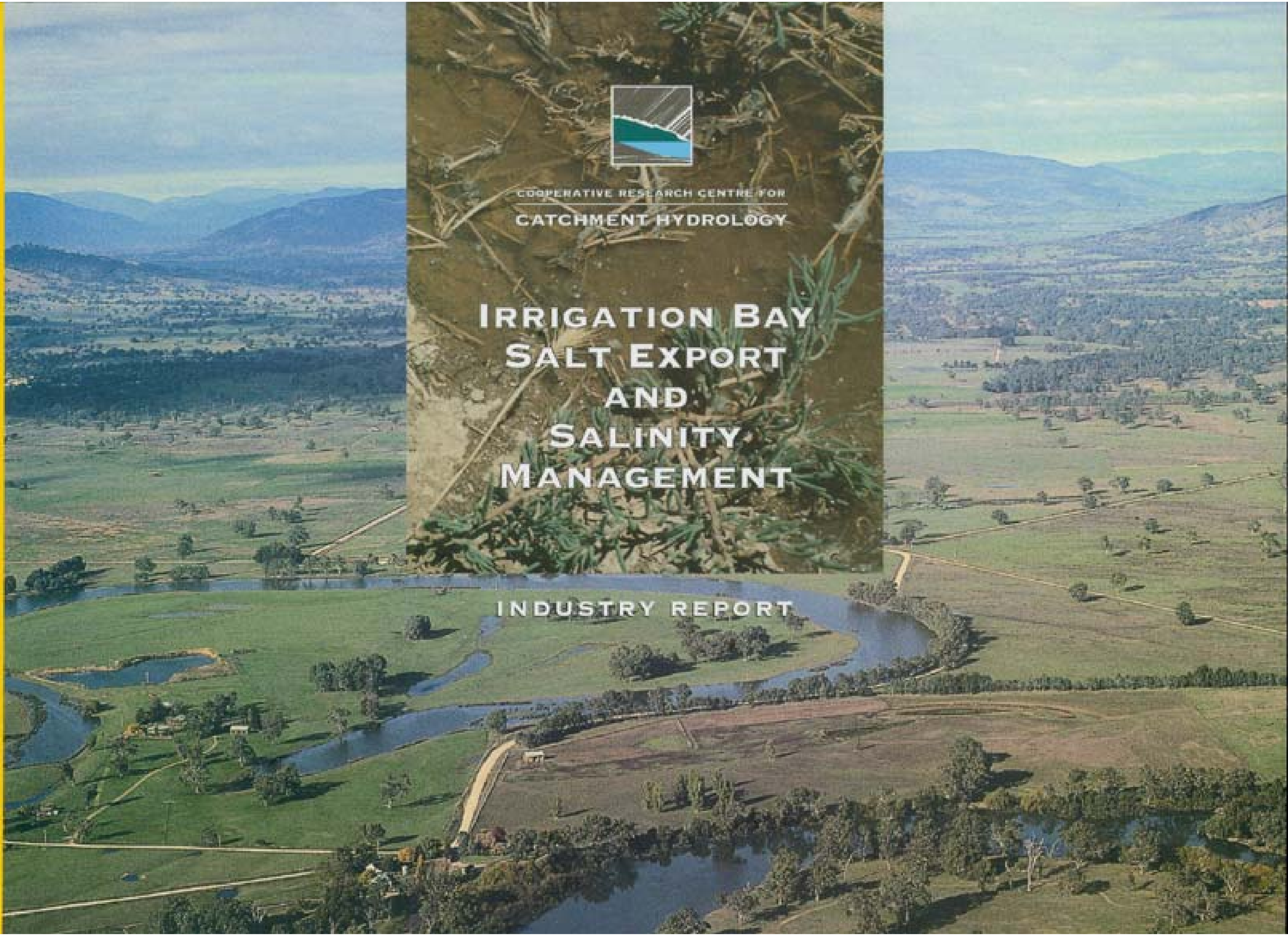

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

IRRIGATION BAY SALT EXPORT AND SALINITY MANAGEMENT

INDUSTRY REPORT

IRRIGATION BAY SALT EXPORT AND SALINITY MANAGEMENT

by

Mat Gilfedder, Luke Connell and John Knight

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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FOREWORD

This Industry Report is one of a series prepared by the Cooperative Research Centre (CRC) for Catchment Hydrology to help provide agencies and consultants in the Australian land and water industry with improved ways of managing catchments.

Through this series of reports and other forms of technology transfer, industry is now able to benefit from the Centre's high-quality, comprehensive research on salinity, forest hydrology, waterway management, urban hydrology and flood hydrology.

This particular Report presents key findings from Project A1 in the CRC's salinity program entitled, 'Runoff and solute processes in high water table areas: measurement, modelling and management'.

The CRC welcomes feedback on the work reported here, and is keen to discuss opportunities for further collaboration with industry to expedite the process of getting research outcomes into practice.

Russell Mein

Director, CRC for Catchment Hydrology

PREFACE

In this report, we have summarised the main findings of an extensive field monitoring program undertaken as part of the Cooperative Research Centre (CRC) for Catchment Hydrology's Project A1, entitled 'Runoff and solute processes in high water table areas: measurement, modelling and management'. The aim of the project was to quantify the processes leading to the export of salt from irrigation bays into the regional drainage network of the Barr Creek catchment in northern Victoria.

This report provides a broader perspective of the project than has been separately presented in scientific journal papers and academic theses (see 'Further Reading' section), in order to make the CRC's research findings more accessible to industry practitioners and other interested groups.

ACKNOWLEDGMENTS

The work described in this report involved substantial field instrumentation and monitoring over several years. Many people and organisations were involved, or provided assistance at different stages of the project. The authors wish to acknowledge the generous support in time and resources from the following organisations:

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- Monash University
- CSIRO Land and Water

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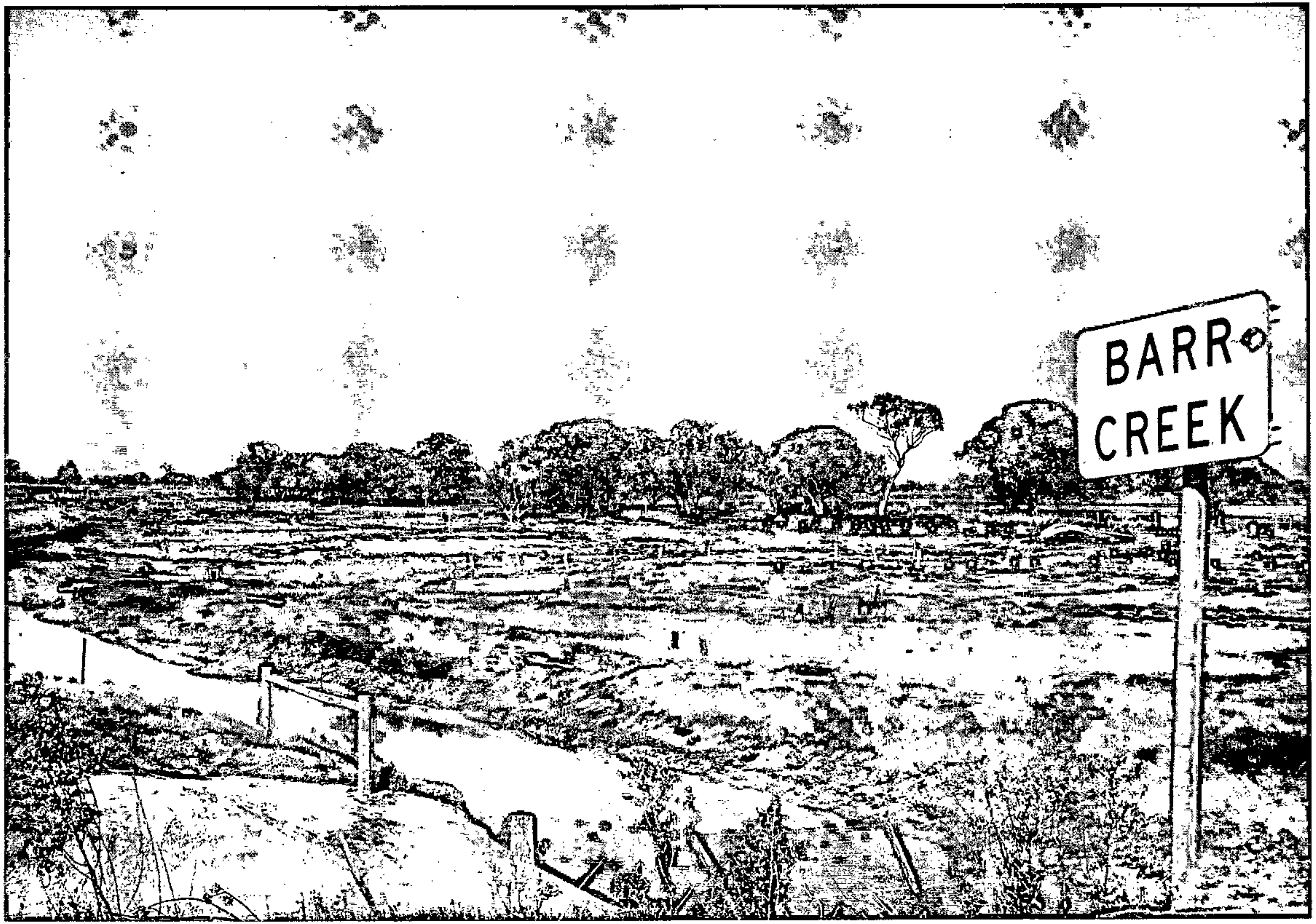


Barr Creek near Cohuna – The main surface drain for salt export from the local irrigated area.

BACKGROUND

SALT EXPORT FROM IRRIGATED AREAS

Long-term irrigation introduces a considerable amount of salt to an irrigation area, adding to the large store of salts already present in the soil. This may increase salinity near the soil surface, where pasture crops extract water, leaving behind the salt.

For irrigation to be sustainable, the salt flushed from the soil along with the excess irrigation water must be drained efficiently. Drainage can occur naturally through porous soils lying above good aquifers, or through some form of engineered drainage. Engineered surface or subsurface drainage is often used in areas with a shallow groundwater table. Water exported from these areas can introduce large quantities of salt into river systems, creating problems for downstream water users and the environment.

Water quality – what is EC?

The salinity of water is usually determined by measuring its electrical conductivity (EC). Water with a higher EC contains more salt and hence has a higher salinity. The measurement unit microSiemens per centimetre (μS cm^{-1}) is a commonly used unit for EC (where 1 dS m^{-1} = 1000 μS cm^{-1}). The *Australian Water Resources Council's* approximate EC values for a range of water qualities are listed below.

