrogeological system after installation of the River weirs, but prior to irrigation development.
3. No growth scenario: simulating no further expansion of irrigation after 2003 until 2105.
4. Growth scenario: simulating an expansion of irrigation in the Block X area of RIT area from 2015 with a recharge rate of 100 mm/y.
5. Irrigation efficiency scenario: simulating no reduction in recharge rates to post-1988 irrigation areas due to irrigation efficiency improvements (the difference between salt loads based on this scenario and on the basis of the no growth scenario will give the post-1988 efficiency credit).
6. SIS no growth scenario: simulating the impact of a SIS scheme implemented in 2005, based on the capped 2003 irrigation area.
7. SIS growth scenario: simulating the impact of a SIS scheme implemented in 2005, under conditions of the post 2005 irrigation expansion on Block X.

6.3 RESULTS

The largest salt loads entering the river are recorded along the eastern edge of the Renmark/Chaffey area and from the eastern and western boundaries of the Berri/Cobdogla area. Table 4 presents selected results from the modelling exercise.

Table 4. Modelling results

Scenario	2005 Saltload (t/d)	2055 Saltload (t/d)
Renmark /Chaffey IAs		
2. Dryland clearing	70	72
3. No growth	140	114
4. Growth (Block X)	140	198
5. Irrigation efficiency	140	149
6. No growth with SIS	140	71
7. Growth with SIS	140	134
Berri IA		
2. Dryland clearing	100	105
3. No growth	125	137
5. Irrigation efficiency	125	136
6. No growth with SIS	125	131

For the Renmark/Chaffey IA, the model shows that irrigation is doubling the natural post-locking salt load to the river by 2005. Application of the reduced recharge rates required to achieve model calibration after 2000 resulted in the salt load to the river being reduced to 114 t/d in 2055. With expansion into the Block X area, the salt load increases to 198 t/d in 2055. With the conceptual SIS under the no growth scenario, the salt load to the River is reduced to 71 t/d in 2055, less than half the 149 t/d predicted for the scenario with no growth and reduction in recharge rates post-1988. Construction of a SIS would thus be effective, but economic analysis would be needed to assess whether it would be cost-effective. With the conceptual SIS and growth, the salt load is 134 t/d in 2055.

For the Berri IA, the model shows that no growth irrigation is increasing the natural post-locking salt load to the River by about 25%. Applying the reduced post-2000 recharge rates resulted in the salt load to the River being reduced to 136 t/d in 2055. With the conceptual SIS under the no growth scenario, the salt load to the River is reduced to 131 t/d in 2055, only 5 t/d less than the 137 t/d predicted for the no growth scenario. Installation of a SIS in the Berri area would thus be ineffective. No growth within the Berri area was modelled and the Block X expansion is too remote to influence the loads from the Berri area.

7. CONCLUSIONS

The irrigation district drainage pump hours operation data indicate that drainage flows have been falling rapidly since about 2000, and are now only a fraction of those when the drainage infrastructure was installed. The major causes of the reduction appear to be changes in crop type (eg from tree crops to wine grapes), changes to irrigation water supply infrastructure, and irrigation technologies and management, which in turn have caused a reduction in groundwater levels. The flow reduction has possibly been accelerated to a small extent by the continuing drought. However market forces have driven the technology changes, and it can be predicted that they will persist, i.e. there is a basis for confidence that flows will remain low provided that there is no large scale conversion to crop types with a higher water requirement.

The salinity of drainage water is determined by the salinity of irrigation water, the drainage fraction, and any mixing with regional saline groundwater. Where there is little evidence of mixing with regional groundwater, drainage water salinity can be estimated from the salinity of irrigation water and the estimated drainage fraction. On this basis, it is concluded that drainage from most of the RIT area and Loxton IA is currently only affected to a limited extent by interaction with groundwater, but the drainage discharging to the two Berri outfalls is strongly (and increasingly) affected by saline groundwater.

The small and decreasing volumes of low salinity drainage water make it unlikely that the cost of the infrastructure needed to use that water for alternative crops (or even for mixing with raw irrigation water and use on existing crops) can be justified.

High intensity rainfall events occasionally result in large volumes of stormwater entering the drainage system, and it will be necessary to make provision for this in future management.

Although the rate of fall of CDS drainage flows is decreasing, flows are still falling and flow has been measured directly for only a little more than twelve months. This is a short period to use for management decisions, and it is recommended that monitoring of flows be maintained at least for a further 12 months.

Although caisson pump hours run data provides a good indication of trends in CDS flows, comparison between that data and direct flow gauging indicates that the use of pump performance can result in serious over-estimation of flows.

Analysis of salinity and flow of drainage water has proved a useful insight into the interaction of drainage water with regional groundwater, but special arrangements had to be made to collect this data for the analysis. Consequently, it is considered that current levels of monitoring of drainage flow by CIT, and salinity by RIT and CIT, and ongoing processing of that data are inadequate, especially considering the Trusts' duty of care relating to discharges to the environment.

