CRC FOR CATCHMENT HYDROLOGY
CSIRO LAND AND WATER
MURRAY-DARLING BASIN COMMISSION

ON-FARM AND COMMUNITY-SCALE SALT DISPOSAL BASINS ON THE RIVERINE PLAIN

EVALUATING BASIN LEAKAGE RATE, DISPOSAL CAPACITY AND PLUME DEVELOPMENT

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Foreword

There are pressures to minimise salt leaving irrigated catchments of the Murray-Darling Basin to limit salinity increases in the River Murray. Part of this strategy is to manage drainage disposal water in the irrigation areas, using disposal basins. Unfortunately, there are no existing guidelines for siting, design and management of such disposal basins. The CRC for Catchment Hydrology and CSIRO Land and Water, with support from the Murray-Darling Basin Commission, have embarked on a project with the overall objective of producing such guidelines for the Riverine Plain of the Murray Basin.

This report is one of several being produced in this project to support the guidelines. It provides information on two important aspects that underpin the use of disposal basins: the disposal capacity of a basin, and what happens to leakage from the basin. It concludes that on-farm and community basins in the Riverine Plain are a technically feasible method for the disposal of saline drainage, while ensuring that detrimental off-site effects are kept to a minimum. In order to maintain evaporative potential, water in the basin should not become too saline; a small amount of leakage (0.5 – 1.0 mm/d) is required for this to occur. These leakage rates are achievable for basins in the Riverine Plain.

Glen Walker
Leader, Salinity Program

Summary

Due to changes in community perception and government policies, there has been a shift towards the use of disposal basins within irrigation areas rather than the development of further disposal basins outside the region. These can be for multiple users (community basins) or individual users (on-farm basins) and each has its own advantages and disadvantages. Guidelines for the siting, design and management of such basins are currently being developed. The two biophysical questions that are essential to these guidelines are:

1. *What fraction of the drainage area needs to be devoted to disposal basins?* If the area devoted to disposal basins is too small, then they will not be able to cope with all the drainage water required to adequately provide groundwater control. On the other hand, if too much area is used, it is likely to take out potentially productive land and hence become uneconomic. Thus, a key physical factor in the design of the disposal basin is the volume of drainage water that can be pumped into an evaporation basin over a specified period of the time *(disposal capacity).*
2. *What is a desirable leakage rate for basins? Can this rate be achieved by appropriate siting, design and management? What is the fate of the leakage?* If the leakage rate is too high, it can lead to problems of salinisation in surrounding areas and migration of highly saline plumes. If the leakage rate is too small, the water within the disposal basin may become very saline, decreasing the rate of evaporation of the water in the disposal basins and hence the disposal capacity. Is there a happy medium and, if so, what can be done to basins in order to achieve it?

The aim of this report is to provide information and methodology to answer these questions. To this end, the following approach was adopted:

- Extensive field studies at Girgarre community basin (Victoria) and on-farm basins in the MIA (Leaney and Christen, 2000).
- A comprehensive literature survey of existing basins in the Riverine Plain.
- Development of a spreadsheet model to predict changes in basin salinity and to estimate disposal capacity for hypothetical basins in the Riverine Plain.
- Analysis and the interpretation of the above.

The conclusions for this work are based predominantly on the results from field studies. Laboratory experiments tend to be less appropriate because they are often conducted on an inadequately small spatial scale and over a short timeframe.

The main factors that determine disposal capacity are the climate (i.e. rainfall and evaporation), basin area and leakage. Across the Riverine Plain, there is a net reduction in net evaporation (evaporation – rainfall) of approximately 500 mm/yr (~30%). Evaporation will also decline considerably with basin area (the oasis or clothesline effect). This results in reduction in evaporation of about 15% for basins of 100 ha compared to a 1 ha basin.

Leakage from basins has the potential to cause detrimental environmental effects around the basin. Thus, it is usual to try to intercept and recycle back to the basin as much of the leakage as possible. This leads to two separate definitions of disposal capacity. We have defined the term *"potential disposal capacity"* to refer to the amount of water that could be placed in a basin, if leakage is considered to move away from the basin and is not recaptured and *"design disposal capacity"* if the water is recycled. Thus *design disposal capacity* is effectively the amount of water that can be evaporated over any period less that received from rainfall. The use of interception drains is the most efficient method of recycling leakage back to the basin. Up to 80% of leakage for smaller basins could be recycled via interception drains.

Leakage also affects the salinity of water remaining in the basin. As basins evaporate water, the salt is left behind a process known as, *'evapo-concentration'*. The rate of evapo-concentration is moderated by leakage from the basin, which results in removal of salt from the basin. Leakage rate therefore affects the design disposal capacity, albeit to a lesser extent than it does the potential disposal capacity. From disposal capacity calculations, we found that the evaporation rate for basins with leakage rates less than 0.5 – 1 mm/d was significantly reduced. If basins are sealed, the loss in evaporative potential is extreme. Hence, unless the aim is to produce salt, basins should not be sealed and ***leakage of 0.5 – 1 mm/d is considered acceptable and desirable*** for basins in the Riverine Plain.

For most basins on the Riverine Plain, the main factor controlling leakage rate is the ability for the groundwater mound under the basin to expand outwards. These basins we have termed as *"expansion limited"*. This explains why the leakage rate per unit area reduces as the basins become larger. Only one basin studied, Girgarre, had unsaturated soil beneath the basin. This, and any other similar basins, we have termed *"infiltration limited"*, because leakage is determined by the soil hydraulic conductivity at the base of the basin.

The main factors identified as likely to significantly reduce infiltration through the base of infiltration limited basins were soil compaction and the build-up of polysaccharide as a result of algal activity in the basin soil. Compaction appears to be the most successful method for reducing infiltration through the floor of the basin to desirable levels of less than 1 mm/d. In order to achieve leakage levels less than 1 mm/d, we suggest that ***the base and sides of all basins less than ~50 ha will need to be compacted.*** It is also important that basins should not be allowed to dry out in order to preserve the polysaccharide clogging and minimise leakage via preferential flow from cracks in the soil.

To assist with the design of basins in the Riverine Plain, we have tabulated the expected potential and design disposal capacity for 1-1000 ha basins at three sites in the Riverine Plain. These are assumed to have leakage rates close to the acceptable values (0.5 to 2.0 mm/d). Input salinity values cover the range expected in the Riverine Plain. When all factors are considered, there is a three-fold (from 7.7 to 22.2 ML/ha/yr) in potential disposal capacity and a two-fold range (from 7.3 to 14.9 ML/ha/yr) in design disposal capacity for 1-1000 ha basins.

As a result of these investigations into the operation of disposal basins in the Riverine Plain, we suggest that it is technically feasible to use on-farm and community basins for the disposal of saline drainage while also ensuring that detrimental off-site effects are kept to a minimum. There will always be a balance between maximising disposal capacity while minimising detrimental off-site effects due to leakage in the design of basins. We suggest that leakage rates of 0.5-1.0 mm/d are desirable and achievable for this balance.

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1. Introduction and Background

1.1 Objectives and Report Structure

CSIRO Land and Water and the CRC for Catchment Hydrology, with support from the Murray-Darling Basin Commission (Strategic Investigation and Education Program, Project I7034 *Managing Disposal Basins for Salt Storage Within Irrigation Areas*) and other agencies, have been investigating the siting, design and management conditions under which constructed, small-scale basins can be successfully used by individuals or groups of landowners.

On the surface, the principle behind the use of constructed disposal basins is simple. An area of land is sacrificed for the construction of a basin. Saline drainage water is pumped into the basin from nearby irrigated areas to allow watertables to be maintained at a level that does not impact on plant health and restrict the economic return from the irrigated area.

In practice, the issues are not as clear cut. The area of land sacrificed for the basin must be large enough to cope with the quantity of drainage from the irrigation area. However, because there is usually no economic return from the basin, there is an incentive to minimise construction costs and the cost of lost productivity associated with the basin. In addition, there should not be any detrimental effects associated with the basin that may impact on neighbouring farmers or the environment. The four major factors that determine the area required for a basin are:

1. The drainage requirement for the irrigated area.
2. The disposal capacity.
3. The degree of environmental safety or acceptable risk factor.
4. The area required for buffer zones and interception drain/channel.

Tools for estimating the drainage requirement have been presented in a companion report (Wu *et al.*, 1999) and acceptable risk has been discussed in the development of principles for disposal basins (Christen *et al.*, 1999a).

In this report, we only discuss factors that determine the disposal capacity of a basin. The disposal capacity of a basin is the amount of water that can be placed into a basin per unit of time. Disposal capacity may or may not include the interception of leakage from a basin. We use the term *"potential disposal capacity"* for the amount of water that can be placed into a basin if leakage interception (and recycling) is not included and *"design disposal capacity"* if leakage is recycled into the basin (see Chapter 1.5 for more detail).

The main aim of this report is to provide information and methodology that will allow determination of the likely Potential and Design Disposal Capacity for basins across the Riverine Plain.

For any given drainage requirement, the use of potential disposal capacity will allow an estimate to be made for the area required for a basin given the most relaxed environmental constraints. Alternatively, the use of design disposal capacity allows estimation of area assuming a more cautious approach. These terms are more fully defined in Section 1.5.

Given the potential problems with scale and spatial variation when using laboratory measurements, our methodology has been primarily to use the results from studies on disposal basins in the Riverine Plain. Included in these studies are the results from field investigations conducted over the last two years for an existing community basin in the Shepparton Irrigation Area and a recently constructed on-farm basin in the Murrumbidgee Irrigation Area (Leaney and Christen, 2000). Rather than reporting this information on a case by case basis, we have attempted to present "common hypotheses" concerning leakage from disposal basins and provide field based data to support or refute these hypotheses. As such, our findings have the strength of being field based on the appropriate scale for implementation of results. However, unlike laboratory or small scale experiments, it is not always possible to isolate one factor from several other factors giving a similar outcome.

The layout for the report is as follows:

Chapter 2 Leakage Rate and Basin Processes

In Chapter 2, we:

- ***provide suggested and realistically achievable LEAKAGE RATES for basins in the Riverine Plain.***

  We summarise the results of previous studies on disposal basins in the Riverine Plain and suggest that the over-riding factor that determines the rate of leakage (mm/d) is the area of the basin. Leakage from existing basins in many cases exceeds the net evaporative capacity (R-E) for basins in the Riverine Plain.

- ***suggest and evaluate two mechanisms for leakage to move from a basin (INFILTRATION and EXPANSION LIMITED). Most existing basins in the Riverine Plain are expansion limited.***

  Infiltration limited basins are throttled by a reduction in hydraulic conductivity at the base of the basin. Expansion limited basins are throttled by the rate at which leakage can move away from the basin via saturated and unsaturated flow.

Chapter 3 Disposal Capacity

In Chapter 3, we:

- ***present ranges for RAINFALL and EVAPORATION and their effect on disposal capacity for the Riverine Plain.***

  These climatic factors provide a primary estimate for disposal capacity for basins in the Riverine Plain.

- ***discuss the inter-relationship between evaporation rate, leakage rate, salinity and the size of the basin and their effect in determining the disposal capacity of a basin.***

  The effect of increasing salinity in water in the basin may considerable reduce evaporation. Low rates of leakage may result in higher salinities in the basin water and a considerable decrease in disposal capacity of basins. Evaporation is also reduced for larger basins as a result of the "oasis" effect.

Chapter 4 Factors Affecting Infiltration

In Chapter 4, we:

- ***evaluate what can be done to reduce leakage from basins (changing basins from expansion to infiltration limited).***

  There are potentially high costs (interception/pumping and environmental) associated with "mopping up" leakage from basins. What are the conditions that impact on the hydraulic conductivity at the base of basins?

Chapter 5 The Leakage Plume

In Chapter 5, we:

- ***evaluate the movement of leakage from disposal basins in the Riverine Plain (the LEAKAGE PLUME).***

  Given the potentially detrimental effects of leakage, any knowledge on the likely movement of leakage from disposal basins will help minimise detrimental off-site effects and help determine the risk associated with leakage.

1.2

History of Irrigation in the Riverine Plain

The Murray-Darling Basin is one of Australia's most important water and land resources. Approximately 73% of all water used in Australia is harvested from the Basin (Fleming, 1982) and approximately 80% of land irrigated in Australia (1.8 million hectares) is located within its' boundaries. Approximately 90% of cereal, 80% of pasture, 65% of fruit and 25% of vegetable production in Australia is derived from irrigated agriculture within the Basin (Murray-Darling Basin Ministerial Council, 1987). Meyer (1992) estimated that the annual value of irrigated agriculture in Australia exceeded \$4.6 billion (including more than \$2.7 billion in export income), the majority of which is from the Murray-Darling Basin. The majority of irrigation occurs in the south-central part of the Basin known widely as the Riverine Plain (Figure 1).

The Basin, in its pre-European state, contained vast amounts of salt which were stored in the soils and groundwater. The use of irrigation, the leakage of water from the associated network of water distribution and drainage channels, and the clearance of deep-rooted perennial plants and their replacement with shallow-rooted annual crops has altered the water balance causing watertables to rise throughout the Basin. This has resulted in mobilisation of the stored salt and, when the watertable comes close to the soil surface, soil salinisation and waterlogging result, with detrimental effects on agricultural production. In addition, raised watertable levels can increase hydraulic gradients between the groundwater and surface water resources, leading to increased movement of salt to drains, streams and rivers.

To maintain productivity in irrigation areas with shallow groundwater, watertable reduction and control is carried out using measures such as horizontal pipe drains, deep open drains, and groundwater pumping from bores and spearpoints. This, however, creates the problem of disposing of large volumes of saline drainage water. One option in common use are disposal basins. Disposal basins function by allowing evaporation from the open water surface in the basin. As this occurs the remaining water in the basin becomes more saline. The remaining water either remains in the basin or "leaks" into the area below and around the basin.

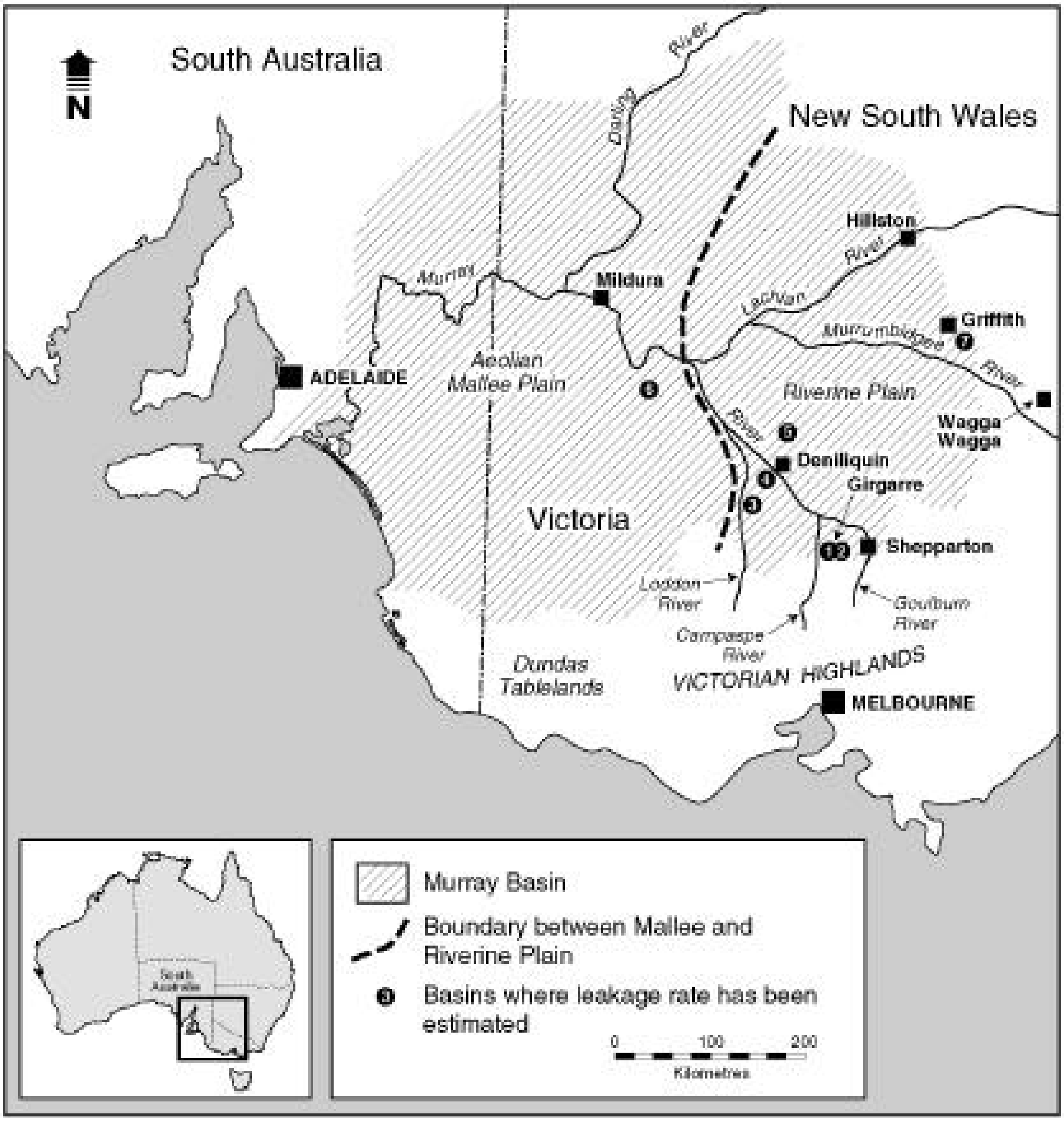


Figure 1. The Murray Basin showing the location of the Riverine Plain and existing basins used in this study.