AWRC water class	EC (μS cm^{-1})
Fresh	0-800
Marginal	800-1600
Brackish	1600-4800
Saline	>4800
Sea water	about 50 000

Natural resource managers such as the Murray-Darling Basin Commission (MDBC) have been greatly concerned about the export of large quantities of salt from irrigated areas in Victoria. To improve the management of River Murray salinity, the MDBC has estimated the relative proportion of salt contributed by tributaries and groundwater inputs to the lower Murray's total salt load (Figure 1). This work revealed the disproportionately large salt contribution from the relatively small but intensively irrigated Barr Creek catchment in northern Victoria. To reduce the downstream effect of the Barr Creek catchment, managers need to better understand the processes that contribute to salt export from the creek. The Barr Creek catchment was chosen as the focus of the research described in this report.

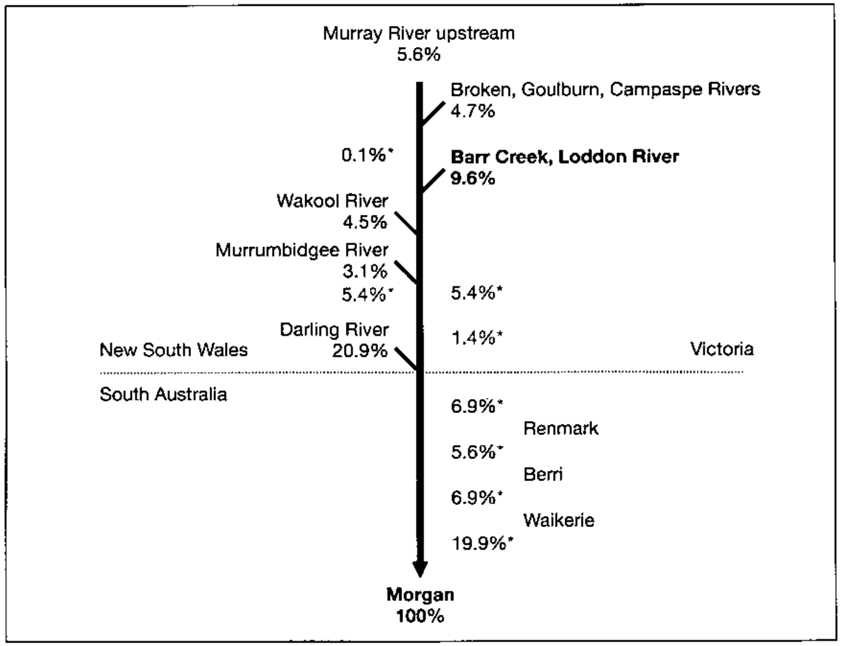


Figure 1: Relative contributions to River Murray salinity at Morgan (South Australia) from subcatchments and groundwater (from Close 1990, p. 141).
*(Note: * indicates direct groundwater contribution to salt load).*

THE BARR CREEK CATCHMENT

The Barr Creek catchment is an intensively irrigated area in northern Victoria (Figure 2). 'Border irrigation' - in which 'irrigation bays' are routinely flooded for the production of pasture for dairy cattle or sheep - is the most common form of irrigation. The catchment area is extremely flat, with a saline groundwater table within 1-2 m of the soil surface in most places. The area is also a discharge zone for regional groundwater, preventing the deep drainage of irrigation water (Figure 3). Before the introduction of irrigation, the groundwater table measured 10 m below the soil surface, but rose quickly after irrigation commenced in the 1880s. This led to widespread waterlogging and salinisation in the area.

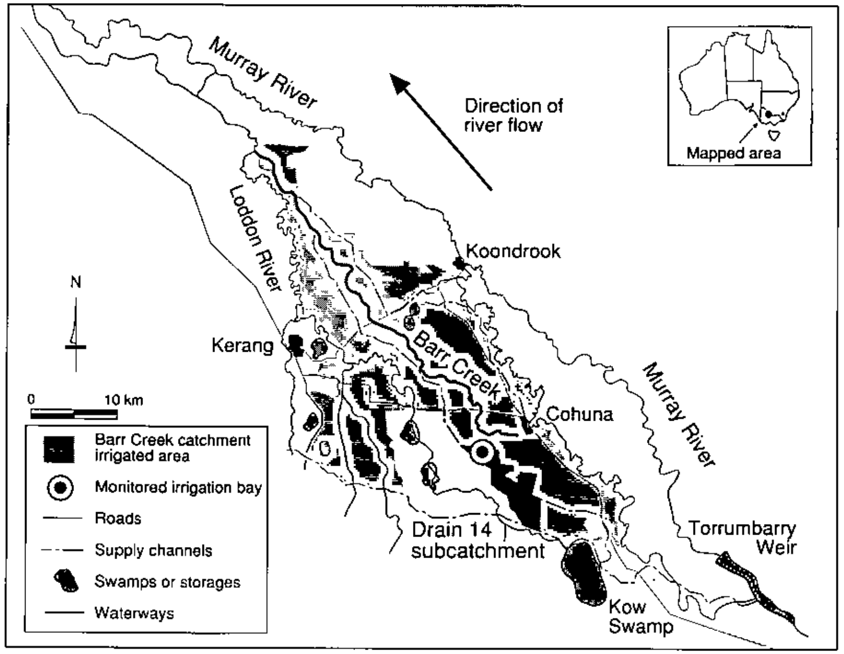


Figure 2: Map of Barr Creek catchment irrigated area, showing the location of the monitored irrigation bay in the Drain 14 subcatchment.

The extremely flat Barr Creek catchment, showing signs of salinisation.

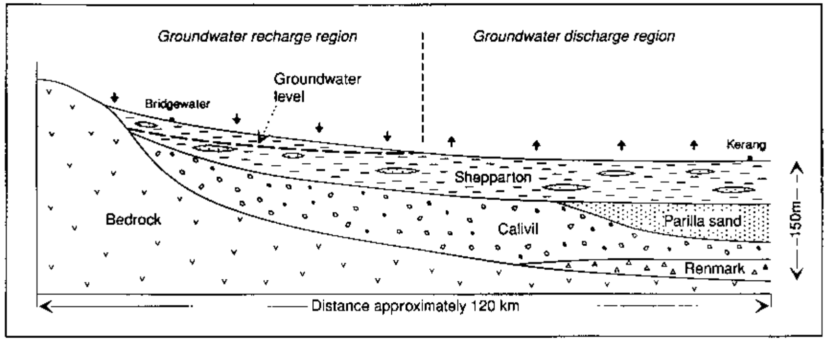
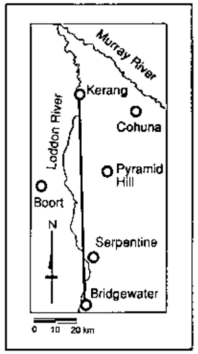


Figure 3: Hydrogeological cross-section of the Loddon Plain showing regional aquifers (above) and cross-section location plan (right). The Barr Creek catchment is to the north, in the groundwater discharge region (after Macumber 1991).



In the 1930s, deep surface drains were constructed using Barr Creek as the main drain into the River Murray. While this reduced the local effects of salinity and waterlogging, it also resulted in a mean annual salt export of around 200 000 tonnes from the area. (This amount can vary widely, depending upon annual rainfall.)

During the 1996-97 irrigation season, the Drain 14 subcatchment of Barr Creek had 1160 tonnes of salt imported with irrigation water, and 4800 tonnes exported as surface drainage. This represents a net salt export ratio of around 400% for the irrigation season.

Resource managers and irrigators can better manage this large salt export through having a more detailed understanding of the essential processes by which water and salt move through soils and drains. To develop effective irrigation management practices that reduce net salt export and enhance irrigation sustainability, this understanding needs to encompass the regional, subcatchment and farm or bay scales.

Although the processes leading to salt export from irrigated areas are well known, their relative contribution is not clearly understood. The main processes by which salt is transported to streams are:

- runoff of excess irrigation water from bays
- runoff of excess rainfall
- seepage of groundwater into regional drains

Several large-scale studies have estimated the relative contributions of these processes to salt export from Barr Creek. However, these studies relied on regionally applied assumptions and total export values. While useful, the results of these studies need to be supported by detailed measurements from smaller farm/bay-scale studies.

CRC PROJECT OBJECTIVES

The purpose of the CRC project was to determine the relative importance of the processes that lead to salt export from the Barr Creek catchment. This involved carrying out intensive field measurements at an irrigation bay scale complemented by computer modelling simulations of irrigation bay processes.

The specific project objectives were to:

- understand and describe salt movement processes occurring within an irrigation bay
- develop and use an 'irrigation bay scale' computer model to estimate the sensitivity of these processes to changes in irrigation management

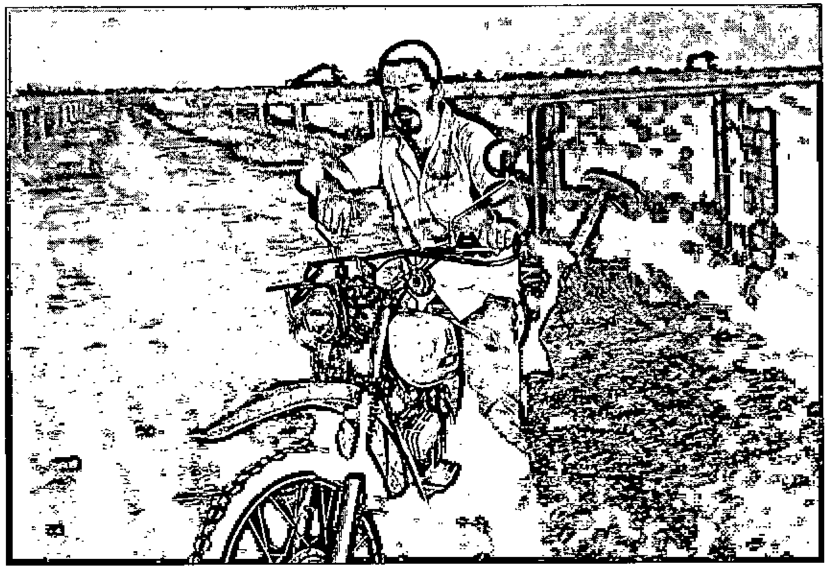
THE IRRIGATION BAY

BORDER IRRIGATION

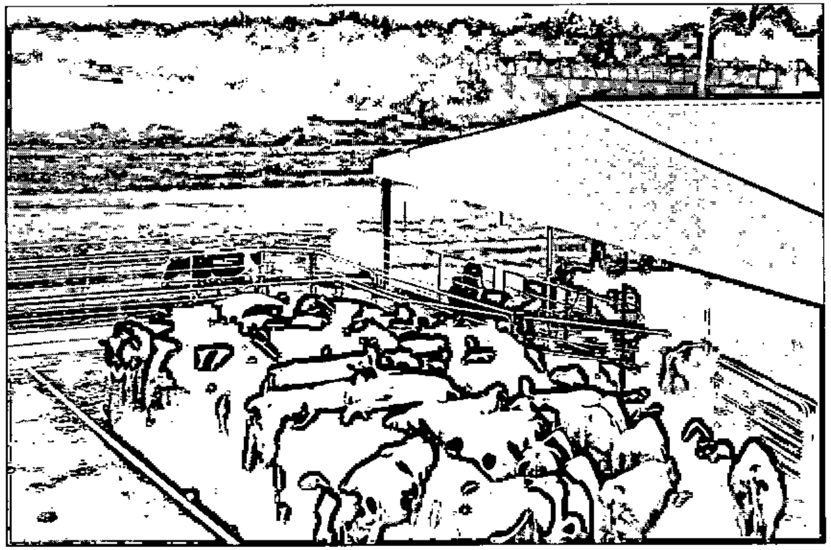
With the border irrigation method, each farm is divided into sloping paddocks, which are separated by low earth check-banks and served by irrigation supply and drainage channels. These paddocks are called bays (or borders) and are irrigated independently, forming the basic unit for on-farm irrigation management.