APPENDICES

A. FLOW AND SALINITY MONITORING STATIONS

Station Name	DWLBC No	Grid Ref., E	Grid Ref., N	Record Start
Loxton North (EC only)	A4261095	140:35:36	34:25:12.4 S	16/09/05
Loxton South (EC only)	A4261096	140:34:26.2	34:26:44.4 S	16/09/05
Berri Basin				
Monash outfall	A426697	140:33:41	34:17:12 S	21/09/05
Puddletown outfall	A426699	140:32:46	34:17:12 S	1/09/05
Disher Creek	A4261085	140:42:37	34:13:43 S	22/09/05
Loveday Basin	A426698	140:24:30	34:15:44 S	21/09/05
Cobdogla Basin	A426592	140:24:23	34:14:17 S	1/09/05

B. CAISSON WATER BORON CONCENTRATIONS FEB 2005

Renmark Irrigation Trust CDS Caisson

Caisson No	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)
1	1.75	6	4.48	11	0.74
2	1.68	7	2.42	12	0.96
3	2.10	8	0.16	13	0.63
4	0.39	9	0.86		
5	3.14	10	1.32		

Ral Ral and Cooltong CDS Caissons

Caisson No	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)
Ral Ral 1	1.45	Ral Ral 3	0.85	Cooltong 1	1.95
Ral Ral 2	0.93	Ral Ral 4	0.17	Cooltong 2	1.36

Loxton CDS Caissons

Caisson No	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)
LX1	1.96	LX5C	3.62	LX9C	1.87
LX1C	0.63	LX6	3.56	LX10	2.80
LX2	2.01	LX7	4.32	LX11	1.52
LX3	3.33	LX7C	1.19	LX12	0.94
LX4	3.03	LX8	3.30	LX13	5.89
LX5	2.25	LX9	2.17	LX14	3.12

Berri CDS Caissons

Caisson No	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)	**Caisson No**	**Boron** (mg/L)
Berri East	1.68	Puddletown	3.04	Penneys	2.95
S. Winkie	1.63	Glossop Tn	3.85	S Lone Gum	1.02
W Winkie	2.94	Mules	1.36	Monash C	2.92
N Winkie	1.37	K Country	2.13	Monash N	3.26
S190-S191	2.73	Fewsters	1.31	Monash S	3.29
S192-S193	2.57	Glossop	1.49	Toorak	2.79
S194-S197	3.34	Vineys	5.25	Toorak E	3.04
490	1.46	Grossers	3.89		

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
megawatt-hours	MWh	10^6 watthours	power
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

~	approximately equal to
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Aquifer, unconfined. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Aquitard. A layer in the geological profile that separates two aquifers and restricts the flow between them.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the *ecosystems (see below)* they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Bore. *See well.*

CDS. Comprehensive Drainage Scheme

CIT. Central Irrigation Trust

DEH. Department for Environment and Heritage

DWLBC. Department of Water, Land and Biodiversity Conservation. Government of South Australia.

E&WS. The former Engineering and Water Supply Department.

EC. Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. Any system in which there is an interdependence upon and interaction between living organisms and their immediate physical, chemical and biological environment.

EPA. Environment Protection Agency.

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

Gigalitre (GL). One thousand million litres (1 000 000 000).

GL. *See gigalitre.*

Groundwater. *See underground water.*

Habitat. The natural place or type of site in which an animal or plant, or communities of plants and animals, lives.

Hydrogeology. The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers. *(See hydrology.)*

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

IA. Irrigation Area.

Infrastructure. Artificial lakes; or dams or reservoirs; or embankments, walls, channels or other works; or buildings or structures; or pipes, machinery or other equipment.

Irrigation. Watering land by any means for the purpose of growing plants.

Irrigation season. The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May.

MDBC. Murray-Darling Basin Commission.

Megalitre (ML). One million litres (1 000 000).

ML. *See megalitre.*

Model. A conceptual or mathematical means of understanding elements of the real world which allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change.

Natural recharge. The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc.) *(See recharge area, artificial recharge.)*

Permeability. A measure of the ease with which water flows through an aquifer or aquitard.

PIRSA. (Department of) Primary Industries and Resources South Australia.

Potentiometric head. The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

RADDS. Renmark and Districts Drainage Scheme

RIT. Renmark Irrigation Trust.

Salinity. The concentration of various salts in a body of water. The bulk of salinity in Australian waters is made up of sodium, calcium, chloride, bicarbonate and sulphate ions.

Underground water (groundwater). Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

WDS. Water Data Services

Well. (a) an opening in the ground excavated for the purpose of obtaining access to underground water; (b) an opening in the ground excavated for some other purpose but that gives access to underground water; (c) a natural opening in the ground that gives access to underground water.

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