Basin names and description are given in Table 1 and Appendix 1. Two reports are available for the Girgarre Basin (1,2).

In the past, use of large regional scale (>100 ha) basins has been the most common approach. These generally accept drainage water from multiple farms and irrigation districts which in some cases may be located many kilometres away (hence salt is exported from the area in which it is produced). These basins most commonly use natural depressions in the landscape (e.g. Lake Tutchewop near Swan Hill), however they can be engineered storages (e.g. Wakool Basin near Deniliquin). Many have occurred by default or have been developed on an ad-hoc basis.

Regional basins were generally developed on the most convenient sites from an engineering standpoint, and often ignored environmental, socioeconomic, aesthetic impacts and any other community concerns. In addition, various unforeseen side-effects (leakage to adjacent farmland, insect and bird problems, odour) experienced by a number of regional scale basins has led in many cases to poor community perception of disposal basins.

Under the Murray Darling Basin Salinity and Drainage Strategy (Murray-Darling Basin Ministerial Council, 1988) severe constraints have been imposed on salt export from a given area. This policy was designed to ensure that the beneficiaries of irrigation are responsible for their own drainage management on the assumption that this would help minimise other environmental effects. While disposal to regional basins will continue in the future, there is a view in environmental protection and other resource agencies that there is a need to depart from the existing "export the problem" mentality. It is becoming mandatory that the option to manage drainage effluent at the source be closely examined before resorting to export.

The above concerns have led to the use of much smaller scale (<100 ha) basins. These can take the form of on-farm basins, which occupy individual properties (such as those being used for new horticultural developments in the Murrumbidgee Irrigation Area) or community basins, which are shared by a small group of properties (such as the Girgarre Basin near Shepparton). The design and management of both types of basin varies widely and currently there are no set guidelines for their use.

1.3
Hydrogeology of the Riverine Plain

The Murray Basin covers 300,000 km^2 of south-eastern Australia. The Murray Basin is a saucer shaped depression underlain by bedrock which resulted from the tectonic uplift associated with the formation of the eastern highlands. A sequence of sedimentation began in the Eocene period, and the basin gradually filled with fluvial and marine sediments.

The Murray Basin can be divided into two distinct regions. The Western part of the Basin is known as the Mallee Region and is the result of past marine inundation. The Eastern part is known as the Riverine Plain and is the result of past river systems associated with various climatic periods (Figure 1).

In the Riverine Plain, the sediments accumulated over time can be divided into three distinct layers. The oldest is the Renmark Group (or Olney Formation), followed by the Calivil formation and finally the Shepparton formation. A summary of the hydrogeology of the Riverine Plain is available from Evans and Kellet (1989). Leakage from disposal basins is likely to impact primarily on the Shepparton Formation which has a thickness in the order of 20-50 m with the groundwatertable located in this formation for all of the irrigation areas.

Because the soils have resulted from deposition of fluvial sediment, they consist predominantly of loams and clays with areas of remnant stream channels commonly called shoestring sand aquifers. As such, the shoestring sand aquifers are not always continuous and vary considerably in size and location. Historically, the shoestring sand aquifers of the Shepparton Formation were recharged from the basin margins and tended to flow in the westerly direction. However, following the introduction of irrigation, watertables have risen to close to the surface in irrigation areas to the extent that the system is now considered to be close to full.

1.4
Existing Basins in the Riverine Plain

As discussed above, until recently, most of the disposal basins in the Riverine Plain have been opportunistically located larger basins. These are commonly called regional basins. A summary of the operation of these basins is given in Hostetler and Radke (1995). Regional basins have had, and will continue to have, an important role in the disposal of saline water originating from irrigation areas. However, the use of constructed basins, both local scale community and on-farm basins is increasing.

On-farm basins are disposal basins that receive saline disposal water from a single farm-holder. Currently, they exist exclusively on the property of the farm-holder and are from 1 to 14 ha although, it is possible to predict circumstances where this type of basin could be larger and may be located outside the farm . There are currently ~20 on-farm disposal basins in the Riverine Plain with the greatest concentration in the Murrumbidgee Irrigation Area (MIA). These on-farm basins are currently increasing at the rate of a few per year.

It is likely that community basins and larger on-farm basins will have multiple bays to allow better management of the basin and control of the salinity of the basin water. This is less likely to be the case with regional basins although the Wakool basin (2,100ha) has many bays.

1.5
How a Disposal Basin Functions

The disposal basins discussed in this report are engineered structures used to evaporate sub-surface drainage water and store the remaining concentrated salt. The salt should be stored within the basin, or in the soils and groundwater in a defined location beneath and around the basin. The key factors that govern the operation of a disposal basin are water loss through evaporation, E, and by leakage, L, beneath the basin and water gain from rainfall, R, and pumping from drainage, P (Figure 2).

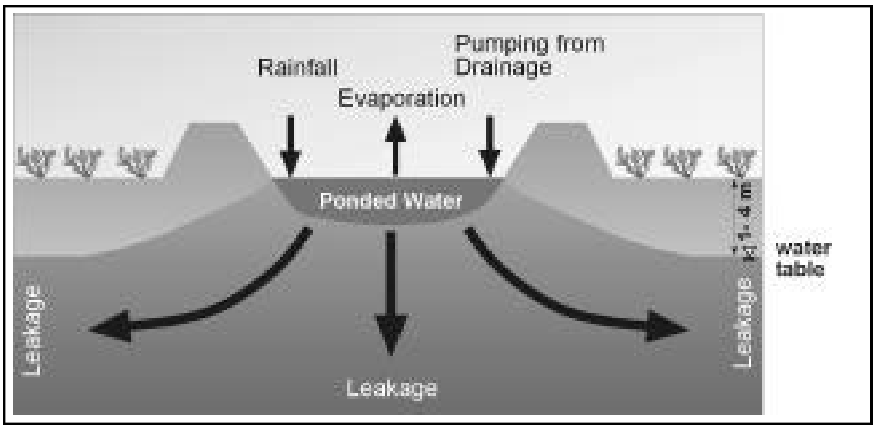


Figure 2. Conceptualisation of a disposal basin water balance.

The disposal capacity of a basin refers to the amount of drainage water that can be pumped into a basin per unit of time (ML/yr). This can be normalised to a rate per unit area (ML/ha/yr) in order to compare the disposal capacity per unit area for different basin sizes. If the system is as described in Figure 2 (i.e. no interception of leakage), then the disposal capacity is termed Potential Disposal Capacity, PDC (ML/ha/yr) and is defined as:

$$PDC = L + E - R \qquad [1]$$

The above description of the operation of disposal basins is considerably simplified. If none of the leakage is intercepted and recirculated into the basin, there is a greater potential for detrimental off-site effects as a result of migration of saline leakage from the basin. For this reason, it is advisable to intercept leakage from the basins and reduce the migration of the saline leakage plume. The primary method of containing the saline leakage is by interception drains around the perimeter of the basin. Because of their close proximity to the basin, they are designed primarily for intercepting and recirculating the shallow lateral leakage close to the basin and minimising salinity and waterlogging problems adjacent to the basin. A secondary form of interception is in the form of the overall subsurface drainage system within which the basin is sited.

Disposal basins are used to dispose of water from a surrounding sub-surface drainage system. As the primary purpose of a basin is to dispose of this drainage, it makes sense to consider the basin and the associated drainage system as an integrated system, rather than as separate entities. The practical purpose for doing this is to use the drainage system to assist in controlling the spread of leakage and enable its recycling back into the basin, (see Chapter 13, Jolly *et al.*, 2000). It also encourages landholders to ensure that their irrigation management minimises the volume of drainage for disposal. While this is the preferred option, it should be noted that there may be cases where the basin needs to be located outside the drainage system in order to find a suitable site.

The aim of a drainage system is to manage watertables, thereby controlling waterlogging and reducing the build up of salt in the plant root zone. Control of shallow watertables can be by horizontal pipe drains (also referred to as tile drains), horizontal open drains, and groundwater pumping from bores (also called tubewells, spearpoints or wells). These drainage techniques remove sub-surface water (generally saline) which is then pumped into a basin (Figure 3).

In the short term (soon after the basin is commissioned), the component of leakage intercepted by the basin is small. However, depending on the orientation and shape of the leakage plume, the drainage system may intercept increasingly larger leakage components as the plume spreads.

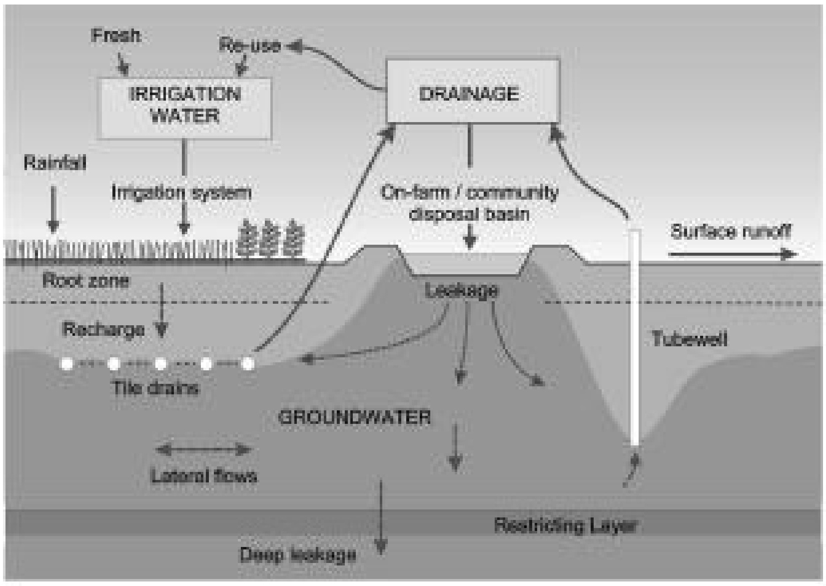


Figure 3. Conceptualisation of the main water movement processes associated with a disposal basin – drainage system.

Hence, by using interception drains and siting the basin within the overall subsurface drainage system, the amount of leakage that is likely to reach the boundaries of the drained area is considerably reduced and the lag time for this to occur, considerably increased. This is particularly the case if basins are placed close to the centre of the irrigation area. The amount of water that can then be disposed of into the basin, D (ML/ha/yr) is given by the following equation where I is the amount of water intercepted and recycled and R is the amount of rainfall entering the basin:

$$D = L + E - R - I \qquad [2]$$

The amount of water intercepted can range from almost nothing to an amount equivalent to that leaving from the basin or, in fact, may even exceed that value. The latter case ($I > L$) would be used, for example, when it is deemed necessary to lower watertables rather than maintain levels at a set depth (as was the case in the first few years at the Girgarre Basin). If the amount of water intercepted is equivalent to that leaked from the basin, we suggest the term ***Design Disposal Capacity, DDC (ML/ha/yr).***

$$DDC = E - R \qquad [3]$$

2. Leakage Rates and Basin Processes

2.1 Estimating Leakage from Disposal Basins

A major reason for estimating leakage from a basin is to adequately predict the disposal capacity of a basin and hence determine the basin size required for a farm or group of farms. Measuring leakage rates for disposal basins is not trivial and the errors associated with the measurement can quite often be considerable.

The following methods were used to estimate leakage for disposal basins in the Riverine Plain.

1. Water Balance Method (whole of basin method, commonly used in studies in the Riverine Plain).
2. Using natural abundance level tracers (point estimates, used at the Girgarre and Wakool basins)
3. Seepage meters (point estimates, used at the Wakool, Girgarre and Nehme's basins).
4. Chloride or salt mass balance (whole of basin or individual bay method, used in conjunction with water balance to improve confidence in leakage estimates).
5. Concentration factor method. This method is a simpler version of the chloride mass balance where the mean concentration of the basin water is compared to the mean concentration of the input water. High concentration factors are indicative of low rates of leakage and vice-versa.

A summary of the leakage estimates for basins in the Riverine Plain is given in Table 1, with a brief description of the methodology and individual studies given in Appendix 1. In this report we make frequent reference to the Girgarre basin near Shepparton, Victoria and the Nehme basin, near Yenda in the Murrumbidgee Irrigation Area (MIA). The Girgarre basin is a 30 ha basin receiving water from groundwater pumps that protect about 600 ha of pasture across several farms. It has been operational since 1985. The Nehme basin is a 2 ha basin receiving drainage water from a horizontal pipe drainage system in a 50 ha vineyard. This basin was newly constructed in 1996 and was monitored from before filling for two years. More information on these and other basins is in Appendix 1. Detailed descriptions of these basins and the studies conducted on them can be found in Leaney and Christen (2000).

Table 1. Summary of leakage estimates

Basin	#*	Area	Leakage (mm/d)	Method(s)	Comments
MIA E	7	0.62	5.4	1 and 5	< 2 years of data
MIA C	7	1.5	4.8	1 and 5	< 2 years of data
MIA D	7	1.9	3.0	1,2,3 and 5	2 years of data
MIA B	7	2.15	4.4	1 and 5	< 2 years of data
MIA A	7	2.33	3.5	1 and 5	< 2 years of data
Cohuna	4	3.3	3.3	1	< 3 years of data
Pyramid Hill	3	3.3	4.3	1	1 year of data
Ranfurly	6	10	1.2	4	limited data available
Girgarre	1,2	30	1.3	1,2,3,4	Groundwater pumping, Unsaturated zone present beneath basin, 9 yrs data
Wakool	5	2100	0.2	1 and 3	Largest of all constructed basins. Becoming hyper-saline in several bays due to low rates of leakage

**Basin location is given in Figure 1. A summary of basin reports is given in Appendix 1. Girgarre has two reports that discuss factors affecting disposal capacity and leakage rate for the basin.*

2.2 Leakage; Infiltration or Expansion Limited?

A wide spectrum of factors are likely to affect the rate at which disposal basins leak. Leakage may be controlled by factors that impact at the base or sides of the basin and throttle flow from the basin to the underlying unsaturated zone. We suggest that this type of leakage be termed *infiltration limited* because the rate of leakage is dependent on hydraulic conductivity near the base of the basin.

Alternatively, leakage from the basin may move relatively unimpeded to the groundwater and then start to form a groundwater mound under the basin until the watertable rises to the bottom of the basin. For this scenario, the rate of leakage is determined by the rate at which the groundwater mound under a disposal basin is able to dissipate. We suggest that this type of basin be termed *expansion limited.* It is likely that, for any basin, different factors may control leakage at different stages of the basin life.

For most of the basins in the Riverine Plain, the groundwater mound beneath the basin had risen to close to or equal to the basin water height at the time they were studied. Hence, it is probable that they are expansion limited. Further evidence for this is presented in the section on the relationship between leakage rate and basin area. The exception to the general rule is the Girgarre Basin, where there is a permanent watertable that rises and falls at a rate similar to the general watertable in the area. It is not clear why the mechanism for leakage at the Girgarre Basin is different from the other basins, although it may be related to the method of water control (nearby groundwater pumping) or compaction of the basin floor.

Results from field studies suggest that the generic mechanism for leakage for expansion limited basins in the Riverine Plain is as shown in Figure 4. The flow of leakage water from the basin is predominantly vertical if the soil beneath the basin is unsaturated. For basins in irrigated areas in the Riverine Plain, watertables are usually within a few metres of the land surface.

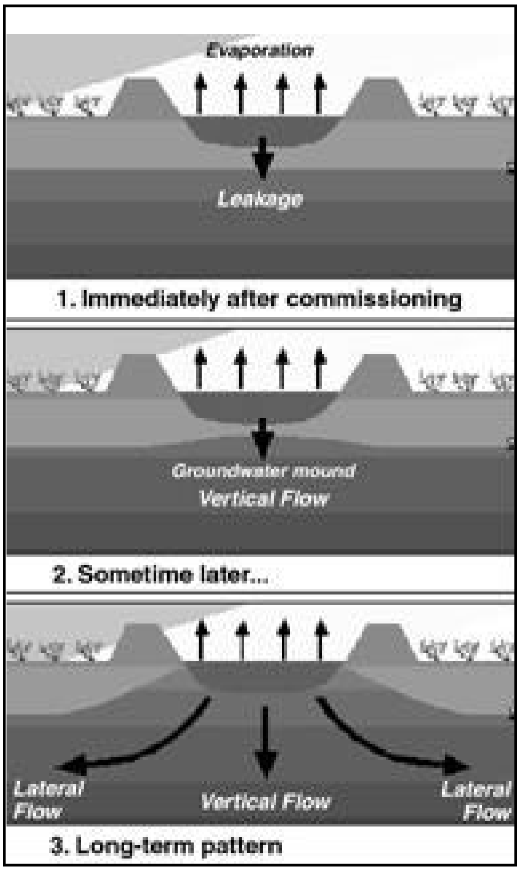


Figure 4. Generalised groundwater flow pattern under an "expansion limited" disposal basin for three time steps.

After initially high vertical flow, during which soil beneath the basin becomes saturated, the vertical flow rate reduces, and lateral flow away from the basin becomes a larger component of the overall flow. The time frame for this is usually within months after the basin starts to fill. At the Nehme Basin, initially watertables were >6 m below the ground surface. However, the watertables had reached the water level of the basin within 5 months after the basin was filled. Lateral flow is considered to be a shallow, 4-5 m thick radial component of flow beneath the basin.

2.3

Leakage Rate and Basin Area

There are numerous factors that may determine the rate of leakage from disposal basins. Many of these are discussed in Chapter 4. However, as a result of this study, we discovered that:

The over-riding factor that determines leakage rate (per unit area) for disposal basins in the Riverine Plain is the size of the basin.