A bay's size is determined by many factors, including surface slope, soil type, irrigation supply rate, and land area available to the farmer. Although bay size varies, in the Barr Creek area bays are commonly 250-500 m long and 40-90 m wide, with slopes of between 1:750 and 1:1000 (limited by the area's extremely flat topography). Irrigation bays used year-round for perennial pasture are irrigated during the driest part of the year (September-April). Each bay will typically be irrigated every 8-14 days, depending on summer weather conditions.

During each irrigation event, water is supplied from a channel at the upper end of the bay and flows freely as a shallow wave of overland flow. This wave moves slowly down the bay over several hours, with a portion of the water infiltrating into the soil. The water supply to the bay is cut off when the farmer judges that sufficient water has been applied. The exact timing of this cut-off depends on local conditions, but is typically when the advancing surface water front has travelled about two-thirds the length of the bay. This takes from 3 to 10 hours, depending on bay size and irrigation supply rate. After cut-off, the advancing water front continues towards the lower end of the bay, and continues to increase in salinity as it dissolves salt from the soil surface and moves it across the bay. At the end of the bay, a shallow drain collects the water, which flows into the regional drain network at a higher salinity than that of the original supply water.



Irrigators can help their management with an improved understanding of irrigation bay processes.



The Drain 14 subcatchment of Barr Creek is mainly used for the irrigation of dairy pasture.

Over much of the Barr Creek catchment, the shallow groundwater table underneath irrigation bays immediately prior to irrigation is less than 1 m below the soil surface, and responds quickly to the application of irrigation water. Cracking soils allow water to flow quickly into the soil, often bringing the groundwater table up to the soil surface over the wetted part of the bay during the early stages of irrigation (within 15-30 minutes of arrival of irrigation water at the CRC's monitored bay).

After this initial rise in the groundwater table, very little surface water can infiltrate; the irrigation bay soil is almost completely saturated, so the remaining surface water either flows into the drain or remains on the surface to evaporate. While this type of infiltration behaviour characterises poorly drained, heavy cracking soils, we would not expect it to occur to the same extent in areas with lighter soil types.

Between irrigation events, evaporation and pasture transpiration remove water from the surface soil and the crop root zone. As the soil dries, salts are left behind, increasing salinity in near-surface soil.

To better understand the factors that influence the volume and salinity of drainage water, we need to separate the irrigation bay system into the following interlinked processes:

- input to the system (e.g. irrigation and precipitation)
- output from the system (e.g. drain flow and evaporation)
- intermediate system processes (e.g. infiltration, overland flow, groundwater movement and capillary rise)

By simplifying bay behaviour, we can more clearly understand and describe the relationships that determine an irrigation bay's response. Figure 4 illustrates some of the processes that occur in an irrigation bay.

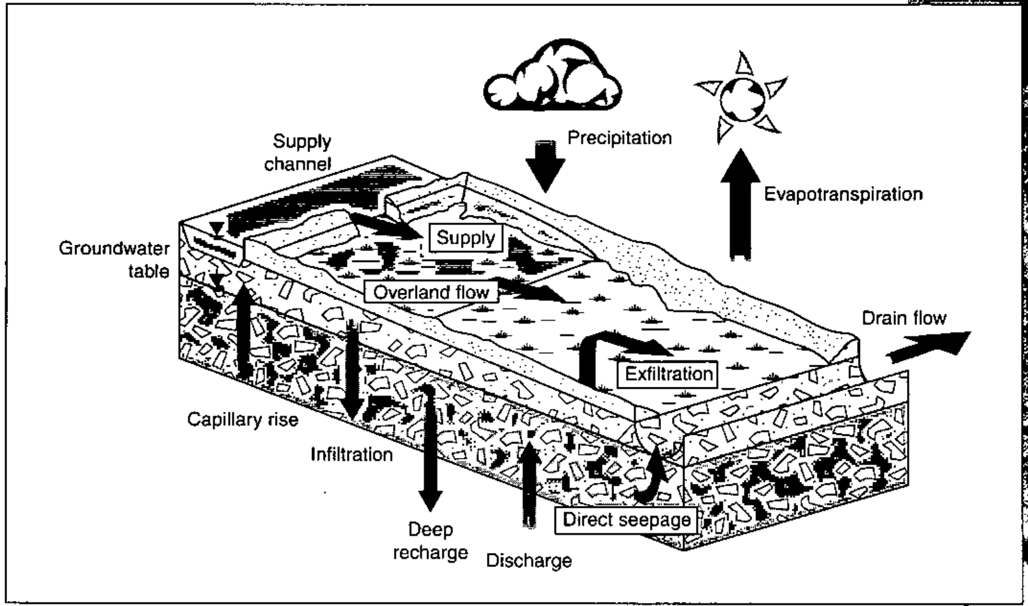


Figure 4: Irrigation bay water movement and salt transport processes.

A more detailed understanding of these irrigation bay processes could be used to make recommendations about the effects of changing current irrigation management practices. For example, we could analyse the effects of the following on irrigation bay salinity and salt export:

- reducing irrigation event volumes
- changing the timing of irrigation
- altering irrigation bay size and slope
- changing the salinity of supplied irrigation water

While our research findings on physical processes within the monitored bay have provided an insight into the mechanisms operating within irrigation bays, practitioners should take care in translating these results to other areas or to other bays in the Barr Creek area without further validation studies.

STUDY SITE DESCRIPTION

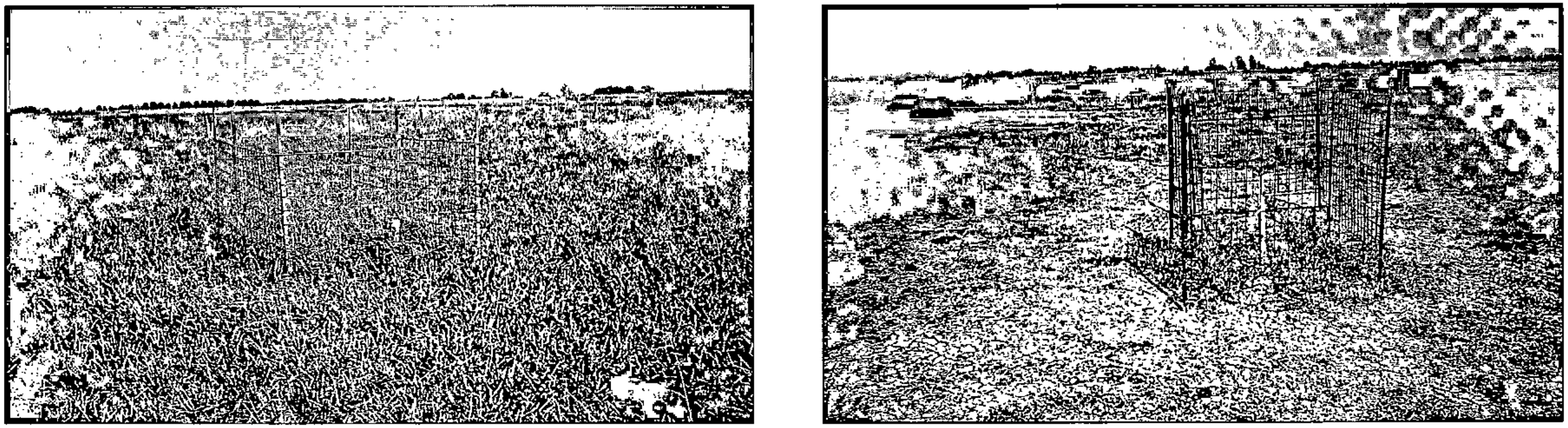
An important part of this CRC study was the extensive monitoring program at the irrigation bay scale. Our study site was a bay in the Drain 14 subcatchment of Barr Creek. The bay had two main soil types - a clay loam in the upper part of the bay, and a light silty clay in the 50 metres closest to the drain in the lower part of the bay.

We measured salt and water movement within the border-irrigated bay (280 m x 55 m, 1:750 slope) to determine the load and timing of salt transport into the surface drainage network. Detailed data were obtained for surface and subsurface water and salt properties over the 1996-97 irrigation season. These included measurements of irrigation supply and drainage volumes and salt load, surface-water salinity and depth, soil water content and salinity, and groundwater table level. Although bays in the Barr Creek area are slightly different, we considered the selected site to be reasonably typical of local conditions. While the soil in the upper part of the bay appeared to be an A Class soil, the lower part of the bay exhibited significant signs of salinisation and was considered a C Class soil. The bay was sown with perennial pasture, and was not an extreme example of size or slope in the area.

Soil salinity classes

Soil salinity classes can provide a simplified indication of the degree of salinisation at a site. EC_e – the salinity of water extracted from a saturated soil sample – is a commonly used measure of soil salinity. The salinity ranges for the four soil salinity classifications are shown in this table.

Soil Salinity class	EC_e ($\mu S\ cm^{-1}$)	Tolerant plants
A	<3800	Most pasture
B	3800-6500	Grass and clover
C	6500-8600	Grass not clover
D	>8600	Some barley grass



The clear difference between the productivity of the upper (left) and lower (right) parts of the monitored bay. Note the salinisation present in the lower part of the bay.

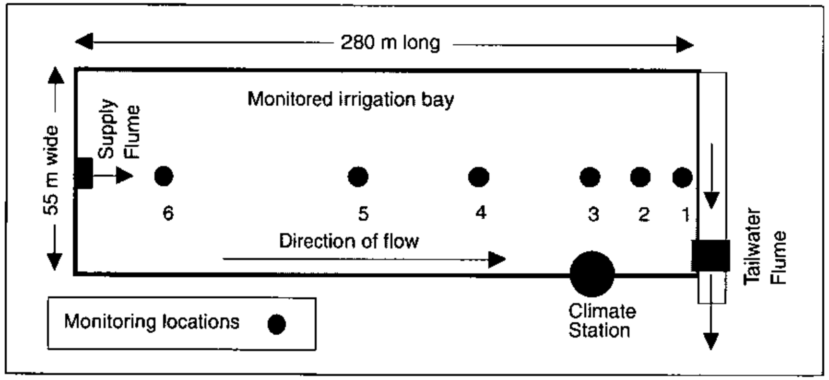


Figure 5: Plan of the bay layout, showing instrumentation and measurement site locations.

Above: The on-site monitoring station, used to measure rainfall and climate for evaporation calculations.

Below: Surface water depths and salinity were measured by hand at several surveyed pegs along the bay during each irrigation event.

For the CRC project, we used several different techniques and instruments to measure the complex movement of water and salt within the irrigation bay. Since reliable field measurements can be difficult to obtain, we kept the monitoring schedule flexible to include both long-term and short-term irrigation monitoring. The data obtained for both surface and subsurface water and salt movement were used to estimate the effects of irrigation on the mobilisation and export of salt from the bay. The locations of monitoring techniques listed in Table 1, are shown in Figure 5.

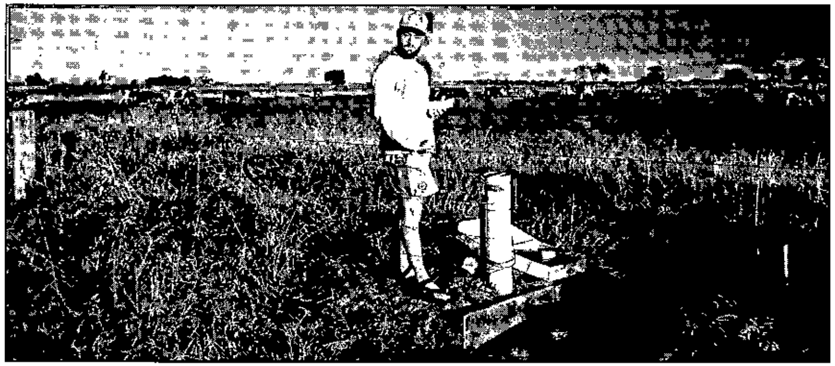
Physical variable	Instrument/technique
Irrigation supply volume & salinity	Rectangular low head flume 1150 mm wide, manual salinity
Drainage volume & salinity	Trapezoidal low head flume 200 mm wide, manual salinity
Surface water depth & salinity	Manual measurements at surveyed pegs
Groundwater elevation	Logged observation wells (2 m deep, six locations)
Soil moisture content	Capacitance probes at (four depths, six locations), & manual sampling
Evapotranspiration	Climate station: temperature, relative humidity, wind, solar radiation and rainfall
Soil salinity	Manual soil samples analysed in lab ($EC_{1:5}$ test) (six locations, 0-750 mm depth)

Table 1: Monitoring techniques used at the CRC's irrigation bay site.

Groundwater levels and salinity were measured manually during each irrigation event.

Irrigation volume units

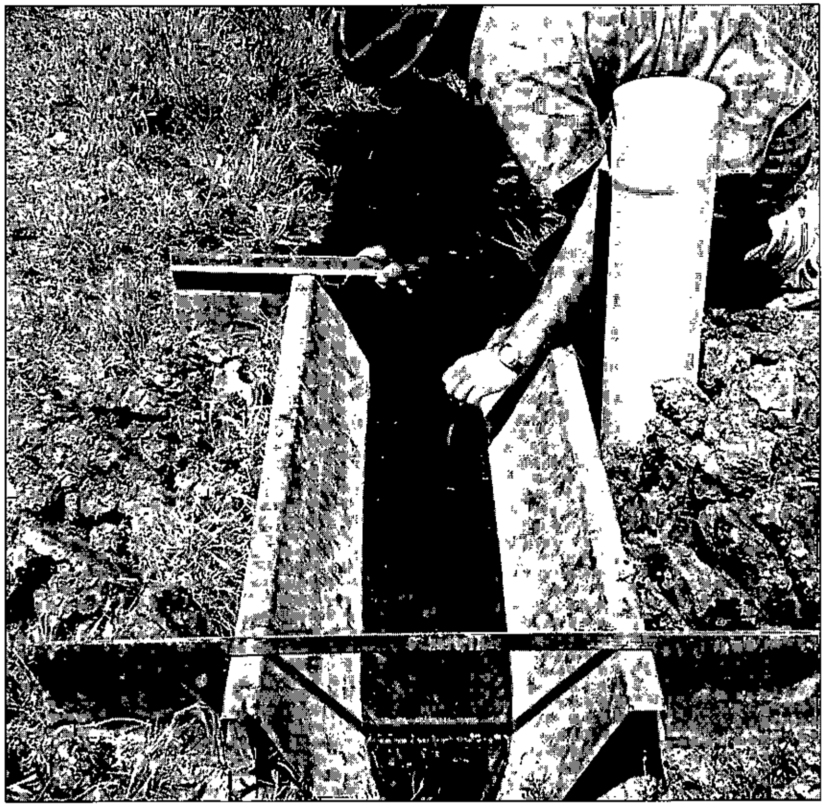
Irrigation water is commonly measured in megalitres (ML). One megalitre is one million litres. If 1 ML were poured over a hectare of land (100 m x 100 m), it would have an average water depth of 10 cm. A traditional unit of water allocation has been the acre-foot; this is about 1.23 ML. A 'typical' irrigation event at the monitored irrigation bay was around 1.2 ML.



The accuracy of the flume's measurement of irrigation water supplied to the bay was confirmed with a flow-velocity meter.

Flow measurement flumes

A flume is a special type of small weir that is used to measure water flow in an open channel. Flumes are often used in locations with low flow rates and where there is not enough slope in the channel to use other methods. When water flows through the flume, it is forced through a constriction, which ensures that a given depth of water corresponds to a given flow rate. A computer program is available to accurately design and calibrate these flumes for a particular situation.



Rapid changes in drainage flow were measured using a flume; manual salinity measurements were also made to ensure accurate calculation of drainage salt loads.

SALT TRANSPORT PROCESSES

We begin this section of the report with a discussion of the effect of irrigation on soil salinity. We then concentrate on two separate processes: the mobilisation of salt from the irrigation bay soil, and the possible export of this mobilised salt. Finally, we discuss the effect of the bay on regional salt export.

IRRIGATION BAY SOIL SALINITY

Soil salinity in the root-zone limits plant growth. Salts build up in this part of the soil profile through evaporation and plant water use. This salt can be removed by applying sufficient water to wash the salt deeper into the soil and/or groundwater, or laterally into surface water that carries the salt into the drain. We periodically measured changes in soil salinity to identify those areas where salt was being moved as a result of irrigation.

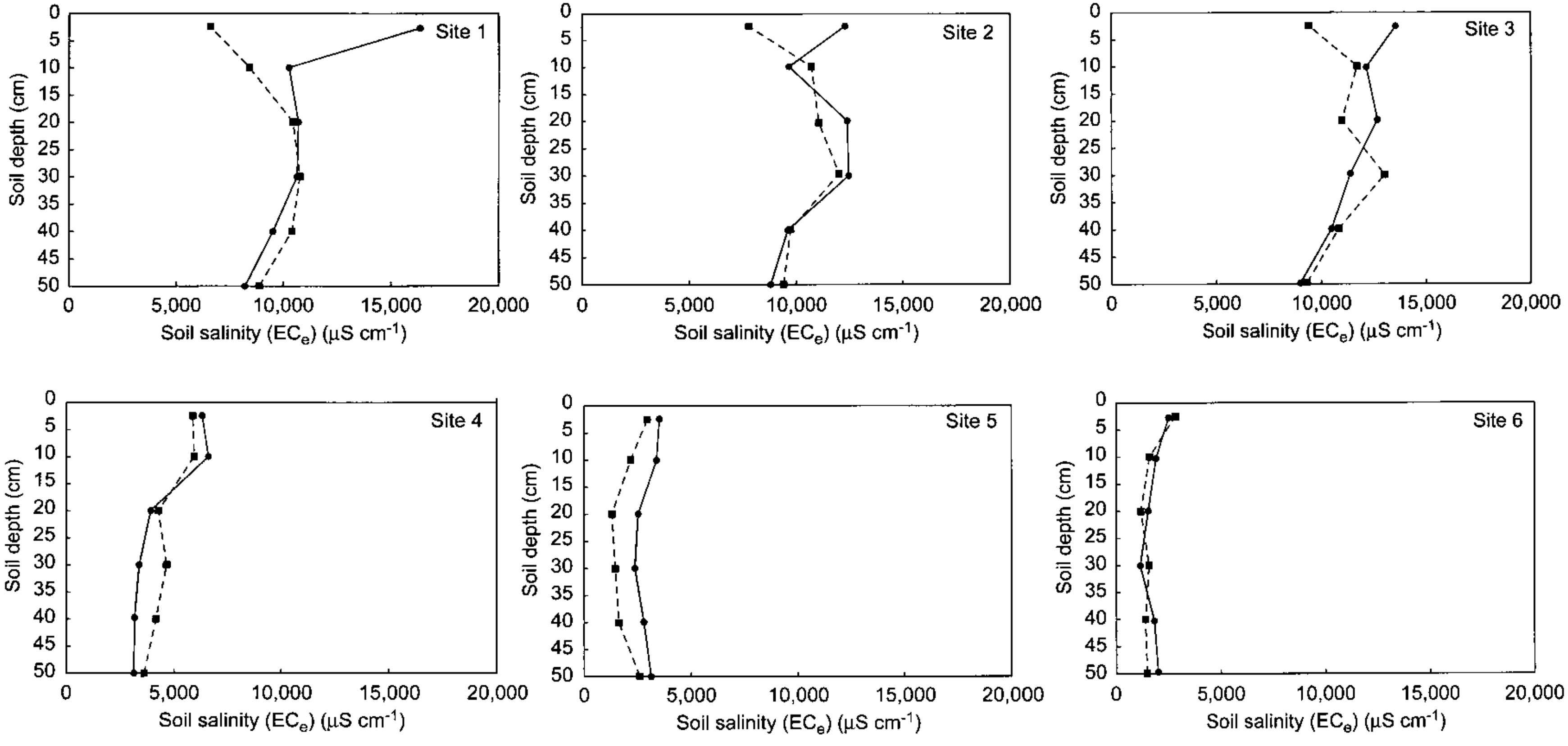
Severe signs of salinity and waterlogging in these bays are clearly evident.