In this section, we present evidence leading to this conclusion. Using the results of estimated leakage rate for existing basins in the Riverine Plain, we observe a clear relationship if leakage estimates are plotted as a function of basin area (Figure 5).

In the above graph of leakage (rate per unit area) versus area, we can see that there is power function decline in leakage, L (mm/d) with increasing area, A (ha). The equation for leakage as a function of area is given by:

$$L \quad 5.36 \text{ x } A^{-0.51} \qquad [4]$$

The exponent for this power function is –0.51. This is very similar to the –0.5 exponent found for the decline in perimeter: area ratio with increasing

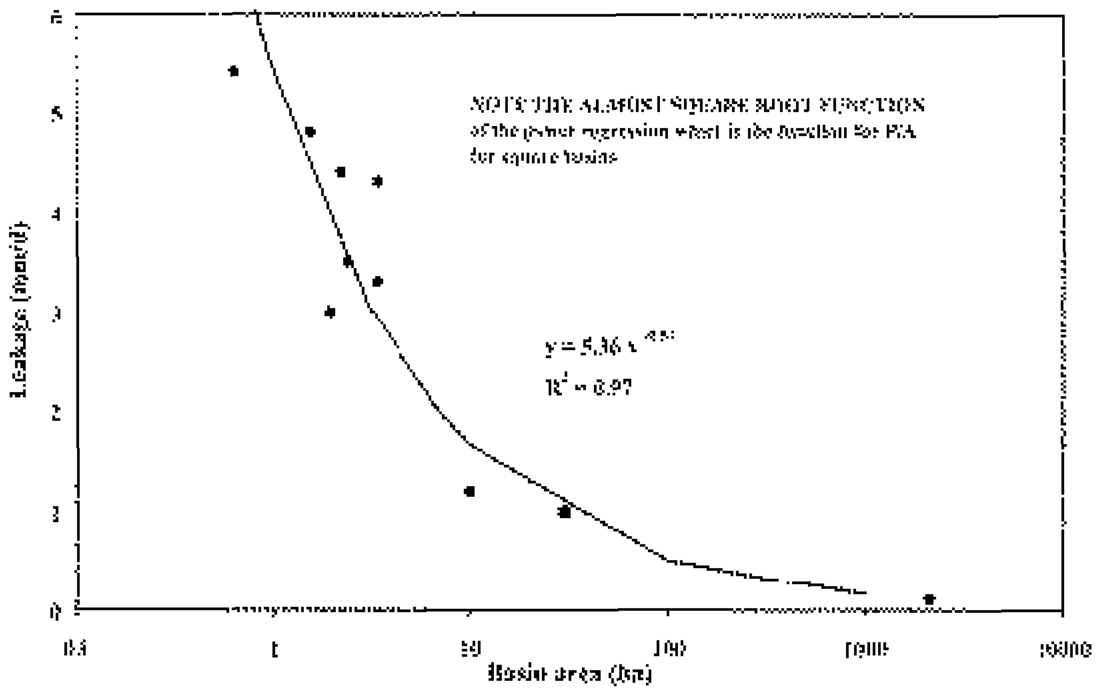


Figure 5. Leakage from basins in the Riverine Plain as a function of basin area

The relationship between leakage rate and area is approximately of the form, $y = k\,x^{-0.5}$*, the same as that expected for perimeter to area ratio as a function of area. Note that the Girgarre basin, shown as a square, is infiltration limited and is not included in regression.*

area. (Per/Area = k $A^{-0.5}$). For example, for square basins, the area of a basin is equal to the square of the side length, L (i.e. Area = L^2) and the perimeter is four times the side length (Per = 4L). Rearranging these equations results in Per/Area = 4 $A^{-0.5}$. For circular basins, similar calculations result in the relationship Per/Area = 3.5 $A^{-0.5}$. For rectangular basins, with one of the sides double that of the other, the relationship is Per/A = 4.2 $\text{Area}^{-0.5}$ and if one of the basin sides is 4 times that of the other, the relationship is Per/A = 5 $\text{Area}^{-0.5}$. In other words, the more irregular the shape, the greater the constant, k, but the relationship remains of the form Per/Area = k $\text{Area}^{-0.5}$ if similar shaped basins are considered.

Thus, we would expect, and find, a linear relationship if leakage rate per unit area is plotted against the perimeter:area ratio (Figure 6, Table 2). The correlation observed is reasonable given the variety of different shapes of basins studied in the Riverine Plain. This correlation suggests that the perimeter to area ratio is a major factor in determining leakage from a basin. Understanding why this is so should give us further insight into the mechanism for leakage from basins in the Riverine Plain.

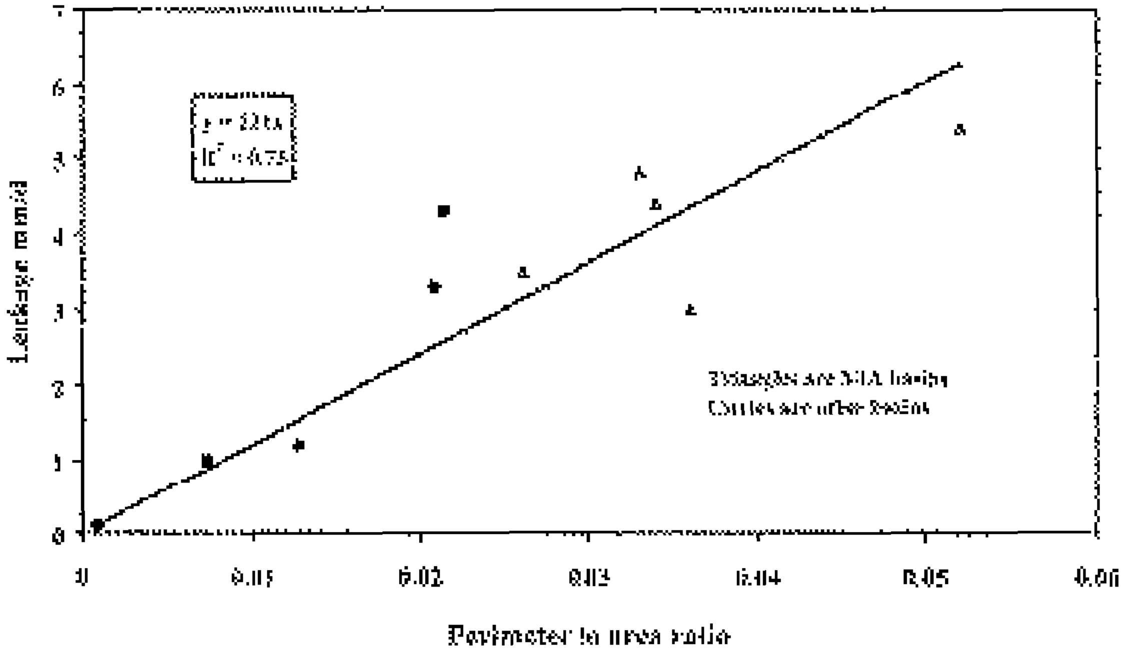


Figure 6. Leakage from basins in the Riverine Plain as a function of perimeter to area ratio

The leakage rate per unit area for basins in the Riverine Plain increases as the perimeter to area ratio increases. Such a relationship is likely for basins that are "expansion limited". Note that the Girgarre basin, shown as a square, is "infiltration limited" and is not included in regression (despite it, fortuitously, fitting the relationship).

Table 2. Leakage and basin geometry factors

Basin	*Area (ha)	*Perimeter (m)	P/A ratio (m^{-1})	Leakage (mm/d)	Leakage (as $m^3/d/m$ of perimeter)
MIA E	0.62	330	0.052	5.4	0.1
MIA C	1.5	480	0.033	4.8	0.15
MIA D***	1.9	680	0.036	3.0	0.08
MIA B	2.15	730	0.034	4.4	0.13
MIA A	2.33	780	0.026	3.5	0.11
Cohuna	3.3	690	0.022	3.3	0.15
P.Hill	3.3	700	0.022	4.3	0.19
Ranfurly	10	1300	0.013	1.2	0.09
Girgarre	30	2190	0.007	1.0	0.14
Wakool	2100	18330	0.001	**0.1	0.13

**All areas and perimeters measured except for Ranfurly and Wakool (estimated from map by Dyer, 1991).*
***Actual leakage estimated to be <0.2 mm/day.*
****MIA D is also known as Nehme basin.*

To further examine the strength of this relationship between leakage and perimeter length we can express the total leakage from the basins in Table 2 as a volume passing through the total perimeter i.e. m^3 of leakage per day per metre of perimeter (Figure 7).

The data in Figure 7 shows that the perimeter flow rates fall in a relatively narrow band between 0.08 and 0.19 m^3/d/m of perimeter and appear independent of basin area. This indicates that the total leakage rates are closely linked with the available perimeter. Field measurements of flows in interceptor drains around basins in the MIA (basins <10ha) were in the range of 0.03- 0.11 m^3/d/m, (Leaney and Christen, 2000), thus the leakage expression as flow through perimeter appears feasible. Assuming the maximum feasible lateral flow could be 0.1m^3/d/m for the soil types encountered, then we find that the leakage rates measured in the field can be substantiated for all sizes of basin (Figure 8).

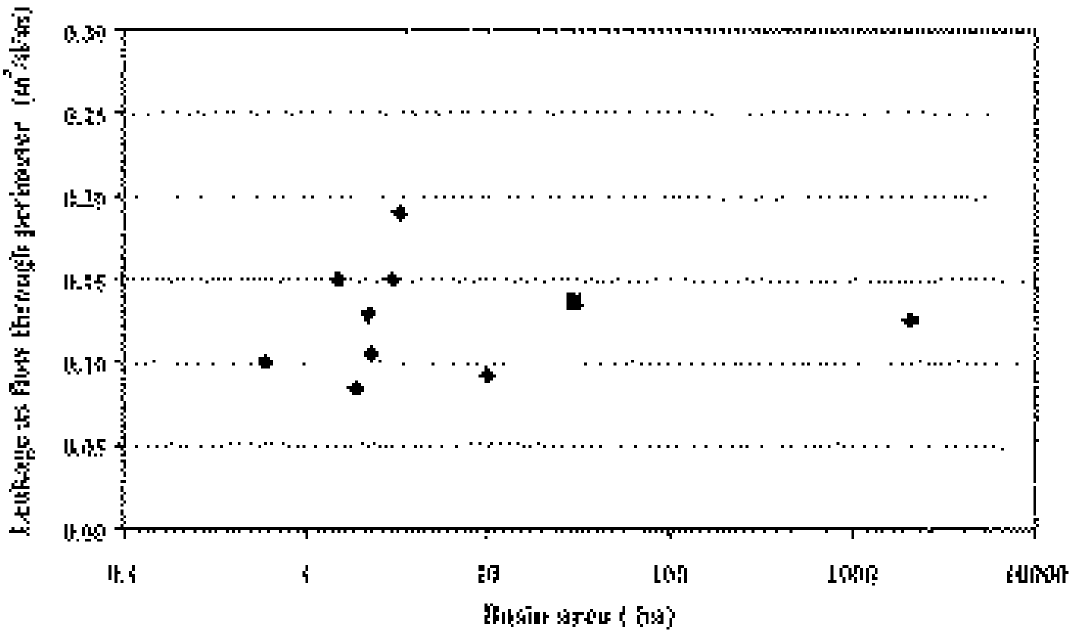


Figure 7. Leakage per unit perimeter for basins in the Riverine Plain

All basins have leakage rates of 0.15 ± 0.05 m^3/d/m flow the through perimeter of the basin. (Note Girgarre basin is shown as a square as it is infiltration limited).

Using analytical solutions for flow from a body of water to an interceptor pipe, it is possible to have flow of up to 0.15m^3/d/m on these soils and basin configurations. For basins without interceptor drains, relying on dissipation of the groundwater mound, it would appear that rates of 0.05m^3/d/m are easily achievable considering the usual conditions of the Riverine Plain of heavy soils and shallow watertables.

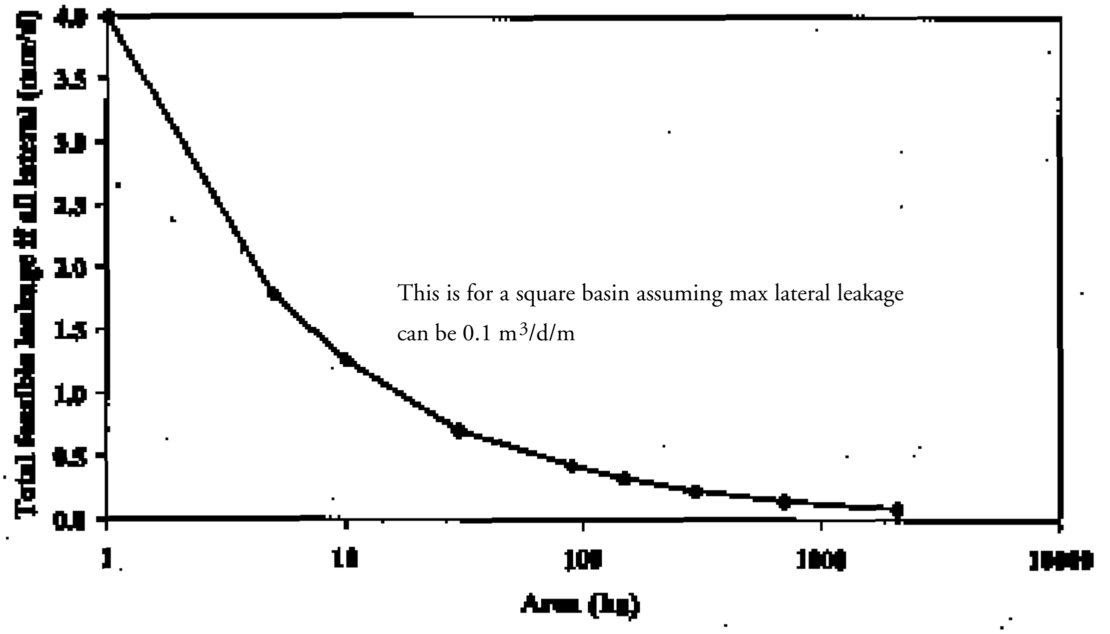
The main question that must be asked is that:

"Given the many possible factors that may control leakage from a disposal basin, why is the area vs leakage relationship so dominant"?

The answer, as suggested above, is clearly that, for the basins studied, leakage from the basins is predominantly expansion limited and that the major factors that determine leakage in expansion limited basins are similar for most of the basins studied. We suggest that the major factors are:

- similar soil types beneath the basin (similar hydraulic conductivity)
- similar hydraulic heads for leakage (the sum of water depth and the depth of the unsaturated zone).

Surface soils on the Riverine Plain are predominantly clay or heavy loam with occasional sandier areas of "shoestring sand" aquifers. The sandier soils formed as a result of stream deposition over many thousands of years and are present at varying depths in the Shepparton Formation depending on how long ago the soil was deposited. The most recent areas of sandier soil are



This is for a square basin assuming max lateral leakage can be 0.1 m^3/d/m

Figure 8. Possible basin leakage on the basis of 0.1m^3/d/m lateral leakage

The range of leakage rates observed for on-farm and community basins in the Riverine Plain may be substantiated by lateral leakage using lateral flow estimates that are feasible for the soil types commonly encountered.

usually located at the soil surfaces but at slightly higher elevations than the predominant areas of clay.

To date, sites for disposal basins in the Riverine Plain have favoured areas with clay surface soils in order to minimise leakage from the basin. In the case of smaller, designed basins, areas with surface shoestring sands were usually able to be avoided when siting disposal basins. Larger regional basins that were, in the main, opportunistically placed were sited in depressions. These areas were often naturally occurring basins or lakes in which fine clay had been deposited over many thousands of years. Hence, as a result of either opportunistic or planned siting, disposal basins have been sited predominantly on areas with at least several metres of clay beneath the basin.

Another commonality for existing disposal basins in the Riverine Plain is that the basins have been placed in irrigation areas as a method of lowering watertables. All of the basins studied are sited in areas with watertables within a few metres of the surface and have been designed to have a mean depth of water between 0.2 and 1.0 m. Hence, the hydraulic head for leakage is 2 ± 1 m for existing basins in the Riverine Plain.

If this is the case, however, why does the Girgarre Basin, a basin clearly infiltration limited (Leaney and Christen, 2000), not have a leakage rate considerably lower than that given in Equation 4? The most likely reason is that groundwater control at the Girgarre Basin is by groundwater pumping and that the basin, itself, is sited within the zone of depression of three large groundwater pumps. Hence, there is a mechanism for removing water from immediately beneath the basin, in so creating an unsaturated zone beneath what would otherwise be an expansion limited basin.

The leakage, L (mm/d) vs Per/Area (m^{-1}) data for disposal basins in the Riverine Plain suggests that large regional basins have small perimeter to area ratios and low leakage rates while small on-farm basins have large perimeter to area ratios and higher leakage rates. The line of best fit for this data is approximately

$$\text{Leakage rate} \quad 121 * \text{Per/Area} \qquad [5]$$

This relationship provides a first estimate for disposal basins varying in size from 2 - 2,000 ha on the Riverine Plain. It should be stressed that while the estimates for leakage seen here may represent a good first estimate for leakage rates for planned disposal basins in the Riverine Plain, they do so only if soil type and hydraulic head are the similar to existing basins. Also, the leakage rates should not be seen as restrictive. In many cases, it may be possible to change infiltration conditions at the base of a basin to such an extent that the throttle to leakage is determined by infiltration through the base and that leakage from the basin is infiltration limited. Possible methods for achieving this are discussed in Chapter 4.