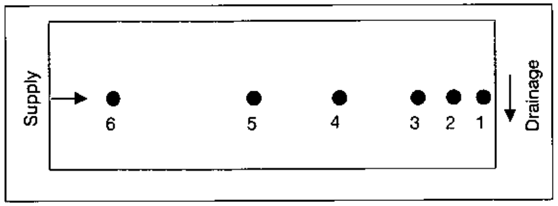
The soil salinity of the monitored irrigation bay was measured before and after an irrigation event using a standard $EC_{1:5}$ test on sampled soil. The salinity of the lower part of the bay (Sites 1, 2 and 3) was much higher than the upper part of the bay (Sites 4, 5 and 6) (Figure 6). In the lower part of the bay, the groundwater table is closer to the surface, making the soil even more prone to waterlogging and salinisation.

What is an $EC_{1:5}$ test?

Normal levels of soil moisture can make it difficult to extract sufficient amounts of water from soil samples to determine salinity. However, to simplify the procedure, there are several tests that involve the addition of water to the soil sample. Common ratios of soil to water are 1:2 and 1:5. For the $EC_{1:5}$ test, 5 parts of water are added to each part of air-dried, crushed soil sample. The mixture is then thoroughly mixed and allowed to settle. The salinity of the solution is measured to give the $EC_{1:5}$ value. These EC values are used to provide a consistent comparison of soil salinity for samples tested by the same method, rather than as an absolute, quantitative value.

The soil salinity in the upper part of the monitored bay was relatively unaffected by the irrigation event shown in Figure 6. This contrasted with the more saline lower part of the bay, which showed a reduction in salinity over the upper 0-10 cm of the soil during the same event. This indicates that much of the salt is being transported as lateral washoff with surface water.





Location of measurement sites along irrigation bay.

Figure 6: Measured soil salinity at six locations within the irrigation bay, before and after an irrigation event.

SALT MOBILISATION BY IRRIGATION WATER

We found further evidence for the lateral movement of salt in the irrigation bay soil when we measured the irrigation water salinity. As the irrigation water advanced down the bay, it dissolved some of the salt from the soil surface. This mobilisation of surface salt happened very quickly, with the lateral movement of salt seen clearly in Figure 7. The large increase in surface water salinity mainly occurred as the water flowed over the lower part of the bay.

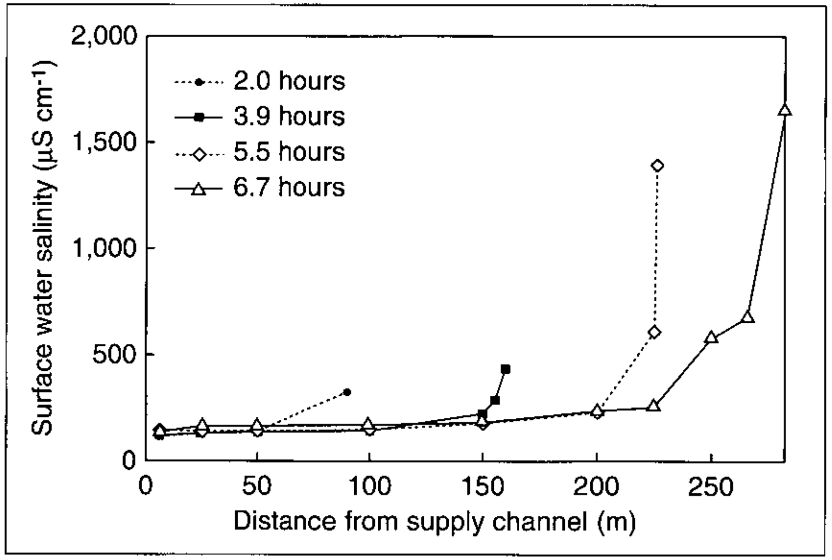
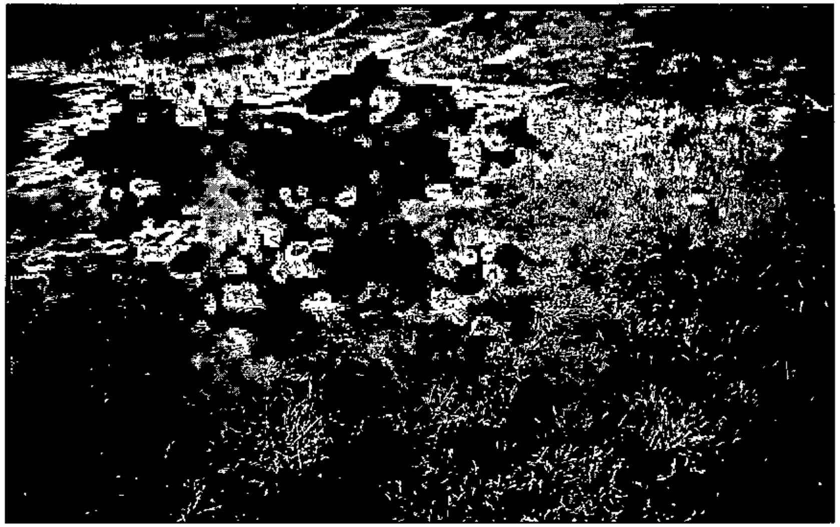


Figure 7: Overland flow salinity changes along the bay at intervals during the irrigation front advance.

During the recession stages of irrigation, after the drain had commenced flowing, salinity levels in the surface water began to increase dramatically, particularly in the lower part of the bay. Because most of the increase occurred when the drain had almost ceased to flow, little of this salt could be exported from the bay in drainage (Figure 8).



Towards the end of each event, some of the irrigation water remains on the bay and evaporates, leaving behind salt on the surface.

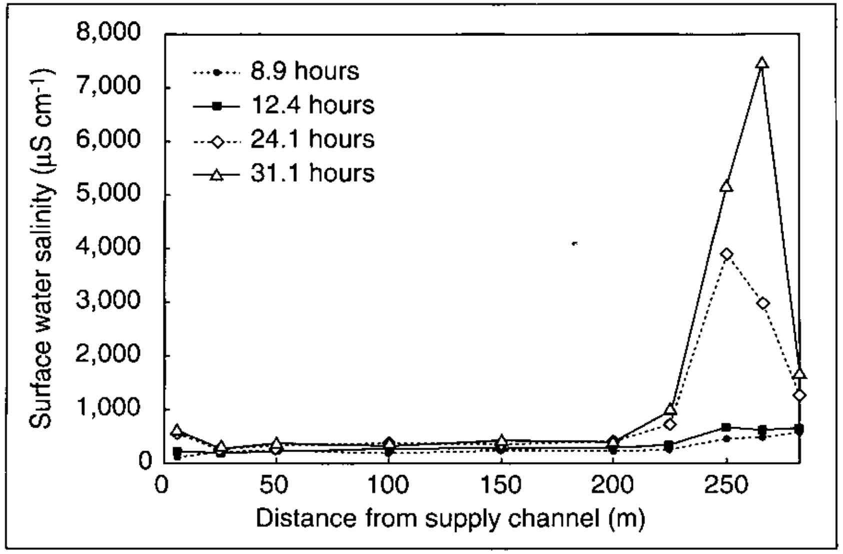


Figure 8: Overland flow salinity changes along the bay at intervals during irrigation recession.

During the irrigation event, water very quickly mobilised salt from the surface and near-surface parts of the soil. The presence of soil cracks, particularly in the lower part of the bay, enhanced this effect due to the increased soil surface area. The rate of salt mobilisation from the soil gradually decreased over the course of a single irrigation event (Figure 9). This supported our conclusion that lateral washoff of salt from the bay surface was the main salt mobilisation process occurring during irrigation in areas with heavy soils, poor drainage and a shallow groundwater table.

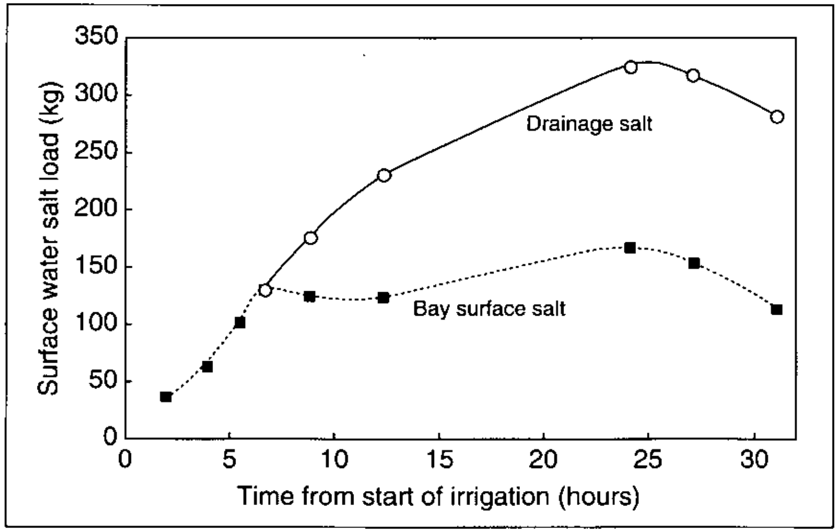


Figure 9: Changes in the amount of salt mobilised from the surface soil during an irrigation event.

SALT EXPORT IN IRRIGATION DRAINAGE

Not all of the salt mobilised during an irrigation event was exported from the bay in the drainage water. Although salts from the soil surface were mobilised quickly, the relative magnitude of the irrigation event determined how much of this salt was actually exported.

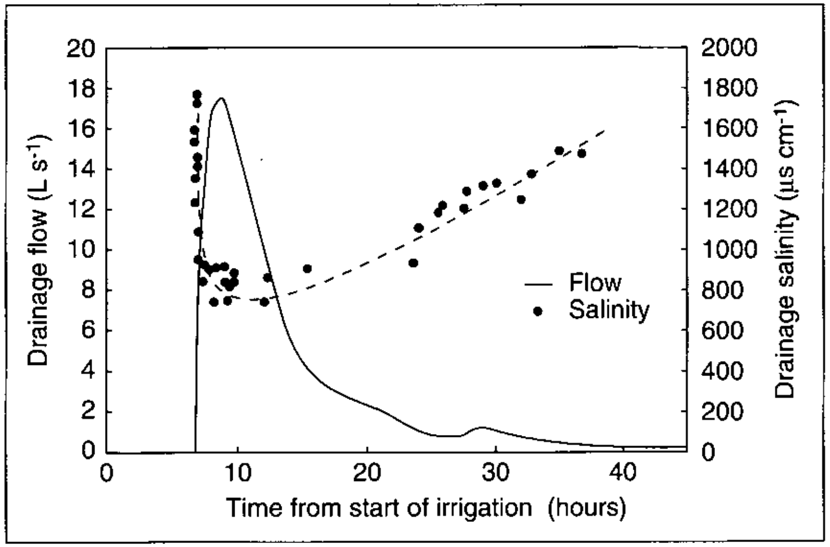


Figure 10: Drainage flow from the bay (hydrograph) and drainage salinity during an irrigation event.

Salt in irrigation water

The salinity of the irrigation water supplied to the Barr Creek area is at least 100 µS cm^{-1}. At this salinity level, each megalitre of water carries 60 kg of salt – a sizeable amount. The monitored bay was 1.55 ha (almost 4 acres) in size, with an average irrigation volume of 1.2 ML. Assuming that there are 20 irrigations each season, then 'fresh' irrigation water can bring almost 1.5 tonnes of salt onto the bay each year.

Drainage flow typically reached its peak within 1 to 2 hours of the commencement of flow in the drain. The gradual recession took much longer, with flow ceasing between 25 and 30 hours after the start of irrigation. Figure 10 shows the changes to drainage flow and salinity throughout a typical irrigation event. The drain is usually dry before an event.

The salinity at the start of drainage flow was high (1500-2000 µS cm^{-1}), but dropped rapidly during the rising part of the hydrograph. This initial elevation in drainage salinity was due mainly to surface salt washoff by the advancing irrigation front as shown in Figure 7. As this high salinity was restricted to water close to the advancing front, drainage salinity dropped rapidly as water from behind the front reached the drain. After the peak in drain flow, salinity gradually rose during the remainder of the event.

NET SALT EXPORT

During the 1996-97 irrigation season, the surface salt export ratio was close to a balance (salt exported in surface drainage / salt imported with irrigation = 1 = 100%). Significant variation in the total mass of salt exported from the bay as surface drainage occurred between the measured irrigation events. Figure 11 shows the salt export ratio for each of the measured events, with points below the 1:1 line indicating a net salt import, and those above the line a net salt export. The balance over the entire season indicated that although the monitored irrigation bay exported salt, it did not significantly contribute to the large regional salt export ratio (see next section).

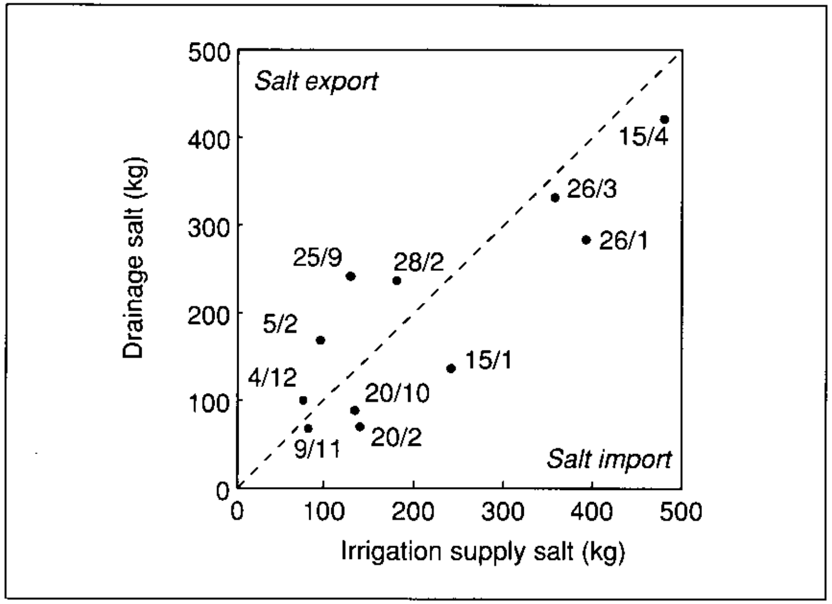


Figure 11: Measured salt export ratio (salt exported with drainage / salt imported with irrigation) for each irrigation event of the 1996-97 season at the monitored irrigation bay.

The significance of salt export ratio

For a hydrological system, the salt export ratio (SER) is the amount of salt output from the system divided by the amount of salt input into the system within the same period. A salt export ratio of 1.0 or 100% means that the system is in salt balance, or equilibrium, over that period. Salt is accumulating in the system when the SER < 1.0, whereas an SER > 1.0 implies that salt stored in the soil or in saline groundwater is leaving the system. Over a long period, most hydrological systems will tend towards equilibrium. Changes in land use often cause the SER to rise, moving back towards equilibrium over a period that may range from tens to thousands of years.

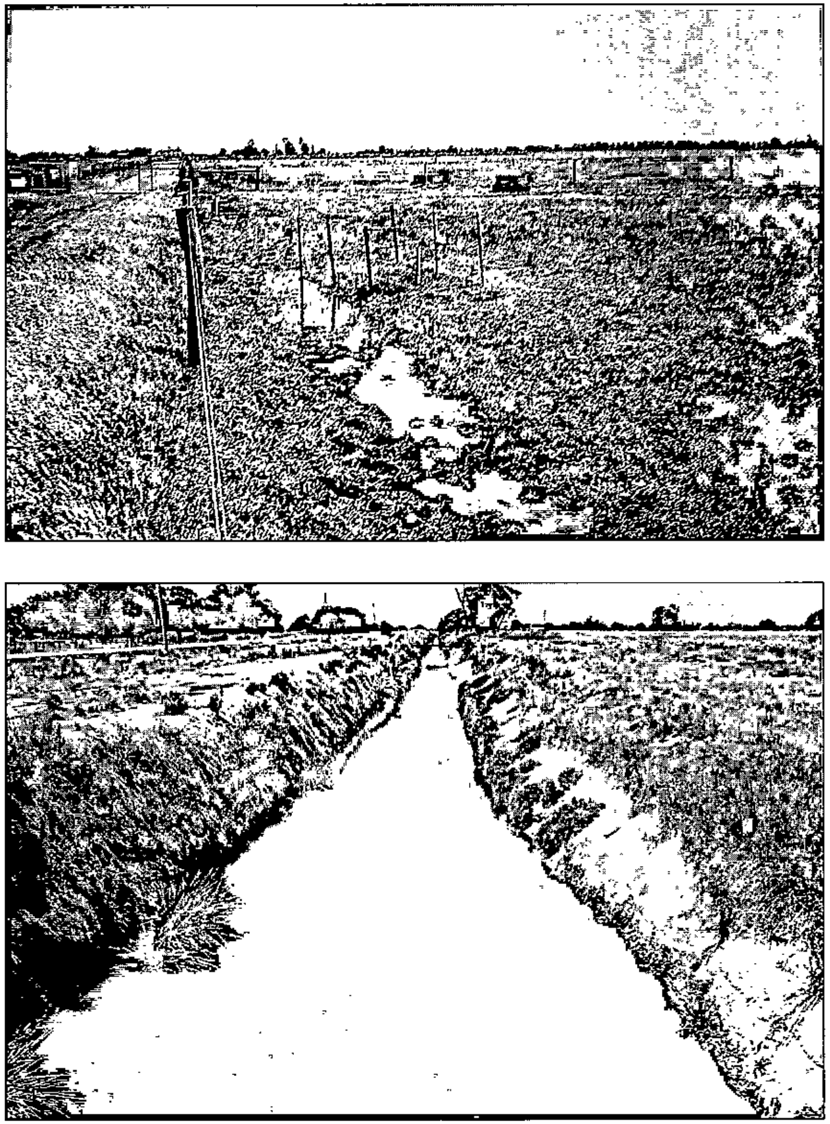
For an irrigation event in an irrigation bay, we calculated the SER as the ratio of salt leaving the bay in the runoff drainage water, to the salt supplied in the irrigation water. For a regional SER, the salt output is the amount contained in the drainage water flowing out of the region, with salt input being the amount in the irrigation water applied over the region, together with any salt in the rainfall.

RELATIVE CONTRIBUTIONS TO REGIONAL SALT EXPORT

The monitored irrigation bay's net salt balance was surprising, given the extremely high regional salt export ratio. The local subcatchment (Drain 14) had a large salt export ratio of 400% for the 1996-97 season. We had expected that irrigation bays would demonstrate a significant salt contribution to the regional salt export ratio, as they form the basis for irrigation water application.

This discrepancy between the irrigation bay and the local subcatchment invited further investigation. If we assumed that all irrigation bays are in a state of net salt balance, then irrigation runoff contributed only about 25% of the total (regional) salt load in Drain 14, a relatively minor contribution. The 1996-97 season had very low rainfall (and minimal runoff from rainfall), which suggested that the remaining 75% of the Drain 14 salt load for the season originated from direct flow of groundwater into the regional drainage network. In a high-rainfall year, the proportion of total salt contributed by irrigation runoff would be even lower.

This finding has important implications for the management of salt export from the Drain 14 area. If irrigation runoff is only a minor contributor to regional salt loads, even a significant decrease in runoff volumes from bays will only have a small effect on regional salt exported via surface drains.



Small on-farm drains (top) for irrigation runoff do not intersect the groundwater table to the same extent as deeper regional drains (above). Groundwater seepage into these deeper drains is a significant source of Barr Creek salt load.

COMPARISON OF MANAGEMENT STRATEGIES

After we had investigated the physical processes occurring at the irrigation bay scale, we assessed how changes in irrigation management could affect both irrigation bay and regional salt export.

While we had obtained good-quality measured data for almost an entire irrigation season at a single bay, we used a computer model to verify our assessment of irrigation bay behaviour. By calibrating the model with measured data, we could simulate irrigation bay behaviour with a high degree of confidence. This enabled us to more readily estimate the sensitivity of irrigation bay processes to controlled changes than we could have using measurements alone. In the following section, we discuss and compare the consequences of two different irrigation management strategies, based on our calibrated model.

STRATEGY 1: REDUCING IRRIGATION SUPPLY VOLUME

Reducing the amount of water supplied to each irrigation bay might seem at first to be an effective strategy for reducing the area's salt export and increasing its irrigation efficiency. It would mean less water being taken from rivers for irrigation, and less drainage water from bays being fed back into rivers. However, the CRC's Barr Creek study suggests that this strategy could also have negative effects.

The 'bay-scale model'

The CRC has developed a physically based, irrigation bay-scale computer model that can simulate and predict water and salt movement within an irrigation bay. The model utilises data on irrigation supply, evapotranspiration, rainfall and physical bay characteristics to simulate the interactions between surface and subsurface processes. The modelled slice of bay has a bottom boundary (set at 10 m below the soil surface), and does not take into account any deep movement of salt across this depth (upwards or downwards). This simplification was considered appropriate, particularly over the short-medium term, given the poor drainage and relatively flat surface and groundwater gradients.