3. Disposal Capacity

When determining the area required for a basin, two parameters need to be calculated. Firstly, one needs to know the amount of water that will be pumped into the basin in order to maintain the watertable at a designated depth. There are numerous factors (such as the sensitivity of the irrigated crop to salinity/water-logging, the economic return of the crop and the cost for the land sacrificed for the basin) that need to be considered when making this determination. These factors are discussed in the companion reports given in the reference list.

Secondly, one needs to determine the long-term rate at which the disposal water can be pumped into the basin without

(i) the input exceeding the basin capacity

(ii) leakage from the basin having a detrimental effect on the environment or neighbours property.

Again, there are numerous factors that will impact on the disposal rate. In Chapter 1, we defined the terms, *potential disposal capacity* and *design disposal capacity. Potential disposal capacity* refers to the amount of water that can be added to a basin per unit of time if the impact of leakage is ignored (in other words, only (i) above is considered). *Design disposal capacity* refers to the disposal capacity if a volume of water, equivalent to that in the leakage is intercepted and pumped back into the basin. The method of interception may be via interception drains around the basin or via the general drainage system (e.g. using tile drains and/or groundwater pumps).

Clearly, using the design disposal capacity for basin design and management does not mean that all the leakage is intercepted. The only way to ensure no detrimental impact on neighbouring farms and the environment is to prevent leakage completely by sealing the basins. In general, this option is not feasible for a variety of reasons (mainly economic) discussed later in this chapter.

3.1 Factors Affecting Disposal Capacity

The disposal capacity (both potential and design) for basins in the Riverine Plain will depend directly on:

1. Climate — Disposal capacity decreases as rainfall increases. Disposal capacity increases as evaporation increases. Evaporation decreases as humidity increases.

2. Leakage rate	Potential disposal capacity increases as net leakage increases. However, design disposal capacity will also change depending on the rate of leakage because the rate of leakage will impact on the salinity of the water in the basin (evapoconcentration effect).

In addition, there are factors that impact indirectly on the disposal capacity of the basin. These include:

1. Basin size	Larger basins tend to develop their own microclimate resulting in increased humidity above the basin and a reduction in evaporation from the basin (the oasis effect). Larger basins tend to have a lower leakage rate. Because of the above two factors, larger basins tend to have higher salinities and therefore reduced evaporation.
2. Basin salinity	Evaporation from basins decreases as basin salinity increases. Basin salinity increases as the salinity of input water increases. Basin salinity increases as leakage decreases.

3.1.1 Climate

The Riverine Plain extends over an area of ~100,000 km^2. Mean annual potential evapo-transpiration (MPET) and rainfall (MAR) ranges from ~1400 – 1900 and ~350 – 500 mm/yr respectively for the area Table 3. If evaporation from basins in the Riverine Plain is equal to MPET (as measured via standard evaporation pans), then MPET-MAR will range from ~900 – 1400 mm (i.e. a disposal capacity of 9 – 14 ML/ha/yr). This is the mean, annual, design disposal capacity of the basin assuming that there is no reduction in evaporation rate as a result of the oasis effect and no reduction in evaporation rate as a result of salinity in the basin water. Also shown in the table, is the design disposal capacity assuming a 20% reduction in evaporation (as is the case for large water bodies) but assuming no reduction in evaporation because of salinity in the basin water. These assumptions are addressed in the following discussion.

Table 3. Evaporative potential across the Riverine plain

Location	Longitude	Latitude	MPET (mm)	MAR (mm)	MPET-MAR (mm)	0.8*MPET-MAR (mm)
					*	**
Shepparton	145.4	-36.38	1470	513	956	662
Swan Hill	143.55	-35.35	1565	345	1220	907
Deniliquin	144.93	-35.52	1541	411	1130	822
W. Wagga	147.37	-35.13	1475	560	915	620
Balranald	143.57	-34.63	1584	319	1265	949
Hay	144.85	-34.5	1637	363	1275	947
Hillston	145.53	-33.48	1728	357	1372	1026
Griffith	146.03	-34.28	1575	415	1160	845
Forbes	148.02	-33.38	1637	526	1112	784
Condoblin	147.15	-33.08	1729	441	1289	943

* *for small basin 1-2 ha* ** *for larger basin 500+ ha*

3.1.2 Oasis effect

For evaporation to take place, there needs to be a humidity gradient between water in the water body and the atmosphere above it. Water will not evaporate if the air above the water body is saturated, and the evaporation rate will increase as the humidity above the water body decreases. Hence, factors that result in more humid conditions above the water will reduce the rate of evaporation below that seen for standard pan evaporation. One such factor is how quickly water evaporating from a basin or lake can be removed from the area. This is mainly related to the size of the water body and the speed and turbulence of the wind. Detailed discussion of these factors is beyond the scope of this report.

The main effect on evaporation for areas with similar climates relates to the size of the water body (in this case, the basin). Morton (1986) suggested that evaporation rate from a water body reduced from a maximum value for small water bodies, as determined for a standard evaporation pan, to a fraction of that value for larger water bodies (Equation 6). The fraction, F is evaporation rate relative to pan evaporation and decreases from unity for small basins to approximately 0.8 ~1,000 ha basins (Figure 9) according to the following relationship :

$$F = 1 - 0.029 \times \ln A \qquad [6]$$

Using this data, we see that value for MPET – MAR decreases by 30% or more for larger basins as opposed to smaller basins in the Riverine Plain (Table 3).

It should be noted, however, that the basins studied by Morton were probably not in intensely irrigated areas. This being the case, it is possible that the relationship presented here may overestimate the reduction in evaporation associated with larger basins if the basin is sited in an intensely irrigated area. We suggest that, where possible, pan evaporation be measured in the irrigation area. The reduction in evaporation, as given in Equation 6, is therefore likely to be a more reasonable approximation of what happens under field conditions.

3.1.3 Salinity effect

Pan evaporation measurements are made by measuring the evaporation of pure water at a particular location. As the concentration of different salts in water increases, there is a corresponding decrease in the availability of free water molecules that are not bound to salt particles. This reduces the availability of water molecules for evaporation and the overall evaporation rate of the water body. The reduction in evaporation is dependent on the

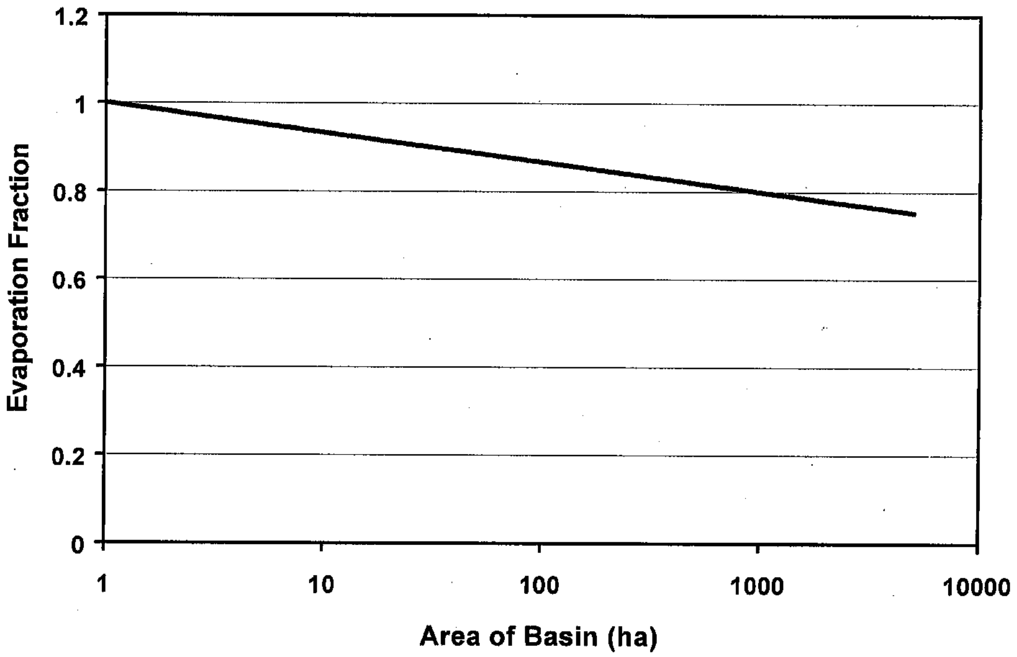


Figure 9. Evaporation fraction for different basin areas

Evaporation from larger basins may be reduced by 20% or more for larger basins because of an increase in humidity above larger basins.

types of salt in the water and is also dependent on the humidity of the atmosphere above the basin. For example, if a water body is saturated with sodium chloride, there will be no evaporation during periods when the atmospheric humidity is above 70%. When other salts are present (e.g. $MgCl_2$), evaporation may cease at much lower humidity levels.

Groundwater in the Murray Basin has a similar anion/cation composition to sea-water. In Figure 10, the decrease in evaporation rate relative to that of pure water is shown as salinity of the water increases to near that of saturated sodium chloride.

The evaporation rate decreases exponentially with increasing salinity. Hence, while there is only a 5% reduction in evaporation rate for water with a salinity of 100 g/L compared to that of pure water, the rate decreases by a further 10% as the concentration increases from 100 to 200 g/L, and a further 20% again, as it increases from 200 to 320 g/L. The reduction in evaporation rate for salinity levels, S (g/L) up to 320 g/L has been approximated by Turk (1970) and Bonython (1969) using the following relationship where F is the evaporation factor:

$$F = 1.025 - 0.0246 \times \text{EXP}\ (0.00879 \times S) \qquad [7]$$

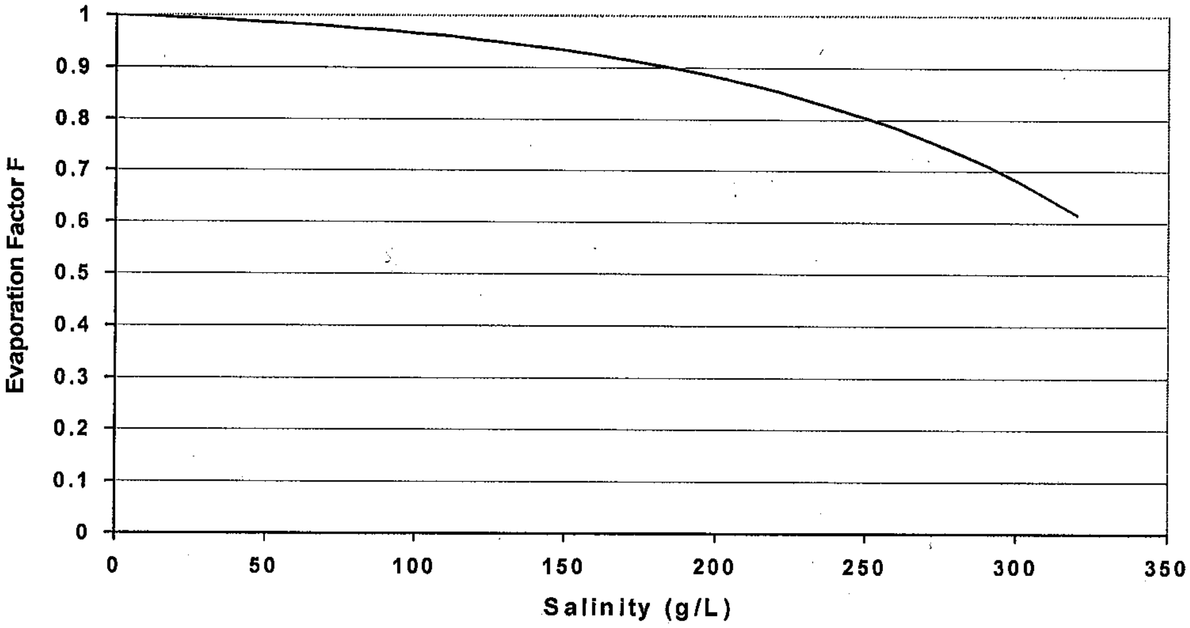


Figure 10. Evaporation fraction of saline water relative to that of pure water.

The relationship uses a curve fitted through the data of Turk (1970) and of Bonython (1969). The decrease in evaporation decreases exponentially with the salinity of the water.

Depending on the chemical composition of the water, salts such as gypsum and calcite may precipitate when the salinity levels reach 160 to 200 g/L. Sodium chloride will usually start to precipitate around 350 g/L. Evaporation rates will continue to decrease as sodium chloride precipitates but the relationship in Equation 7 no longer applies.

3.2

Relationship Between Evaporation, Leakage, Basin Salinity, Basin Area and Disposal Capacity

In the above section, we introduced independently factors affecting the disposal capacity of a basin. However, many factors do not operate independently of each other. For example, while the reduction in evaporation rate as a result of increasing basin salinity (the evapo-concentration effect) may be relatively straightforward, determining the salinity of the water is not. The salinity of water in a disposal basin will depend on:

1. the salinity of the input water
2. the climate of the area (Potential evaporation rate, Rainfall, Humidity)
3. the area of the basin (the oasis effect)
4. the leakage rate of the basin

If this is then incorporated with the reduction in evaporation rate for larger basins (the oasis effect), the likely reduction in leakage for larger basins and the range of pan evaporation and rainfall across the basin, disposal capacity becomes complicated. In the following discussion, we have combined these effects using a spreadsheet hydrochemical model for hypothesised scenarios in the Riverine Plain. The model has been tested using data from the Girgarre Basin for the years 1987-1999 (Leaney and Christen, 2000).

3.2.1 Potential disposal capacity

In the following discussion, we incorporate the previously discussed factors and evaluate how the disposal capacity will be affected by the salinity of input water, climate, basin size and leakage rate for basins in the Riverine Plain.

We have used a 40 year record (1957 – 1997) for pan evaporation and rainfall for three sites (Shepparton, Deniliquin and Hillston). In each scenario, the disposal capacity is the mean for the 40 year period. In most cases, the disposal rate will decrease with time as the mean salinity of the basin increases. The climatic records were interpolated from actual data from meteorological stations in the Riverine Plain using the SILO Datadrill programme developed by the Queensland Department of Natural Resources.

When determining the salinity of the basin, it is assumed that there is complete mixing spatially throughout the basin and there is no salinity stratification with depth for water in the basin. The first of these assumptions is reasonable, at least for small to moderate sized bays (as seen at Girgarre Basin, Leaney and Christen, 2000). The potential for salinity stratification has not been studied in detail but is considered possible, particularly for hyper-saline basins. Preliminary results for the Wakool basin (Appendix 2) suggest that stratification of fresher water over more saline water may occur when the conditions are optimal (sheltered areas on days with low wind speed). During these days, the reduction in evaporation as a result of salinisation of basin water may be less than predicted for very saline basins. In these situations, the potential disposal capacity will be greater than that predicted by the spreadsheet model. However it would be unwise to rely on stratification to maintain evaporation rates.

When comparing the relative effect of different factors on disposal capacity, we have used the results for Hillston, which has the highest net evaporative capacity (15.0 ML/ha/yr) and Shepparton which has the lowest net evaporative capacity (9.5 ML/ha/yr) (Figure 11).

The values for net evaporative capacity are considered as reference disposal capacities and equal the Potential Evaporation minus Rainfall for each site. They assume that there is no evaporative loss due to evapoconcentration and the basin size and that no leakage occurs. Note that the net evaporative capacity at Hillston for the last 40 years (15.0 ML/ha/yr) is considerably greater than the mean for the period of record (13.5 ML/ha/yr) reflecting drought conditions during the last few decades.

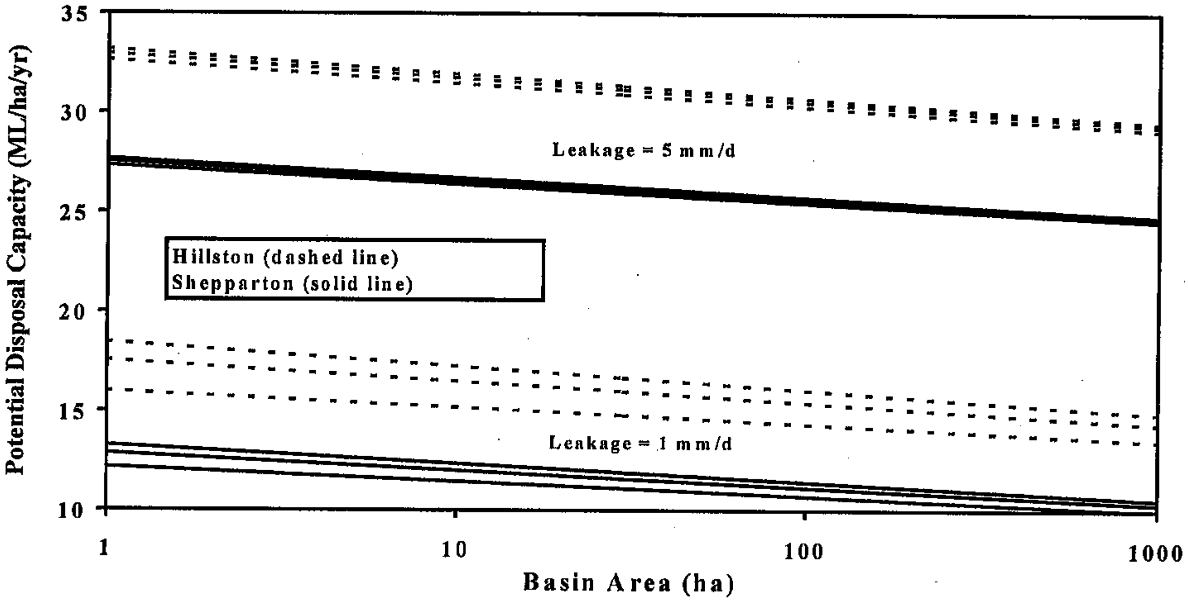


Figure 11. Potential disposal capacity for basins at two sites in the Riverine Plain (leakage Rates of 1 & 5 mm/d).

For each set of three lines, the top, middle and bottom line assumes input salinites of 10, 20 and 30 g/L respectively. Potential disposal capacity is only marginally reduced for higher salinity input water for basins with leakage rates of 5 mm/d compared to those with leakage rates of 1 mm/d. The potential disposal capacity at Shepparton, for basins with 5 mm/d leakage and input salinity in the range 10-30 g/L, can not be distinguished in this plot.

Clearly, climatic factors may result in a difference in disposal capacity of over 5 ML/ha/yr for different sites in the Riverine Plain. The effect of leakage, salinity and basin area on disposal capacity may be seen by comparison to the reference disposal capacity at each of these sites.

We have used the spreadsheet model (Leaney and Christen, 2000) for calculations and, unless otherwise stated, assumed that the disposal basins have single bays. Evaporation rate has been determined from pan estimates and reduced according to the size of the basin (Equation 5) and the salinity of the basin (Equation 6) for the hypothetical scenarios. Results have not been presented for scenarios where the water in the basin (or in the terminal bay for the triple basin) exceeds 320,000 mg/L because it is difficult to predict the reduction in evaporation rate at these high concentrations (except to say that evaporation rates will be significantly reduced). The leakage rates and input salinity values span the range expected for basins in the Riverine Plain (see chapter 2).

Potential disposal capacity for the basins is highly dependent on the leakage rates for basins. If factors such as basin size, leakage rate and salinity of basin water are ignored, then the potential disposal capacity will increase by 3.65 ML/ha/yr for every mm/d of leakage from the basin. Hence, if a basin leaks at the rate of ~5 mm/d (a rate not uncommon for small disposal basins) and this leakage is not intercepted, then the potential disposal capacity should be 14.6 ML/ha/yr greater than if the basin leaks at ~1mm/d. This is close to that predicted using the spreadsheet model at both sites (Figure 11) suggesting that the effect of salinity does not impact greatly on disposal capacity for these scenarios. However, there is an additional reduction in disposal capacity associated with increased basin salinity for the lower leakage rate scenario and higher salinity of input water.

The loss in potential disposal capacity when the leakage rate is less than 1 mm/d decreases considerably as the salinity of input water increases. For example, for 10 g/L salinity input water, the disposal capacity at Hillston would be close to 15 ML/ha/yr for a one hectare basin and 11.5 ML/ha/yr for a 1000ha basin. However, if the salinity of the input water is 30 g/L, this is reduced to <9 and < 8 ML/ha/yr respectively (Figure 12). The reduced evaporation rate associated with larger basins is clearly seen in both figures.

Another way of viewing this trend is to look at the change in the potential disposal capacity of a basin as a function of leakage rate and the salinity of input water (Figure 13). In the case illustrated (a one hectare basin sited at either Shepparton or Hillston and receiving 10 g/L salinity input water), there is no loss in disposal capacity associated with salinisation of the water in the basin for leakage rates above 0.2 mm/d (as seen by the linear relationship between disposal rate and leakage rate). However, there is a reduction in the potential disposal rate as the salinity of the input water increases. The reduction is considerable at leakage rates below 1 mm/d and, for very saline input water, the disposal capacity may be close to zero if leakage is stopped completely (and during times when salinity stratification does not take place).

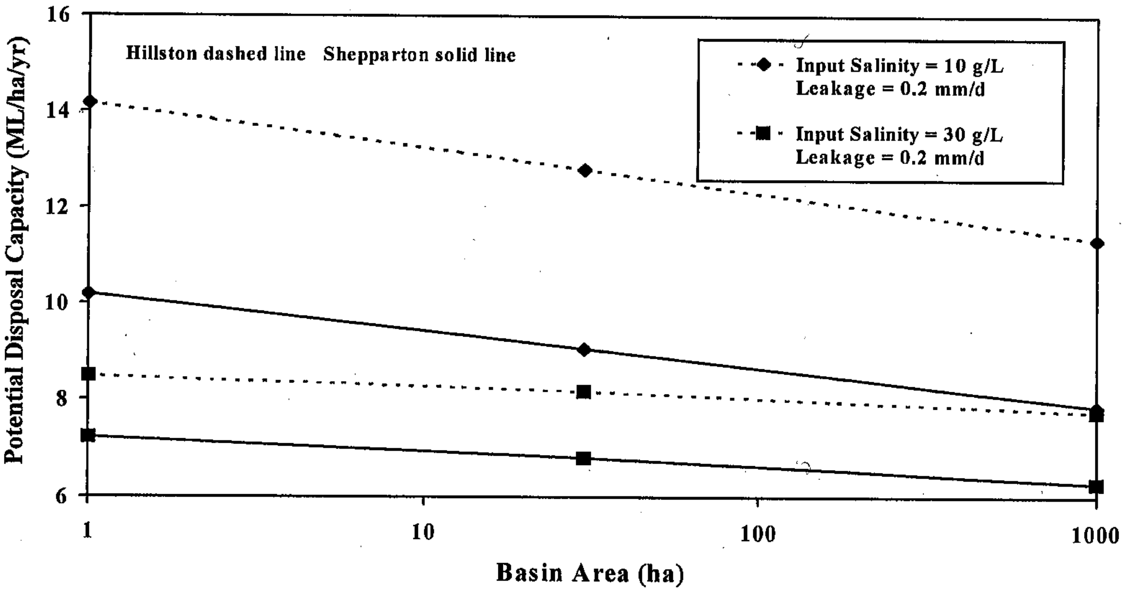


Figure 12. Potential disposal capacity for basins at two sites in the Riverine Plain (leakage rate of 0.2 mm/d)

If leakage rates are very low, there may be a large reduction in disposal capacity as a result of evapoconcentration.

The above scenarios have assumed that all of the basins consist of single bays. However, there are good reasons relating to containment of the leakage plume why basins may be designed as multi-bay (see next chapter). The potential disposal capacity for multi bay basins will always be slightly less than or equal to that for single bay basins. This is because, although the mean salinity of the water in multi-bay basins is likely to be similar to that of single basins, there will be a component of water of considerable higher salinity than the mean in the terminal bays of the basin and water of considerably lower salinity in the initial bays (assuming other factors to be equal). The relationship between salinity and evaporation rate is non linear and hence, the loss of evaporation in the more saline bays is greater than the higher rate of evaporation in the lower salinity bays.

The difference, however, is quite small for most basins. For example, the potential disposal capacity for a triple bay set-up with area ratios 0.43, 0.43, 0.14 (as used at Girgarre) is almost the same as that for a single bay of the same overall area (Figure 14). The examples shown are for basins at Shepparton and Hillston with input water of 10 g/L. The difference in disposal capacity is greater if leakage rates are less than 1 mm/d and/or the input water is very saline as these conditions will tend to result in precipitation of salts in the terminal bays.

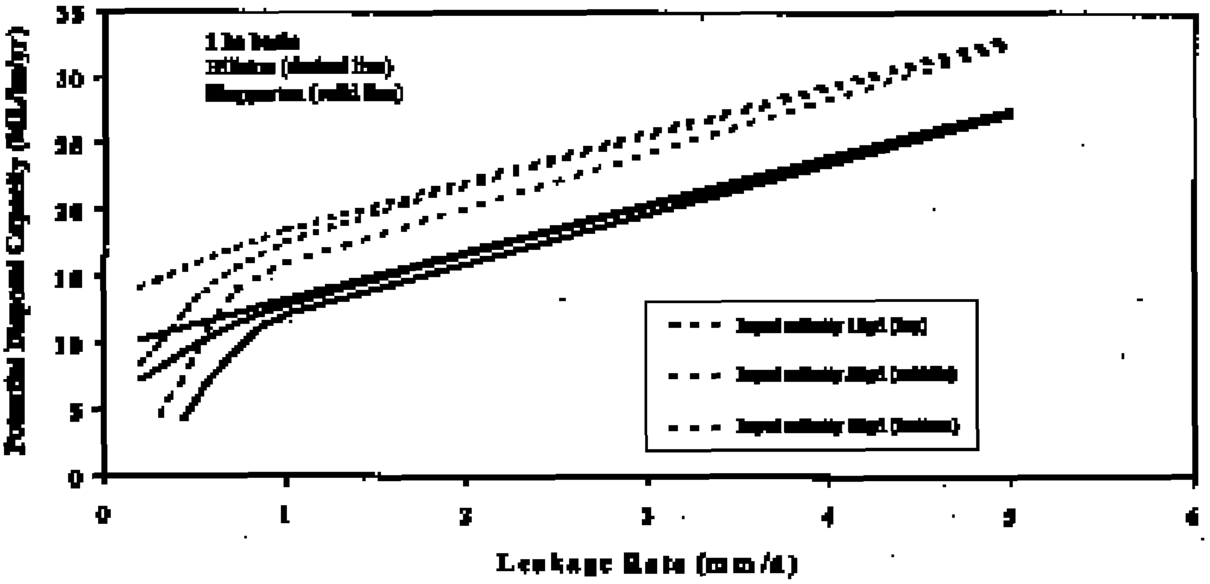


Figure 13. The change in potential disposal capacity with leakage rate and salinity.

For each set of three lines, the top, middle and bottom lines show the disposal capacity for a given leakage rate assuming input salinities of 10, 30 and 50 g/L. The effect is most marked for leakage rates less than ~1 mm/d.

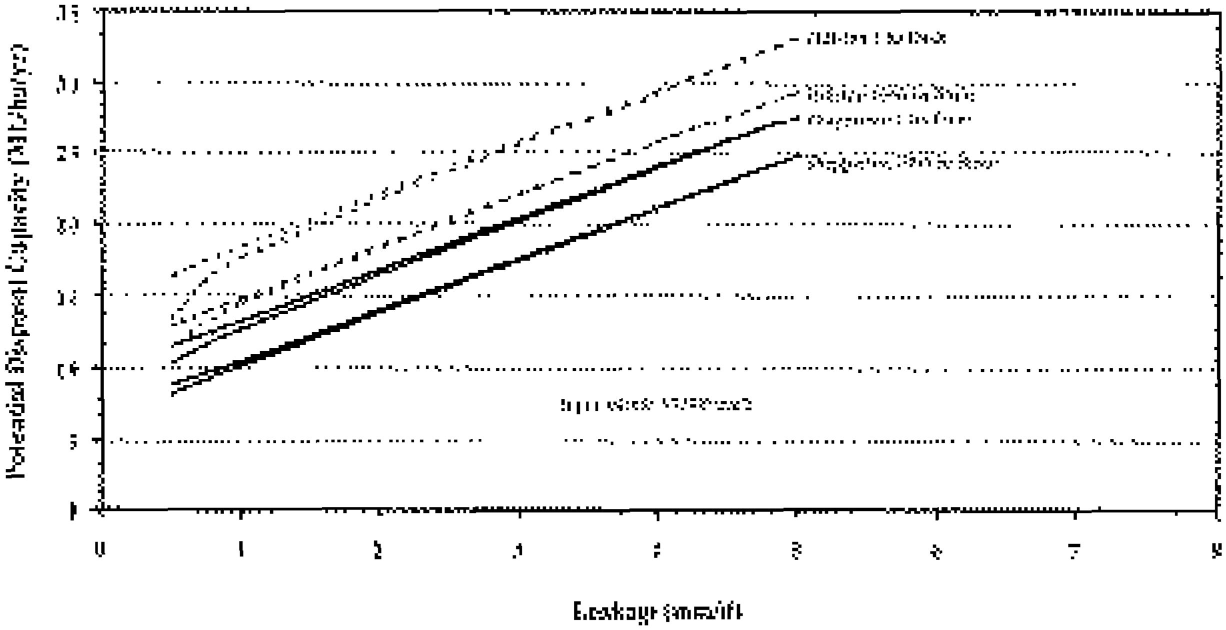


Figure 14. Comparison of potential disposal capacity for single and triple bay basins

For each of the 4 scenarios, disposal capacity for a triple bay is slightly less than or equal to that for a single bay. The difference, however, is negligible. The scenarios presented in this plot assume 10 g/L salinity input water. There will be a slightly greater loss in disposal capacity for triple (or multiple) bays if the salinity of the input water is greater and/or the leakage rate is lower.

3.2.2 Design Disposal Capacity

The term, *design disposal capacity*, has been suggested as a safer alternative to potential disposal capacity when determining the area of a basin. As discussed earlier, the design disposal capacity assumes interception and recirculation back into the basin of a volume of water equivalent to that present in the leakage. The effect of evapoconcentration and the oasis effect, as discussed in the previous section on potential disposal capacity, will also apply to design disposal capacity and hence, are not repeated in this section. An extreme example of design disposal capacity would be the situation when there is no leakage from the basin.

3.2.3 Effect of stopping leakage

One may suggest that the **only** way to ensure that there will be no detrimental off-site effects as a result of saline leakage from disposal basins is to design the basins so that they do not leak. This is theoretically possible but practically and economically difficult to do. At a few locations in the Riverine Plain evaporation basins have been used with the major focus being on salt production. The most commercial of these operations has decided that plastic liners are the least expensive option to ensure that leakage is reduced to close to zero and hence, enhance the production of salt. This option is very expensive (~$8,000 per ha) and, as yet, the long-term integrity of the barrier has not been proven.

Apart from the large cost to ensure very low leakage rates, there is another important economic reason why basins should have some leakage. If basins are prevented from leaking, salt would start to precipitate (usually gypsum initially then calcite, halite and other salts) at some time after the commissioning of the basin. The lag time before salts precipitate is dependent on the salinity of the input water, the depth of the basin and the climate at the location of the basin. It may be less than 2 years if water of salinity 50,000 mg/L is pumped into a 0.3 m deep basin at Hillston or, at the other extreme, it may be 30-40 years if fresher water (salinity = 10,000 mg/L) is pumped into a 1 m deep basin at Shepparton. Once the basin commences salt precipitation, the disposal capacity decreases markedly to the point where, at the point of halite precipitation, it is virtually zero for periods with greater than 70% humidity. At that point, either the salt and the saline water needs to be removed from the basin or the basin volume (area or depth) needs to be increased if disposal is to continue. All of these are costly options as discussed in the economic assessment of basins in the Riverine.

The amount of leakage required to moderate the effect of evapoconcentration is usually not high. Depending on the salinity of the input water and, to a lesser extent, the climatic conditions, leakage of around 1 mm/d will be sufficient to allow the basin to function at near the maximum evaporative capacity (as shown for a 1 ha basin at Hillston, Figure 15). As shown in Chapter 2, leakage rates are usually in excess of 0.5 –1.0 mm/d except for the case of very large (regional) basins. For regional basins and sealed basins leakage rates close to zero may be achieved but at the expense of very low rates for design disposal capacity.

In Figure 15 (and Table 5), the design disposal capacity was given as a mean over a 40 year period. In actual fact, usually the design disposal capacity will either remain constant or reduce with time. Depending on the salinity of the input water, the reduction in disposal capacity as a result of evapoconcentration may not be obvious for some time following the commissioning of the basin. In the case of one hectare basin at Hillston with input water of salinity 30,000 mg/L, it will take 10 years before a reduction in design disposal capacity will be observed (Figure 16). At that time, the disposal capacity would start to reduce considerably if leakage is ~0.2 mm/d, or less, but will be maintained at near optimum levels if leakage is in excess of 0.5 mm/d.

3.3 Interception/ Recycling

In the previous sections, we discussed factors that determine the potential and design disposal capacities for basins in the Riverine Plain. Whether or not either of these are useful in determining the area required for a basin will depend on several factors, most importantly, the economic and environmental risk associated with leakage and the efficiency of interception/recycling of leakage from the basin.

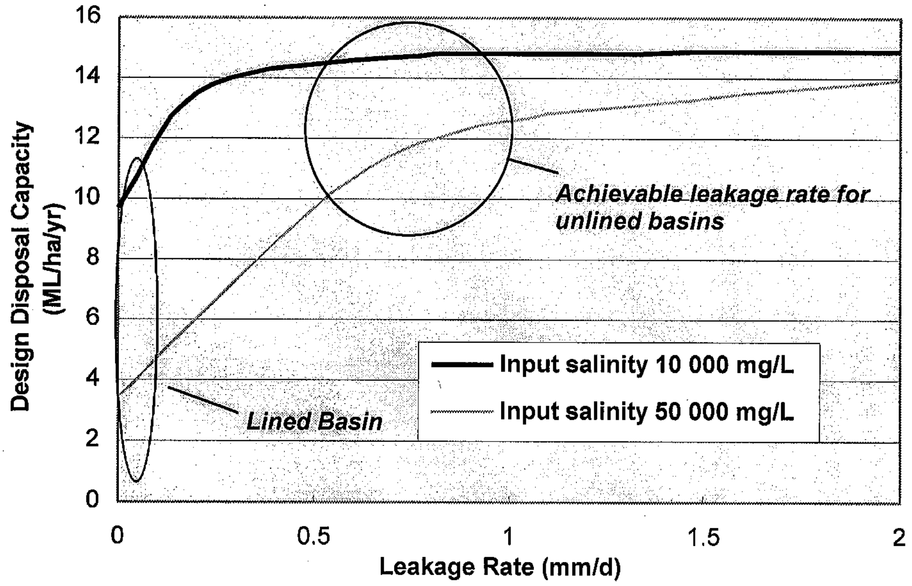


Figure 15. Mean design disposal capacity between 1957-1997 with leakage rates between 0.1 and 2.0 mm/d.