As well as using actual physical characteristics of the monitored bay, some model parameters were fitted during the calibration with measured results from the monitoring study. The ability of the model to simulate behaviour and match measured results provided confidence in the model output.

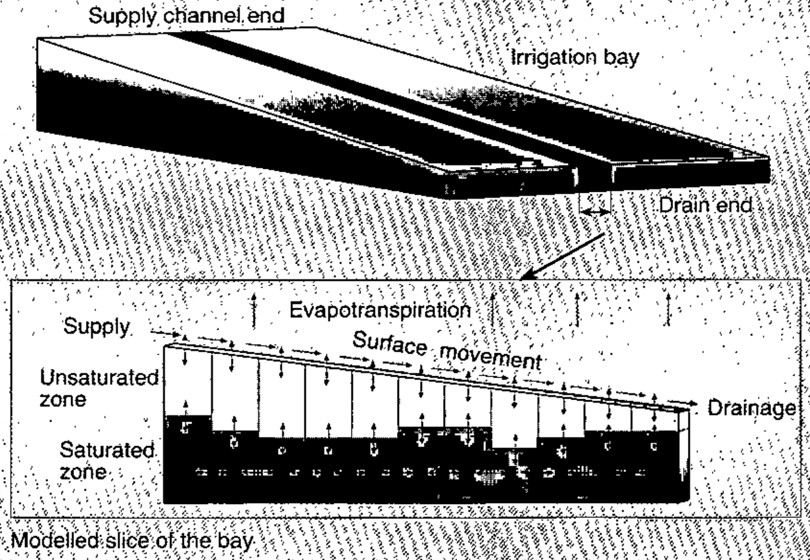
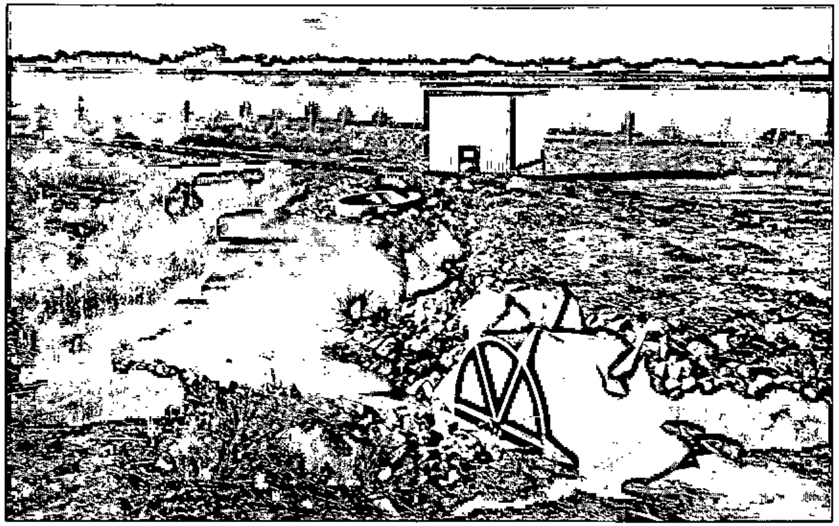


Diagram showing the vertical cell structure used by the CRC to model an irrigation bay.



The supply of irrigation water to the farm is measured using a standard water wheel.

The drainage volume ratio (drainage volume / irrigation supply volume) for each event at the monitored bay was typically around 20-30%. 'Best practice' is thought to be about 15%. Unfortunately, this lower drainage volume ratio would affect the build-up of salt in the lower parts of an irrigation bay (since salt is washed off the soil surface), and have only a limited effect in reducing regional salt export.

In earlier sections of this report, we highlighted the distinction between mobilised and exported salt. While all irrigation events quickly mobilised the salt concentrated at the soil surface, high-volume irrigation events that produced greater drainage volumes exported more of this mobilised salt. Figure 12 shows how large irrigation events with large drainage volumes exported larger amounts of salt mobilised from the soil. Thus, reducing irrigation water volume will reduce the drainage volume, the drainage salt load, and the export of salt mobilised from the bay.

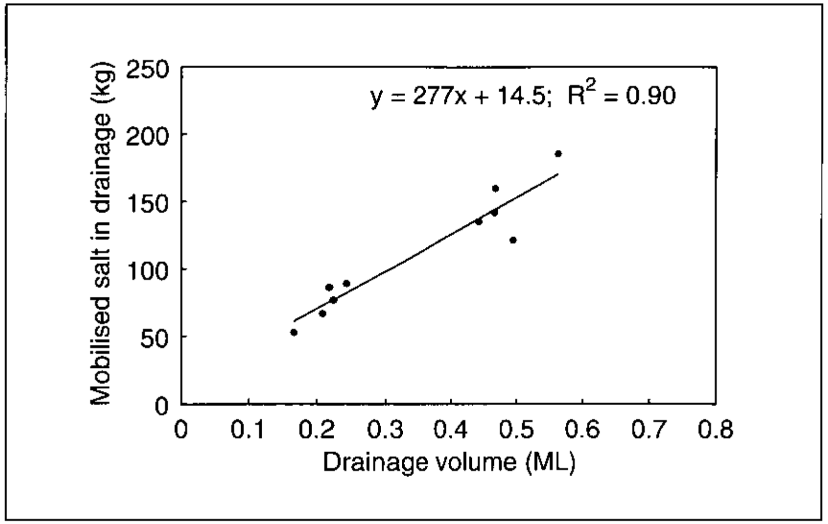


Figure 12: Changes in the export of mobilised soil salt, as a result of changes in drainage volume for each event.

We used our model to confirm this prediction, by using monitored data to simulate a single event. We modified the simulation of this event by reducing the irrigation supply (by an earlier cut-off of supply water), or by extending the period of irrigation supply (at the same flow rate as at the end of the actual monitored event). By changing the supply period, we were able to simulate a range of irrigation event volumes. We were then able to simulate the changes in drainage salt load and salt export ratio resulting from changes to supply volume. This process was carried out for four separate events, with each event shown as a line in Figure 13. Each line in Figure 13 indicates changes in salt export ratio due to simulated changes in irrigation supply volume, with each event responding in a similar manner.

For the lowest simulated irrigation volume - an event in which no drainage is produced (drainage volume ratio = 0%) - there is obviously no salt export from the bay. If the simulated irrigation volume is then increased to produce a drainage volume ratio close to 20%, the salt exported from the bay increases to an approximate salt balance. If the same irrigation event is simulated with increased irrigation supply volume (drainage volume ratio greater than 20%), the actual drainage salt load from the bay increases, although the bay's salt export ratio remains relatively consistent.

The model results show that there is a certain drainage volume ratio (in this case 20%) below which there will be a significant net import of salt to the bay. Higher drainage volume ratios (from higher irrigation volumes) will merely maintain a consistent salt export ratio while increasing the drainage salt load exported. Figure 13 shows this relationship for four separate irrigation events

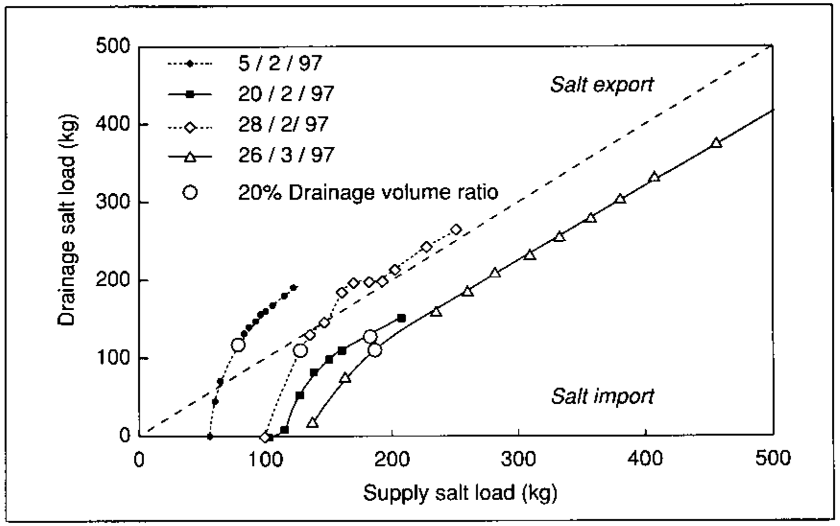
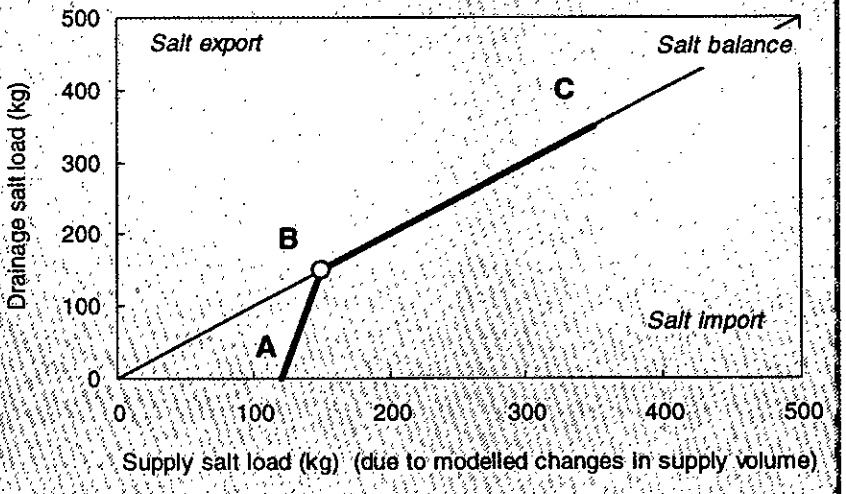


Figure 13: Simulated changes in irrigation event salt export ratio (SER) as a result of changing the supplied irrigation volume for four separate events.

Simplification of Figure 13 results

We used the bay-scale model to change the supply volume for a given irrigation event. This meant that we were able to simulate what 'could have happened' to drain salt load and to the salt export ratio if different amounts of irrigation water were applied during that event. An example of this effect on the salt export ratio and salt export for a single event is shown in the following table. A chart for the same simplified data is also presented.

Chart label	Irrigation volume	Drainage vol. ratio	Drainage salt load	Salt export ratio
(A) - (B)	low	0-20%	low	0% (high import)
(B)	suggested	20%	medium	100% (balance)
(B) - (C)	high	>20%	high	100% (balance)



Decreased irrigation water volumes would decrease the salt exported with irrigation runoff into regional drainage. However, since this runoff is only a minor contributor to the high regional salt export ratio, such decreases are unlikely to result in a significantly lower salt export ratio for the region.