The use of potential disposal capacity to determine the evaporative area required for a basin implies that there are no concerns with what happens to the water leaking from the basin. In other words, the land surrounding the basin and the groundwater beneath the basin are considered to have minimum economic and environmental value. Waterlogging and salinisation around the basin are likely outcomes if this approach is followed and, in irrigation areas, this is unlikely to be a satisfactory outcome. However, one can envisage an interest in the use of potential design capacity in areas where the economic return is not good, land is reasonably inexpensive and there is a need to minimise construction costs (area) for the basin. However, environmental impacts and off-site effects would still need to be accounted for.

In general, however, the design disposal capacity should be used as a basis for determining the evaporative area required for a basin. If this is so, we need to determine the possible ways to intercept leakage and any advantages associated with some compared to others. In their report on the use of basins in the Riverine Plain, Jolly *et al.*, (2000), strongly recommend that basins be considered in association with drainage from the basin and not as a separate entity. Hence, they recommend that the drainage system be considered as a

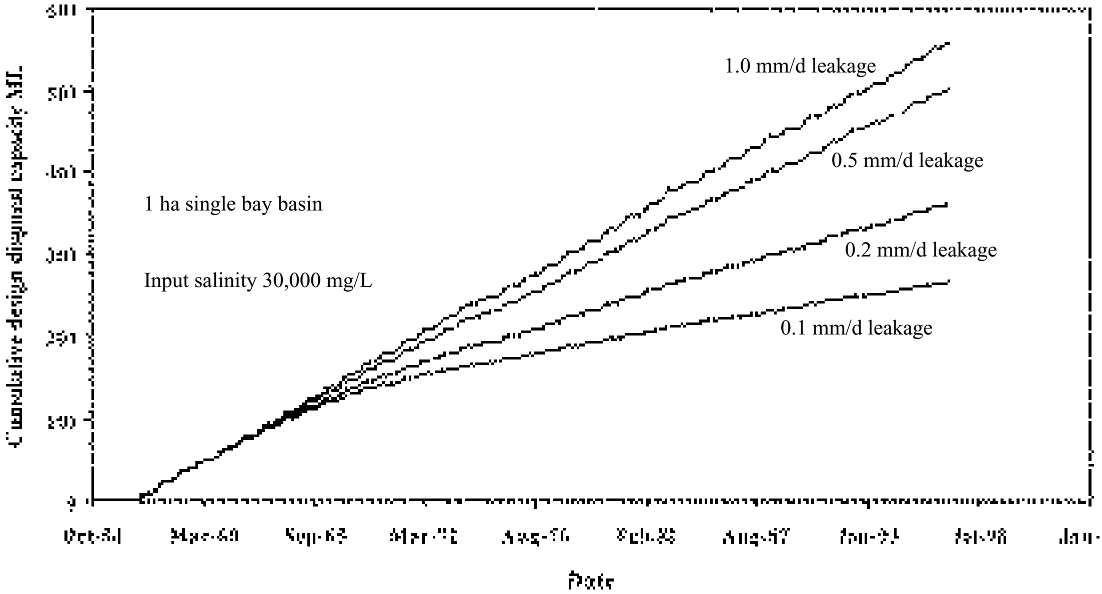


Figure 16. *Cumulative design disposal capacity for a 1 ha,0.3 m deep,basin at Hillston for leakage rates of 0.1 to 1.0 mm/d.*

The design disposal capacity for this basin at Hillston is independent of leakage from the basin for approximately the first ten years of operation. After that time, the basin reaches salinity levels that start to impact on the evaporation rate. Lower rates of leakage result in more saline basin water and lower design disposal capacity. There is minimal reduction in design disposal capacity for this basin for leakage rates in greater than 0.5 mm/d.

way of intercepting leakage from the basin. Hence, for tile drain systems, the drains themselves intercept leakage from the basin as well as drainage from the irrigation area. For groundwater pumping systems, the groundwater pumps themselves are considered part of the recycling system.

The main advantage with using pumps and tile drains to intercept leakage is that they already exist and require minimal, if any, additional expense. The main disadvantage is that they only intercept leakage at some considerable distance from the basin and significant problems may occur before the water is intercepted. Also, the percentage of leakage water recycled becomes less with increasing distance from the basin and lower salinity (potentially useful) water may be pumped unnecessarily into the basin. For many basins, interception channels are considered as a way of recycling leakage back to the basin and reducing problems close to the basin. In the next section, we look at the use of interception drains and their efficiency of recycling.

3.3.1 Interception drains

Interception drains are shallow subsurface pipe drains or open drains usually located 5-20 m outside the basin and designed to intercept water (intentionally leakage) when watertables rise above a certain height. The interception depth is usually set at or about the average for the winter watertable. For most of the constructed basins in the Riverine Plain, there have been attempts to intercept the lateral leakage via interception drains. No interception drains have been placed around the opportunistically placed basins. A summary of this data is presented in Table 4.

Table 4. Interception by Drains and Net Leakage for Basins in the Riverine Plain

Basin	Area ha	Total basin leakage (L) m^3/d	Flow from interceptor drains (I) m^3/d	Interceptor drain length m	Interceptor flow per unit length $m^3/d/m$	I/L %	Net basin leakage (L-I) mm/d
MIA D	1.9	57	28	680	0.046	50	1.5
MIA B	2.2	97	85	730	0.114	88	0.5
MIA A	2.3	80	66	775	0.087	83	0.6
Cohuna	3.3	106	33	726	0.045	31	2.3
Pyramid Hill	3.3	142	36	726	0.050	25	3.2
Girgarre*	30	300	25	1640	0.015	8	0.9

** Note Girgarre is infiltration limited and thus behaves differently to other basins studied in the Riverine Plain. The value of 8% is the amount of water that was pumped out of the interception channel and probably represents water from the local watertable during high water table periods.*

The amount of water intercepted by these channels varies from 0.015 to 0.087 $m^3/m/d$. If we exclude the Girgarre Basin, the only basin where leakage is infiltration limited, the range in interception by these drains is reduced (0.045 - 0.087 $m^3/m/d$). These amounts are comparable with analytical solution of flow to such drains assuming that the soil saturated hydraulic conductivity is about 0.1 m/d, there is an impermeable layer 2-3 m beneath the basin and the distance from basin water to drain is about 10 m. These assumptions are reasonable for these basins in the Riverine plain and result in predicted flows of around 0.06 $m^3/m/d$.

The amount of water intercepted will clearly be dependent on the proximity of the drain to the basin (both laterally and vertically), the hydraulic characteristics of the soil and the head of water (basin height to regional watertable). If the drain is too high, most of the leakage will pass beneath the drain and, if too low, it will intercept water from the watertable rather than leakage. It is possible that using an interception drain may, in itself, increase leakage from the basin. For some of the basins, it is observed that the interception drains intercept a volume of water close to the volume leaked from the basin. If the water intercepted is predominantly leakage from the basin, the use of interception drains clearly represent a useful method of recycling salt and minimising detrimental effects associated with leakage.

For the on-farm basins described in Table 4, the net basin leakage or effective leakage (mm/d) is that passing beyond the interception drain. This value is equal to 25 – 88% of the observed leakage from all of the expansion limited basins (i.e. excluding Girgarre Basin). Hence, the effective leakage for the basins ranges from 1–3 mm/d. It is this value for leakage that will, along with climate, basin size and salinity of the input water, determine the salinity of the water in the basin. The range is quite small given the variation in the construction of the basins and interception drains and the estimates associated with measurement. At this rate of leakage, there is no reduction in evaporation associated with evapoconcentration of the basin water but the detrimental effects of leakage from the basin are significantly minimised compared to basins with no interception drain. There is insufficient data to determine whether similar amounts of interception are likely for larger basins where leakage is expansion limited.

There have been no attempts to intercept deep leakage from any of the existing, opportunistically placed, basins in the Riverine Plain. This is mainly due to difficulties in differentiating between deep leakage from the basin and groundwater (and then pumping accordingly). It is possible to argue that, in the cases where groundwater is pumped to lower watertables, the groundwater pumps themselves will act as a method of interception. The time frame for this to happen, however, may be of the order of several decades. At Girgarre, groundwater pumping has taken several years to induce flow up to 20 m from the basin in the direction of the major pumps. One can foresee it taking at least 10 times that long for groundwater to travel a further 500 m to the pump.

3.4

Disposal Capacity for the Riverine Plain

The discussion in this, and the preceeding chapter, suggests that the effective leakage rates (leakage less interception) for basins less than 100 ha in the Riverine Plains are likely to be in the range of 1 to 3 mm/d if the basin floor has no treatment to reduce infiltration. In Table 5, we suggest potential and design disposal capacities for 1 – 1000 ha basins with leakage rates up to 2 mm/d, sited at Hillston, Deniliquin and Shepparton. We believe that effective leakage rates in this range are achieveable by appropriate treatment of the basin floor and design and management of the basin and interception drain (see next chapter). Input salinities of 10, 20 and 50 g/L have been chosen for water pumped into the basin and, as before, the disposal capacity averaged for the years 1957 to 1996 using results of the spreadsheet model for a single bay basin.

Table 5. *Calculated Values for Mean Disposal Capacity for Selected Sites in the Riverine Plain (1957-1996)*

Site	Leakage mm/day	Basin Area ha	Potential ML/ha/yr *	Potential ML/ha/yr **	Potential ML/ha/yr ***	Design ML/ha/yr *	Design ML/ha/yr **	Design ML/ha/yr ***	Pan E-R ML/ha/yr
Hillston	0.5	1	16.5	15.4	11.8	14.7	13.6	9.9	15.0
	1	1	18.5	18.1	16.3	14.8	14.5	12.6	15.0
	2	1	22.2	22.0	21.2	14.9	14.7	13.9	15.0
	0.5	10	15.3	14.5	11.3	13.5	12.7	9.5	15.0
	1	10	17.3	17.0	15.5	13.6	13.3	11.8	15.0
	2	10	21.0	20.8	20.2	13.7	13.5	12.9	15.0
	0.5	100	14.2	13.5	10.9	12.3	11.7	9.0	15.0
	1	100	16.1	15.8	14.6	12.4	12.2	10.9	15.0
	2	100	19.8	19.6	19.1	12.5	12.3	11.8	15.0
	0.5	1000	13.0	12.5	10.3	11.2	10.6	8.5	15.0
	1	1000	14.9	14.6	13.7	11.2	11.1	10.0	15.0
	2	1000	18.5	18.4	17.9	11.2	11.1	10.7	15.0
Deniliquin	0.5	1	15.2	14.5	10.7	13.3	12.5	8.9	13.6
	1	1	17.1	16.8	15.1	13.5	13.2	11.4	13.6
	2	1	20.8	20.7	19.9	13.5	13.4	12.6	13.6
	0.5	10	14.1	13.4	10.3	12.2	11.6	8.5	13.6
	1	10	16.0	15.7	14.3	12.3	12.1	10.7	13.6
	2	10	19.7	19.5	18.9	12.4	12.2	11.6	13.6
	0.5	100	13.0	12.5	9.9	11.2	10.6	8.0	13.6
	1	100	14.8	14.6	13.5	11.2	11.1	9.8	13.6
	2	100	18.5	18.4	17.8	11.2	11.1	10.5	13.6
	0.5	1000	11.9	11.5	9.4	10.1	9.7	7.6	13.6
	1	1000	13.7	13.5	12.6	10.1	9.9	8.9	13.6
	2	1000	17.3	17.2	16.8	10.0	9.9	9.5	13.6
Shepparton	0.5	1	11.6	11.2	9.1	9.7	9.3	7.3	9.5
	1	1	13.3	13.1	12.2	9.6	9.4	8.5	9.5
	2	1	16.8	16.7	16.2	9.5	9.4	8.9	9.5
	0.5	10	10.7	10.4	8.6	8.9	8.5	6.8	9.5
	1	10	12.4	12.2	11.5	8.7	8.5	7.8	9.5
	2	10	15.8	15.7	15.3	8.5	8.5	8.1	9.5
	0.5	100	9.8	9.6	8.2	8.0	7.7	6.3	9.5
	1	100	11.4	11.3	10.7	7.8	7.7	7.1	9.5
	2	100	14.9	14.8	14.5	7.6	7.7	7.2	9.5
	0.5	1000	8.9	8.7	7.7	7.1	6.8	5.8	9.5
	1	1000	10.5	10.4	9.9	6.9	6.8	6.3	9.5
	2	1000	13.9	13.9	13.6	6.6	6.8	6.3	9.5

**assuming input salinity 10 g/L ([Cl] = 5.5 g/L)*

***assuming input salinity 20 g/L ([Cl] = 11 g/L)*

****assuming input salinity 50 g/L ([Cl] = 27.5 g/L)*

The highest potential disposal capacities for basins in the Riverine Plain are likely to range from ~22 ML/ha/yr near Hillston to ~17 ML/ha/yr near Shepparton (both for small basins with leakage rates of 2 mm/d). Leakage from the basin results in an additional 7 ML/ha/yr above the potential evaporative capacity (PEC), resulting in an increase in disposal capacity of ~50% at Hillston and close to double at Shepparton compared to the PEC. Larger basins will have significantly reduced disposal capacity per unit area as a result of both the reduction in evaporation (the oasis effect) and a likely reduction in leakage from the basin. While potential disposal capacity is a useful concept, using it for basin design is likely to result in problems with groundwater and soil salinisation (and waterlogging) around the basin. For this reason, we recommend using the design disposal capacity when determining the area required for a basin.

The design disposal capacity of a basin will always be less than, or at best, equal to the potential evaporative capacity. In disposal basins, the evaporative capacity of the basin (and hence the disposal basin) may be reduced considerably as a result of evapo-concentration of the basin water. Higher input salinity and low rates of leakage increase the salinity of water in the basin and reduce disposal capacity. For the leakage rates chosen, there is a reasonably small loss in disposal capacity (up to 1.4 ML/ha/yr) for small basins with input water salinity up to 20 g/L. However, if the water is 50 g/L, the loss is more significant (up to ~5 ML/ha/yr).

The results of modelling the design disposal capacity for a range of input water salinities and leakage rate scenarios across the basin suggest that leakage rates of 0.5 – 1.0 mm/d are sufficient to moderate the effect of evapo-concentration and thus, allow the basin to function at near its maximum evaporative (and disposal) capacity for the full range of input water salinities likely to be experienced in the Riverine Plain.

Moderate to large disposal basins (50 – 500 ha) will probably have leakage rates close to that suggested above (0.5 – 1.0 mm/d) while smaller on-farm basins may be considerably higher. However, appropriately designed interception drains are likely to intercept and recycle up to 80% or more of leakage back into the basin and effectively reduce leakage rates to 1.0 – 3.0 mm/d. If these basins also have compacted floors, leakage is likely to be reduced further (see next chapter).

It is interesting to note that, for the 40 years scenarios studied, the amount of salt stored in the basin represents a very small percentage of the total salt disposal. There is only a limited capacity for salt storage in the basin. Even if leakage is limited to 0.2 mm/d, only ~10% of the salt remains in the basin with the remaining 90% stored in the soil and groundwater around and beneath the basin (assuming that the depth of the basin is 0.3 m). If leakage rates are 2 mm/d then virtually all of the salt is stored outside of the basin.

Clearly, the amount of salt stored outside of the basin represents a potential source of contamination to the neighbouring farms and groundwater. For this reason, we recommend the use of design disposal capacity (i.e. that determined assuming interception of all leakage) when determining the area required for a basin.

It is also important to note that the disposal capacities are based on seasonal averages for the 40 year period up until 1997. Climatic fluctuations are likely to vary greatly from year to year and also have longer term fluctuations. Evidence for this can be seen in the mean of the potential evaporative capacity for the period of recording compared to that for the 40 year record used in these calculations. Whilst these are similar for Shepparton (9.6 and 9.5 ML/ha/yr respectively), the differences are considerable for Deniliquin (11.3 and 13.6 ML/ha/yr respectively) and Hillston (13.5 and 15.0 ML/ha/yr respectively).

3.4.1 Seasonal changes in disposal capacity

The disposal capacities calculated in the previous sections are annual means for the 40 year period 1957 – 1997. Clearly, seasonal changes will have a large effect on the disposal capacity of a basin. Figure 17 presents the mean monthly design disposal capacity for a 30 ha, 0.3 m deep basin with 10 g/L salinity water pumped into the basin and leakage of 1 mm/d (ie conditions similar to that at Girgarre) sited at Hillston, Deniliquin and Shepparton. The range at each site is from ~2 ML/ha/month during summer to close to zero or negative during winter. The zero and negative values for the Deniliquin and Shepparton basins mean that, during the winter period, disposal capacity will be limited to any available storage within the basin. This will affect the possibility of being able to intercept all of the leakage at that time.

The seasonal fluctuations for drainage are not of great importance if the basin is being used to maintain a long term salt balance. In this case, such as for pasture production, the timing of the drainage pumping and disposal is not critical. This can be undertaken when there is adequate disposal capacity in the basin. This would be targeted to spring and summer.

If the basin is being used with a subsurface drainage system to protect crops that are sensitive to waterlogging then these seasonal changes in disposal capacity are important. Modelling of a subsurface drainage system with evaporation basin using the BASINMAN model, Wu *et al.,* (1999), found that it is important to manage the drainage system and disposal basin to provide maximum storage capacity in critical periods. For example waterlogging should be avoided in grapevines at bud burst in the Spring. It was found that for the MIA it was critical to enter the autumn/winter period with a relatively dry soil, deep watertables and basin less than half full.

This then provides the maximum storage capacity for rainfall in the profile and some capacity to dispose to the basin during the spring. These factors are examined in detail by Christen *et al.*, (1999b) and overall it was found that irrigation and drainage system management were more important than the influence of "wet winters". Thus it is important to consider crop sensitivity to waterlogging in basin design. However, for most crops it is probably still adequate to design a basin upon annual average disposal as long as the management considers the seasonal fluctuation in disposal capacity.

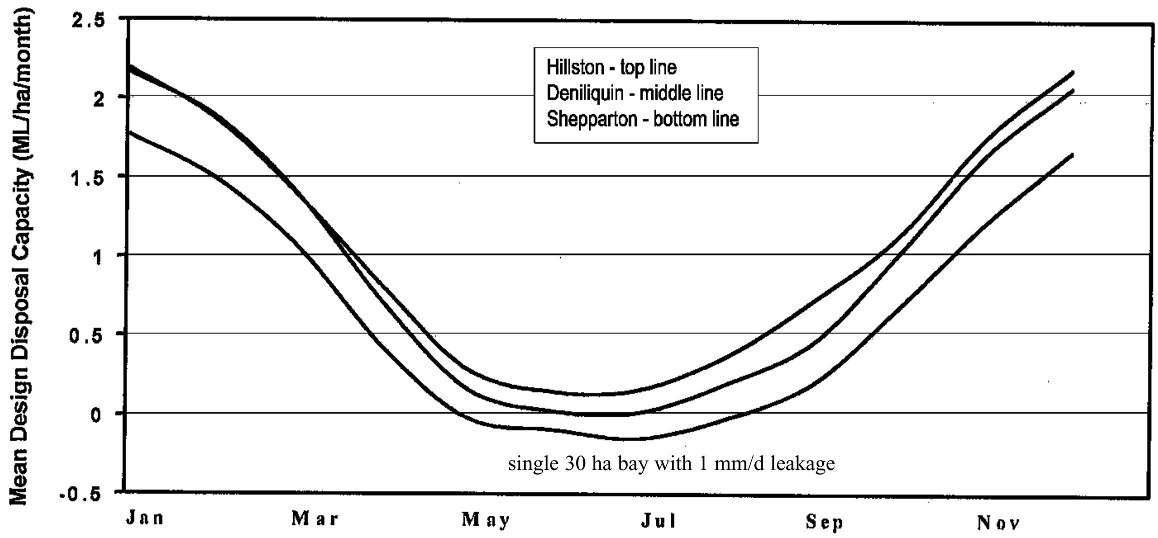


Figure 17. Seasonal fluctuations in mean monthly disposal capacity in the Riverine Plain.

There is a large seasonal fluctuation in the disposal capacity for basins in the Riverine Plain. For winter months, there is virtually no disposal capacity to the basin. In fact, at Shepparton, the value is negative from June to September indicating that, on average, it will not be possible to intercept and recycle leakage from the basin during that period.

3.4.2 Freeboard for disposal basins

In order to accommodate seasonal and year to year changes in disposal capacity, basins will need to be designed such that the depth of the basin is considerably deeper than the design depth of water in the basin. The height difference between the top of the basin walls and the design water depth is known as *freeboard*. When calculating the required freeboard, it is necessary to allow for:

1. zero or negative disposal capacity during wet years.
2. the leakage from the basin during that period.
3. drainage water generated during that period.
4. wave action on the water in the basin.

To determine the magnitude of the first of these requirements, we have estimated the water level rise for 30 ha basins (20,000 mg/L salinity input water, leakage of 1.0 mm/d) sited at Hillston and at Shepparton (Figure 18). We have used the same spreadsheet model described earlier in this report using monthly evaporation and rainfall as input data for the period January 1957 to December 1996. For the periods when basin levels are at their highest (1973-75), we have also modelled the water level changes on a daily basis (shown in ellipses with design levels of 0.15 and 0.4 m for Hillston and Shepparton respectively) to determine the extent to which monthly monitoring underestimates the depth of water in the basin. In order to differentiate between the water levels at the two sites, we have chosen a design water level of 0.1 m for Hillston and 0.3 m at Shepparton.

For the conditions presented here, wet periods during the last 40 years would have resulted in maximum water level rises of ~0.1 and ~0.2 m at Hillston and Shepparton respectively. At Shepparton, water level rises routinely exceed 0.1 m. Using daily measurements for evaporation and rainfall results in an increase of ~0.05 – 0.06 m in the water depth. The estimate for depth is relatively insensitive to basin size and water salinity. Rainfall amount is the major determinant of the water level rise (maximum water depths usually arise in late winter).

In addition to above requirement of 0.1 to 0.2 m freeboard because of limited disposal during wet periods, it is necessary to consider components 2 – 4 listed above. Over a 4 month period of rainfall greater than evaporation, there will be an additional component of 0.12 m arising from the leakage from the basin (.001 mm/d x 120 d). Depending on the timing for drainage, and whether, during these extreme periods, drainage will be needed, there may also be an additional component for drainage.

Finally, there must be an allowance for additional freeboard such that wave action does not cause overtopping of the basin and damage to the basin and surrounding area. The magnitude of this component will depend on local conditions and community acceptance of risk associated with overtopping. As a guide, the Girgarre basin and Pyramid Hill basin basins were designed to have an additional 0.45 to 0.70 m allowance for wave action. Hence, overall, if it is accepted as necessary to cease drainage during extreme wet periods, the amount of freeboard will probably be in the range of 0.6 to 0.8 m (the lesser value for drier areas). If drainage is required during this time, the amount of freeboard is probably unacceptably high. It is probable that, under these conditions, drainage will have to cease or alternative arrangements for disposal of the drainage water will be required.

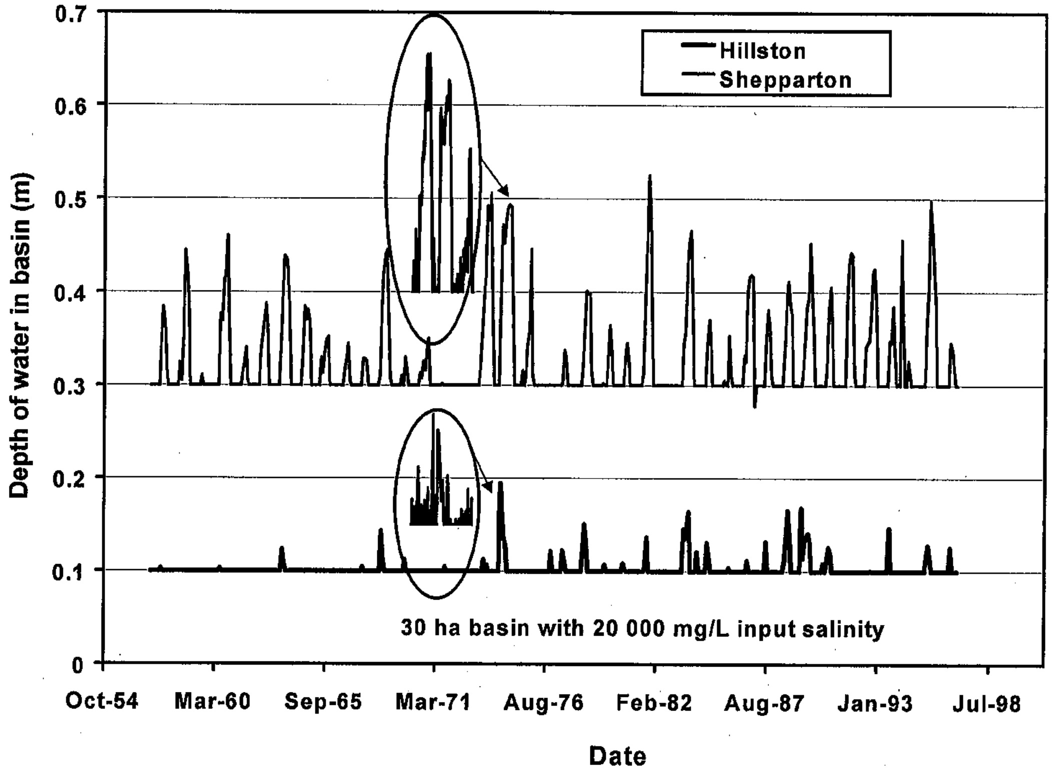


Figure 18. Modelled water level fluctuations in basins at Hillston and Shepparton using monthly water balance (1957-1996).Daily balance shown in ellipses.

Basins should be designed so that they do not overflow during wet periods. The amount of freeboard required to account for these periods ranges from ~0.1 to 0.3 m for the climatic conditions from 1957 to 1996. If an additional allowance of ~0.5 m is included for wave action, the overall freeboard required is 0.6 to 0.8 m.

4. Factors Affecting Infiltration

In the previous chapters, we presented data to show that leakage for most of the basins in the Riverine Plain was expansion limited. If the basin is not treated in any way to reduce leakage, the effective leakage (leakage minus interception from the interception drain) is likely to be 1 – 3 mm/d for smaller sized basins and, for basins in excess of 30-50 ha, probably less than 1 mm/d. We also suggested that there was probably minimal loss in evaporative potential (and hence design disposal capacity) if basins had effective leakage rates of 0.5 to 1 mm/d.

When using the design disposal capacity, the underlying assumption is that the leakage (or a volume of water equal in volume) will be intercepted and recycled into the basin. Hence, there are environmental (salinisation/waterlogging) and economic costs (pumping) associated with having a leakage rate in excess of that required to maintain near maximum disposal capacity. We therefore suggest that the *optimum leakage rate* for most basins in the Riverine Plain is therefore somewhere in the range *0.5 to 1.0 mm/d.*

This being so, it is worth exploring the ways in which leakage from the basin can be reduced. Earlier in this report, we introduced the concept of expansion and infiltration limited basins. Hence, we need to consider ways in which we can change the hydraulic conductivity at the base of the basin so that the mechanism for leakage from the basin is infiltration limited.

Factors affecting leakage from a basin

The following factors have been identified in the literature as potentially important in determining leakage from disposal basins:

1. Soil type and soil compaction (Heavier soils or compacted soils will, in general, have lower rates of leakage)
2. Hydraulic head of water (Deeper basins and/or lower regional watertables may enhance leakage).
3. Soil and water sodicity (Chemical interaction of water and soil may lead to dispersion or flocculation of the soil and changed infiltration rates).
4. Algal clogging (Polysaccharide production as a result of microbiological activity may reduce leakage from the basins).
5. Preferential flow paths (Leakage may be enhanced if leakage from the basin proceeds via preferential rather than piston-type flow).

Most of these factors may impact on leakage for basins if they are infiltration limited. The hydraulic head of water will also affect basins that are expansion limited. The following discussion of these factors is based predominantly on results from studies in the Riverine Plain.

4.1
Soil Type and Compaction

In Chapter 2, we suggested that most of the existing basins in the Riverine Plain had been sited on clay soils. This is clearly the favoured option in order to minimise off-site effects. While this option has been possible up until now because of the relatively few basins in the Riverine Plain, in the future, as the number of on-farm and community basins increases, basins may possibly be sited on soils of lighter texture.

Unlike the Mallee region in the western half of the Murray Basin, there are no large areas of sandy soils in the Riverine Plain. Hence, in most cases, the decisions that will need to be made are what is the likely increase in leakage as a result of placing a basin on a loam as opposed to a clay soil and what is the effect of locating a basin partially on or near a shoestring sand. From existing studies, there is only a limited amount of information that can help with these questions.

Twenty-nine soil cores (1-4 m deep) were collected from several of the existing basins in the Riverine Plain and for some of the soils around the basins, and analysed for particle size. While other factors apart from particle size (eg soil chemistry, see later section) are likely to have an impact on leakage rate, particle size or the amount of clay in the soil is likely to be one of the more dominant effects. All of the soils had an average of 40-70% clay content for most of the top 2 m of soil. Typically soils of this nature could be expected to have very varied hydraulic conductivities depending upon structure and chemical composition.

Hornbuckle and Christen (1999) report that for horticultural soils in the MIA hydraulic conductivity can vary from 0.06 – 1 m/d whereas heavier soils in the non-horticultural areas are likely to have hydraulic conductivities of 0.1 mm/d or less. Van der Lely and Talsma (1978) conducted infiltration test over 16 weeks and found rates of about 0.5 – 1.5mm/d for heavy clay soils and Transitional Red-Brown Earths.

However, this difference in hydraulic conductivity may not be important in the field situation. Unfortunately, in this case, it is not possible to evaluate the importance of soil type in determining leakage from disposal basins using studies on existing disposal basins because any likely differences will be masked by the perimeter:area effect discussed earlier in this report

Soil compaction is often suggested as a method for reducing the hydraulic conductivity of the soil and hence to reduce leakage in basins. Theoretically, it is possible to increase the density of soils and reduce the hydraulic conductivity to very low levels. The compaction of soils is also likely to reduce the occurrence of preferential flow paths resulting from macrobiotic activity.

Although the technique is theoretically sound, the only attempt to verify that it works under field conditions at the field scale was conducted at the Girgarre Basin (Goulburn-Murray Water and Sinclair Knight Merz, 1995). In their study, the first large bay (Bay A) and a smaller trial bay (T4) were not compacted but the second and third bays (Bays B and C) and several trial bays (Bays T2, T3 and T7) had the topsoil removed and either the 'A' or 'B' horizon ripped and compacted prior to filling. Using a combined chloride and water balance approach, leakage estimates for Bays A and B were found to be approximately equal while that for Bay C was reduced by half (Leaney and Christen, 2000). However, there is a larger than normal error associated with leakage from the first bay and it is possible that the leakage for the bay without compaction may be significantly greater (or less) than that in the compacted bay.

The short term trials using water balance calculations for the bays at Girgarre were carried out over 5 or 6 years during winter months (to minimise the error associated with measurement of evaporation). Their results suggested that leakage rate for the uncompacted Bay A (2.3 mm/d) were on average at least 5 times higher than the other bays (0.48 and -0.17 for Bays B and C respectively). However, the range in estimated leakage rates was considerably higher and there may have been problems when estimating the loss in evaporation as a result of salinisation of the water in the bays.

The results for the compacted trial bays, give a reduction in leakage by approximately 50% when compared to the untreated bays (1.2 mm/d for uncompacted bay and 0.3 – 0.5 mm/d for compacted bays). While the absolute values for leakage rate may be too high or too low, it is probable that compaction on these soils has led to a reduction of at least 50% in leakage rate. It is worth noting that this reduction in leakage was achieved for a basin in which leakage was already determined by infiltration through the basin base (as indicated by the presence of an unsaturated zone beneath each bay).

Further investigations on the influence of soil type and compaction on leakage rates were conducted in each of the three bays at Girgarre. The Girgarre basin is one of the few, and perhaps the only, basin in the Riverine Plains that has an unsaturated zone beneath the basin. Leaney and Christen (2000) attempted to determine whether there is any correlation between the depth at which flow beneath the basin is throttled (i.e. saturated flow stops and the system becomes unsaturated) and the clay content of the soil.

At the base of the Girgarre basin, there is a 0.1 to 0.3 m thick layer of black silt and below that depth is the original soil. The silt layer has a low bulk density and is obviously saturated. Results of soil-water potential measurements for the soil beneath the sludge showed that the soil was saturated at the top but, within 0.1 to 0.2 m from the surface, the soil was unsaturated. Hence, leakage from the basin is throttled within the first 0.2 m of the base of the basin.

This is about the same depth as where the highest clay content is observed for sites in the first two Bays, A and B. For Bay C, the 'A' soil horizon was removed when the bay was constructed and hence, the layer of heavier clay has been removed. There is no correlation between the depth where unsaturated conditions commence and clay content for Bay C. Hence, while it is possible that the presence of heavier soils may be a major factor in reducing leakage from the basin, it is unlikely to be the only factor.

The depth at which compaction is likely to impact is approximately the same as the depth at which the "throttle" operates. Hence, it is likely that, provided that the soil has at least 30% clay, compaction of the soil will result in a significant reduction in leakage rate.

Research regarding reducing leakage from rice bays may be useful to consider for evaporation basins. Techniques that have been tried are puddling of the soil and using a sheepsfoot roller, which is the usual civil engineering method of compaction. Humphreys et al (1992) showed that puddling of rice bays could reduce deep percolation by 75%. A later development has been the use of impact compaction which is also used in civil engineering work. Clark and Humphreys (1997) found that impact compaction reduced leakage from an average 2.4 mm/d to 0.1 – 0.4 mm/d depending upon the number of passes of the machine.

In general, compaction is used extensively in dam construction and other civil engineering works. If applied properly, it would appear to be a viable method for reducing leakage from evaporation basins

Conclusion **Compaction of appropriate (medium to heavy textured) soils should considerably reduce infiltration beneath basins.**

4.2
Head Difference

Earlier in this chapter, we suggested that the head difference between basin level and the watertable was between one and three metres for existing basins in the Riverine Plain. If the throttle to leakage from the basin is not at the base of the basin then leakage rate must be determined by how fast the leakage can move away from the basin. Leakage movement away from the basins is predominantly a function of the head of water, leakage, and factors affecting saturated flow (i.e. vertical and horizontal hydraulic conductivity).

If the hydraulic conductivity of the soil at the sites of existing basins is similar and the hydraulic head is similar, then the leakage rate for any basin should be inversely proportional to the perimeter of the basin as seen in the previous section. Hence, the main evidence that the hydraulic head is a major factor in determining leakage from basins is the observed inverse relationship between leakage rate and basin perimeter for existing basins in the Riverine Plain.