These findings also suggest that, in order to minimise the build-up of salt in the irrigation bay soil surface, irrigation volumes should not drop to a level where the percentage of irrigation water that becomes drainage is less than 20%. If even less water is applied, salt build-up on the soil surface is likely to occur in those parts of the bay where mobilised salt remains after irrigation. Although the total amount of salt stored within the bay soil profile is very large, the bay's heavy soils and poor, deep drainage mean that it is the mobilisation and export (flushing) of surface salt that will largely ensure crop survival.

STRATEGY 2: ON-FARM DRAINAGE WATER RE-USE

The process of re-irrigating with drainage water is known as 're-use'. Both on-farm and regional drainage water can be pumped into a farm's supply channels. In this study, we have considered only the re-use of on-farm irrigation runoff.

Re-use is considered by regional catchment and water supply authorities to be an attractive salinity control option, because salt that would otherwise add to regional salt export is recycled within the farm. From a farmer's perspective, re-use increases the amount of water available for irrigation; allows for the recycling of irrigation runoff from excessively large ('mistake') events; and allows for the harvesting of rainfall runoff for later irrigation.

A re-use system allows irrigators to return irrigation runoff to their supply channel for re-irrigation. This increases their available water and minimises the farm's contribution to regional drainage.

Further, since water is recycled, less drainage water is produced, increasing water-use efficiency.

In this study, we investigated the impact of a range of re-use levels on bay soil salinity and salt export ratio, and determined appropriate levels of re-use that avoid excessive net salt import or export.

We used the CRC 'bay-scale model' to simulate the effect of different re-use levels over an entire season. The model used information on the physical characteristics of the bay (e.g. size, soil type and salinity) and measured climate data. We then simulated an irrigation season using the model's four 'rules of irrigation':

- the average soil moisture deficit (dryness) of the bay to trigger the start of an irrigation (cm)
- the salinity of the irrigation supply water (μS cm^{-1})
- the rate of irrigation supply to the bay (L/s)
- the distance along the bay the irrigation water advances before supply is cut off (% distance)

In this study, we focused on the effect of increasing the salinity of irrigation supply (through more re-use), and on increasing irrigation event volume (increasing the distance travelled by irrigation water along the bay before cut-off).

Changes in soil salinity

In the Barr Creek area, 'fresh' irrigation supply water is typically around 100 μS cm^{-1}. We carried out a simulation that assumed a level of re-use over an irrigation season in which a consistent supply salinity of 100-400 μS cm^{-1} was maintained.

Over a single, simulated season we noted no apparent difference in soil salinity in the lower part of the bay due to the different salinity and volume options simulated (100-400 μS cm^{-1} or cut-off distance from 50 to 100%). The low soil permeability of the soil, the limited drying out of the soil profile during the irrigation season, and the large salt store in the soil profile supported this result. Over a much longer time frame (such as several decades), however, a response could occur.

Our simulation showed a slight increase in soil salinity in the upper part of the bay due to higher supply salinity (i.e. more re-use). From an initial soil salinity of 1300 μS cm^{-1} (at 60 m from the supply end, and at 10 cm depth), the soil salinity became 1700 μS cm^{-1} over an entire irrigation season without re-use. When we simulated re-use (up to a supply salinity of 400 μS cm^{-1}), however, soil salinity at this location increased to 2100 μS cm^{-1}. This increase in soil salinity over the upper part of the bay provides evidence of salt redistribution from the lower end of the bay to the upper end, although the increase in soil salinity with re-use was only marginally greater than for conventional irrigation practice.

Over a single irrigation season, the relatively small changes in soil salinity made this an unsuitable variable for assessing the impact of re-use on the irrigation bay in the short term. To investigate the impact of different amounts of re-use, we calculated the salt export ratio (SER) for the bay. The SER indicated levels of re-use that could minimise salt export without a large net salt import into the bay. (The SER, however, ignores any redistribution of salt within the bay itself, and provides a simplified view of salt transport.)

Changing the amount of re-use

We assumed that the irrigation bay operated independently, and that all of its irrigation runoff was stored for re-use (Figure 14). We kept a running total of the salt load stored in drainage over the simulated season. This accounted for the removal of salt for each event to re-use, and for the addition of new salt in irrigation runoff to the storage. We also calculated the net salt export ratio (SER) for the bay (salt remaining in storage / salt supplied with 'fresh' irrigation water) at the end of the season.

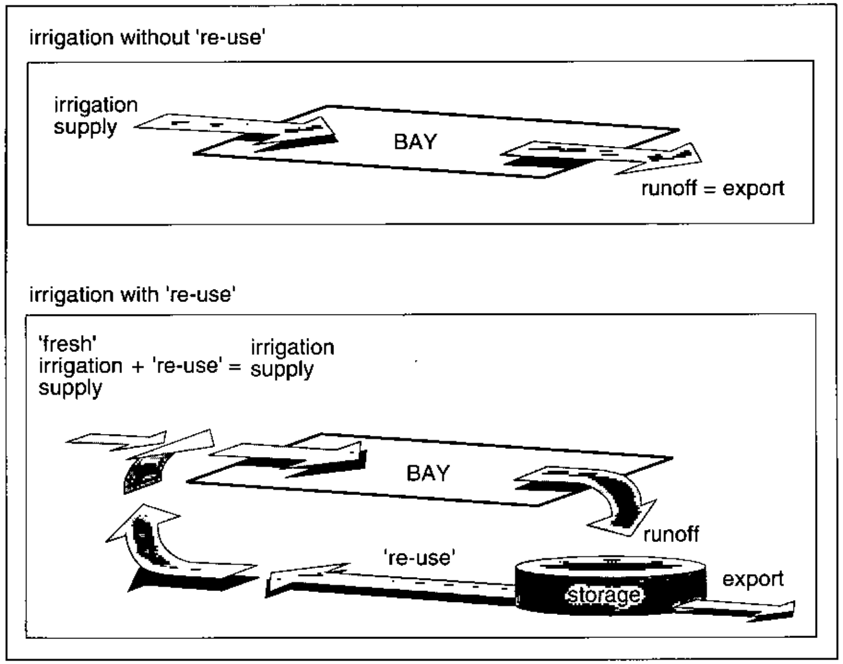


Figure 14: Effect of 're-use' on irrigation bay drainage.

The CRC's simulation confirmed that increased re-use resulted in a lower SER (Figure 15). Each line in the figure shows the change in SER for the entire season for a given irrigation cut-off distance. Interestingly, the results indicated that although an SER close to a balance (100%) was achieved with moderate levels of re-use water (200 µS cm^{-1} supply water), for higher levels of re-use there was a much lower SER (i.e. increased salt import). This implies that the amount of re-use must be monitored closely to avoid excessive salt import, while maintaining an approximate salt balance for the irrigation bay.

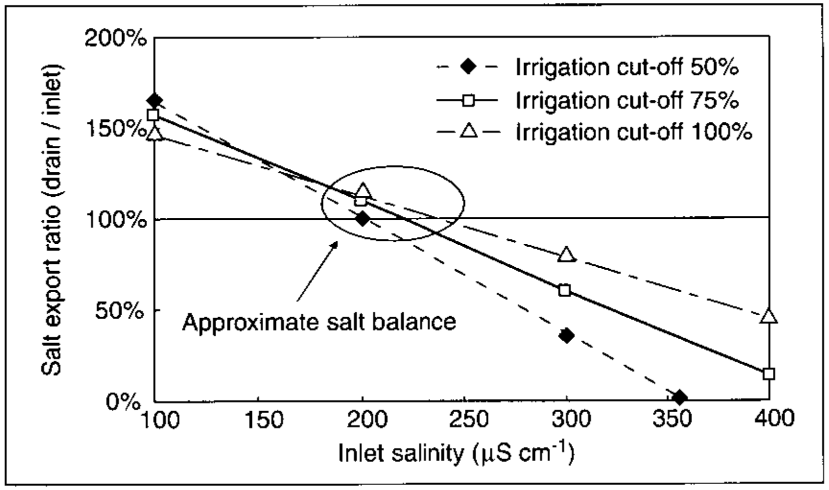


Figure 15: Simulated changes in salt export ratio (SER) for different amounts of 're-use' and increased irrigation volume over a single season.

Changing the irrigation volume

Figure 15 also shows that for a consistent level of re-use (where supply salinity was higher than 200 µS cm^{-1}), an increase in the water volume applied to the bay with each irrigation increased the SER, which resulted in a ratio closer to a balance. In other words, the higher the salinity of the supply water, the greater the volume of irrigation water required to prevent a large import of salt to the bay. The results also showed that the salt export ratio was more sensitive to changes in the amount of re-use than it was to changes in irrigation supply volume. The simulation showed that at the monitored bay, a salt balance occurred with a level of re-use that elevated the supply salinity to 200 µS cm^{-1}.

KEY RESEARCH FINDINGS

The main findings of this study were:

- The monitored irrigation bay showed a net surface salt balance, excluding rainfall runoff. In other words, the amount of salt supplied in irrigation water was almost equal to the amount of salt exported in surface drainage over a season. This has significant implications for irrigation management. If the result is assumed true for the entire Drain 14 catchment, then irrigation runoff contributes about 25% of the total regional salt export through surface drainage over the irrigation season. This finding highlights the greater significance of salt contributions from other sources - such as groundwater seepage into deep regional drains, or rainfall runoff.
- A reduction in irrigation supply volumes below the level at which drainage volume is less than 20% of the supply volume led to a build-up of salt on the soil surface, particularly in the lower part of the monitored bay. Much of the salt readily mobilised from the soil surface was only exported by large volume irrigation events. Salt mobilisation occurred during smaller events, but the salt accumulated on the soil surface, rather than being exported.
- On-farm re-use of irrigation drainage water is a suitable strategy for reducing the volume of irrigation runoff from a bay into regional drainage, and for minimising the build-up of salt at the bay's surface. By re-using drainage water, irrigators can maintain the high volumes of irrigation supply water needed to remove mobilised salt, while increasing irrigation efficiency by supplementing their 'fresh' irrigation supply. While some redistribution of salt from the lower end of the bay to the upper end may occur, this effect should be relatively insignificant in the short term.

SUGGESTIONS FOR FUTURE RESEARCH

This work was part of the CRC's Project A1, which focused on the processes of salt and water movement at an irrigation bay scale. The CRC's current Project S1 is focused on scaling this work up from a bay scale to a catchment scale using tools such as Geographical Information Systems (GIS).

The results highlight the significant influence that deep regional drains have on catchment salt export. Future research could focus on investigating the role of regional drains. This could include a study of the interaction between regional drains and shallow groundwater, and a study of the variation in salt load contributions to deep drains throughout the catchment. Further, the scope of the work presented in this report could be expanded with the measurement and modelling of irrigation bays in other areas, with different soil types.

Further information on the current work in Project S1: 'Salt export from irrigated catchments' can be obtained from the CRC for Catchment Hydrology Office, or from the project leader, Dr John Knight.

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