In at least 4 of the studies on basins in the Riverine Plain (Cohuna, Pyramid Hill, Girgarre and Nehme basin), the authors attempted to measure directly changes in leakage rate for changes in the hydraulic head of water. At Cohuna, the head was measured between the basin level and the water level at a test well located a few metres outside the basin and leakage was measured using a monthly water balance. They found that leakage ranged from <3 to >8 mm/d as the head doubled from ~0.4 to 0.9 m respectively. At the Pyramid Hill site, the range observed in the leakage rates were similar to that at Cohuna (2.1 to 7.4 mm/d) but there was no correlation observed between leakage rate and the head of water. This was also the case at the Girgarre basin.

Measurements of the hydraulic head at the Nehme basin indicate that during the initial filling the leakage rate is correlated with head difference directly below the basin. However once the groundwater mound has developed below the basin the head difference between the basin and the surrounding land takes over (Leaney and Christen, 2000). At the Nehme basin the watertable in the surrounding land fluctuated between 1 and 2 m deep. However, there was inadequate data to investigate this relationship properly. The relationship between depth of water in the basin and flow from interceptor drains is however quite clear as discussed in Leaney and Christen (2000). In simulating an on-farm evaporation basin in the BASINMAN model (Wu *et al.* 1999) it was found that if the watertables in the farm area were maintained at a depth of 2 m compared to 1 m then this resulted in only 60 mm extra pumping per year, about 0.2 mm/year. However, this is not purely a function of basin leakage but involves other processes of watertable evaporation, storage in the basin and depth of unsaturated zone.

A possible reason why it may be difficult to identify any correlation between leakage rate and hydraulic head is the error associated with the storage factor in water balance calculations for the time steps required in monthly measurements of leakage as identified by the authors working at the Girgarre basin. For several monthly measurements, water balance calculations at the Girgarre basin resulted in negative leakage rates, which is impossible given that the watertable is permanently beneath the base of the basin. Usually, results for the preceding month and/or the following month were very high. The authors suggested that these monthly errors were probably the result of over- or under-estimation in the storage component of the basin from one monitoring period to the next. Over a period of years, the storage component in water balance calculations is small compared with the other components and hence introduces less error in long term measurements of leakage rate when compared to monthly measurements. If similar problems occurred with measurements at the other sites, it may be very difficult to identify a correlation between leakage rate and hydraulic head using monthly water balance comparisons.

If, as we suggest, leakage rate is highly dependent on the hydraulic head of water, then, in irrigation areas, the leakage rate from basins that are expansion limited will depend on the depth of water in the basin and the depth at which the groundwater is maintained. Unless the watertable is very shallow, variations in the depth of water in the basin will only provide a small change in the overall driving head and therefore leakage rate. In the case of infiltration limited basins, the driving head is basically dependent on the depth of water in the basin and, therfore, relatively speaking, leakage rates are likely to be more dependent on water depth of the basin than for expansion limited basins.

If the leakage rate needs to be minimised, then the amount of water in the basin should be kept to a minimum, particularly for infiltration limited basins. This is not always possible given that the volume of water to be pumped into the basin is dependent on seasonal climatic variations and irrigation requirements. Also, leakage from basins will depend on decisions on watertable control required by the farmer (the greater the depth of watertable control, the greater the pumped volume of water and the greater the leakage). These types of considerations are analysed in Wu *et al.,* (1999) and Christen *et al.*, (1999b).

Conclusion **Results from field monitoring and analytical solutions of this problem generally indicate that the depth of water in the basin may be important for infiltration limited basins and that the head difference between the water in the basin and the watertable is important for expansion limited basins.**

4.3
Soil Chemistry

Most of the soils in the Riverine Plain are sodic. Rengasamy and Olsson (1991) defines sodic soils in Australia as occurring when the adsorption of sodium exceeds 6% of the total cation exchange capacity of the soil (i.e. ESP > 6). Addition of fresh water to sodic soils results in dispersion of the clay in the soil and a general reduction in hydraulic conductivity. Alternatively, the addition of saline water to sodic soils causes the clay to flocculate resulting in an increase in the hydraulic conductivity of the soil.

There have been numerous studies on changing the hydraulic properties of sodic soils by the addition of fresh or saline water (Rengasamy and Olsson; 1991, McIntyre *et al.*, 1982). These were mainly agriculturally based field studies or laboratory studies that assessed the impact of changing infiltration rates in soils following irrigation with water of differing salinity.

More directly related to disposal basins was a small field experiment that measured the effect of sodicity and soil dispersion on preventing seepage from small dams (Rengasamy *et al.*, 1996). They found that, if fresh water was added to trial basins with a sodic soil base and the water/soil was puddled, the basin no longer had any measurable leakage. If saline water was added, the leakage rates were ~7 mm/d. The work by Rengasamy et al (1996), if able to be reproduced on a larger scale, suggests that the salinity of water placed in the basin may have a considerable impact on leakage from a disposal basin. Leakage may be reduced if basins are initially filled with fresh water prior to filling with saline water. If this is the case, it is not known how long the leakage rate will remain low and whether basins filled with more saline water will leak faster than basins filled with fresher water.

To test this, the Girgarre basin was initially filled with fresh water (0.68-1.1 dS/m) and the water stored in the basin for several weeks prior to the introduction of more saline water (18 dS/m). Leakage from the basin was estimated to be ~1.3 mm/d for the first 6 years of operation (1987-1993) with no obvious increase in leakage during that time. In fact, the leakage rate for the basin decreased to ~0.7 mm/d for the following 4 years (1993-1997) of operation of the basin. Hence, in this instance, there is no evidence that the application of fresh groundwater has reduced leakage from the basin. It should be noted however, that, although freshwater was added, the basin water was not puddled as was the case in the smaller field experiment by Rengasamy *et al.*, (1996).

There is also no evidence of an increased rate of leakage for the most saline bay in the basin. The terminal bay has a mean salinity of close to 100 dS/m significantly greater than that in the first two bays (21 and 36 dS/m respectively). In fact for the first 6 years, the leakage in the most saline bay was approximately half that in the other two bays.

From these results, we suggest that although dispersion and flocculation (as a result of the addition of fresh and saline water repectively on sodic soils) have been proven to be important in small scale studies, there is no evidence that this is the case for larger basins. Further tests on using this as a method for reducing leakage from basins should ensure that the basins are not only initially filled with fresh water but that the soils are puddled at the same time.

Conclusion **There is no evidence from the field investigations to suggest that the application high salinity water to sodic soils results in soil flocculation or, if it does, that it results in increased leakage from the basin. There is some suggestion that the alternative may be true in field situations (i.e. the application of freshwater to sodic soils may cause soil dispersion and reduce leakage). There is strong laboratory evidence that the application of fresher water to sodic soils results in soil dispersion and leakage reduction. Hence, it is advisable initially basins are filled with fresh water for a period of several weeks before saline drainage is pumped into the basin.**

4.4
Biological Clogging

Another factor that may result in the reduction of leakage through the base of the basin is the production of polysaccharide material as a result of benthic micro-organisms in the basins. Polysaccharides reduce leakage by clogging the pores between soil particles. Disposal basins provide an ideal environment for algal growth and polysaccharide production because the waters are usually clear and shallow (allowing light penetration), have reasonably high concentrations of nutrients (for growth) and the waters are stationary allowing the algal material to deposit on the base of the basin.

In 1994, Ragusa *et al.* conducted laboratory experiments to measure the reduction in hydraulic conductivity as a result of polysaccharide production and made some field measurements on polysaccharide concentrations for sediment in irrigation channels. Their main aim was to determine whether clogging from polysaccharides as a result of algal seeding could help reduce leakage from irrigation channels. In the laboratory experiments, the hydraulic conductivity of a fine sandy loam reduced from ~3 x 10^{-7} m/s (~26 mm/d) to ~1.5 – 3.0 x 10^{-8} m/s (~1.3 – 2.6 mm/d) over a one month period following algal seeding. Results suggested that the hydraulic conductivity would have reduced further had the experiment continued beyond one month. The final polysaccharide concentrations in the soil ranged from 2.6 to 3.4 mg polysaccharide/g dry soil.

Leaney and Christen (2000) measured the polysaccharide concentration of sediment in the soil at the base of the bays at the Girgarre and Nehme (Griffith) basins and from soil at defunct basins at Pyramid Hill. For basins that are still operational, the polysaccharide concentrations from the base of the basin to a depth of ~10 cm ranged from ~4 to 10 times than that found in irrigation channels and, in many cases, was greater than the concentrations measured in the laboratory experiments. For the defunct basins, no samples were collected at depths less than 10 cm. At depths greater than ~20 cm, the polysaccharide concentrations were usually less than those measured in the laboratory experiments and from the sediment in the irrigation channels. The hydraulic conductivity measured in the laboratory experiments by Ragusa *et al*. (1994) following algal seeding are similar to the leakage rates observed at the Girgarre and Nehme Basins.

Leaney and Christen (2000) also noted that leakage rates, measured using seepage meters, were considerably greater if the layer of sludge and top soil was removed compared to leakage rates when the sludge was intact. The sludge and layer of top soil have concentrations of polysaccharides similar to those observed in the laboratory experiment by Ragusa *et al.* (1994). Another observation that supports the importance of algal clogging in reducing the hydraulic conductivity of the soil is that, at the Girgarre basin, leakage rates tend to decrease as the basin ages. One would expect that algal clogging would have a cumulative effect on leakage although whether this would be over a time frame of 10 years is uncertain.

Hence, at Girgarre, polysaccharide material is found at concentrations that have been observed to reduce leakage rates and at or near to the sludge/soil interface (i.e. the depth at which leakage from the basin is throttled). When these results are considered together, there is reasonable evidence to suggest that, at least at the Girgarre basin, algal clogging is an important factor in reducing leakage rates. The Girgarre basin is the only basin that has been shown to have unsaturated flow beneath it although, for some of the basins, there has been insufficient work to prove whether or not an unsaturated zone exists. Hence, the throttle to leakage is associated with factors affecting hydraulic conductivity at the base of the basin. Many of the other basins studied do not remain permanently filled. Polysaccharides continue to decompose after deposition and need to be replaced. This process would be disrupted if the basin were dry for any length of time.

Conclusion **There is strong evidence from small scale field experiments that polysaccharide production, a product of algal activity in basins, reduces infiltration. Disposal basins are an ideal environment for this to occur providing the basins have a permanent water cover. Therefore, we suggest that basin floors should remain covered with water to promote the production and prevent the decomposition of polysaccharide material in basins.**

4.5 Preferential Flow Paths

Preferential leakage from disposal basins occurs whenever there is a mechanism by which water can flow faster than the general flow through the soil matrix below the basin. There are numerous mechanisms by which, and spatial scales, at which, this may take place. These include preferential flow through lighter soils, enhanced leakage in areas of biological activity, and density induced flow (e.g. for hyper-saline basins).

There are a few observations to suggest that increased leakage is occurring in parts of existing basins as a result of the preferential leakage through lighter soils (e.g. through shoestring sands at or close to the basin). At Pyramid Hill, it was noted that the discharge to the interception drain and capillary rise was much more noticeable on the northern and western sides of the basin. However, this component of preferential leakage was estimated to represent only a small percentage of the overall leakage from the basin and they could not confirm that the areas in question were the result of preferential leakage or some other process. The same was also found for the Wakool basin.

In the Nehme and Girgarre basins, the results of leakage tests using seepage meters suggested very variable rates of leakage across the basin (Leaney and Christen, 2000). The reasons for this are not clear. Particle size analysis at various positions found that a high leakage infiltrometer had about 10% less clay (40% compared to 50%) than at the other positions, and that this was accompanied by a 10% increase in sand. Whether this small reduction in clay content would be responsible for an order of magnitude increase in leakage is uncertain. Also at the Nehme basin, there was a six-fold difference in apparent conductivity (from EM38 measurements) across the basin (Leaney and Christen, 2000). They suggested that this could be reflecting variation in leakage across the basin, with lower apparent conductivity indicating higher leakage but acknowledged that other factors may have also caused this variation.

The above discussion gives examples of preferential, shallow leakage. There are also examples where preferential flow has resulted in leakage reaching deeper aquifers sooner than expected. At the Girgarre basin, the average "whole of basin" leakage for the life of the basin was estimated to be about 1.3 mm/d. Soilwater chloride analyses on samples from soil cores suggested little evidence that saline leakage from the basin had extended beyond a depth of a few metres beneath the basin (Leaney and Christen, 2000). This was also reflected in the results from down-hole EM39 profiles which showed that, at most sites, the apparent conductivity at depths between ~ 2 and 10 m did not change during the life of the basin.

However, results from monitoring groundwater bores around the basin have shown that the groundwater salinity, at a depth of ~15 m beneath the basin, the depth of the shoestring sand aquifer, started to rise approximately 6 - 12 years after the commissioning of the basin. The apparent conductivity in the shoestring sand, as reflected in EM39 measurements, also rose at that time.

Clearly, there is considerable by-pass flow taking place. Leaney and Christen (2000) suggested that, as much as 80% of the soil matrix, may be by-passed or only partially involved in the leakage process.

Any preferential flow paths that by-pass the zone of minimum hydraulic conductivity (throttle) will result in increased leakage. If the throttle is at the base of the basin, then it is important to make sure that the soil does not crack and that biological activity is kept to a minimum. Because of the high salinity levels, most basins do not support large biota and hence these are considered a minor problem. However, if the basin is allowed to dry there is the potential for cracking and preferential flow when filled. For this reason, we recommend that the base of the basin be permanently covered with water.

The potential for preferential flow for leakage away from the basin clearly will have implications on the development of the leakage plume around the basin and the potential for detrimental off-site effects. This is discussed in the next chapter.

Conclusion **There is considerable evidence that the spatial variation in leakage from both infiltration and expansion limited basins is highly variable. The spatial variation at the base of basins due to soil cracking can be kept to a minimum if the basins are not allowed to dry.**

4.6
Summary of Factors Affecting Leakage from Disposal Basins

In this chapter, several factors were identified that may result in throttling of leakage at the base of the basin. Of these, there was evidence that soil compaction and algal clogging may reduce the hydraulic conductivity near the base of the basin, as found at Girgarre. While basins should be sited on heavier textured soils, the occurrence of soils with high clay content alone did not appear to provide a reliable throttle to leakage (without compaction or algal clogging).

There was insufficient evidence from the field studies at the Girgarre basin to determine conclusively whether or not dispersion of soil following the addition of fresh water to sodic soils may reduce hydraulic conductivity at the basin scale. From our work, it seems unlikely that the reverse will happen (i.e. that the addition of saline water will result in increased hydraulic conductivity and increased leakage). There is, however, considerable evidence from laboratory based studies to support at least the former of these sodicity related issues (i.e. decreased infiltration following the application of fresh water to sodic soils). Given that, under most conditions, it will be deemed necessary to reduce leakage from basins, we suggest that basins are initially filled with fresh water and the water maintained for a several weeks prior to the application of more saline water.

The question must also be asked as to why leakage at the Girgarre basin is throttled at the base of the basin while leakage for larger and smaller basins in the Riverine Plain is determined by how fast the mound beneath the basin can dissipate. The reason must be that vertical leakage beneath the basin is, for some reason, sufficiently greater than leakage determined by the throttle at the base of the basin. This may be because groundwater pumping has enhanced vertical flow beneath the basin or that the treatment at the base of the Girgarre basin to reduce leakage (compaction, initial filling with fresh water, development of algal clogging) has had the desired effect.

5. The Leakage Plume

In the previous chapter, we suggested likely disposal capacities for basins in the Riverine Plain. Potential disposal capacity, and to a lesser extent, design disposal capacity, is largely dependent on the rate of leakage from the basin. Basins should only be placed in areas where negative impacts around the basin are minimal and accepted by the community. Hence, there will be an associated "tolerable" leakage rate for basins in certain areas. Leakage results in salinisation of the unsaturated zone beneath the basin (if such a zone exists) and the groundwater around and beneath the basin. The way in which leakage translates to salinisation will depend on factors such as the relative components of shallow lateral leakage and deep vertical leakage and whether flow is piston type or whether there is a component of preferential flow.

The principles for siting and design of disposal basins in the Riverine Plain (Christen *et al.*, 1999a) state that there should be no contamination of groundwater outside the drainage area of the farm or community of farms using the basin. Information provided in this chapter is aimed at providing information on leakage processes from basins that will assist water managers to determine what leakage rate is tolerable for a particular area. As discussed previously, although zero leakage may be an option in some cases, we believe that, for most situations, it is not economical to design basins so that they do not leak.

5.1
Previous Work

Most of the previous work for basins in the Riverine Plain has attempted to trace the lateral movement of leakage by sampling the soil and/or groundwater around the basin and analysing for chemical (higher salinity) or isotopic indicators of leakage. Unfortunately, most of the studies only ran for a year or two and the results were usually inconclusive because of the limited leakage that had occurred during that time and the inappropriate spacing of sampling points outside the basin.

The exceptions to this are at Girgarre, where bore salinity and EM39 measurements were measured at three monthly intervals for 10-15 years after the commissioning of the basin, and at the newly constructed basin (Nehmi's) near Griffith, where shallow groundwater samples were collected every few metres in a lateral transect from the basin. A summary of the conclusions from these field studies (Leaney and Christen, 2000) follow.

At the Girgarre Basin:

- Leakage is "infiltration limited". There is an unsaturated zone beneath the basin for most of the year.
- Leakage moves by piston flow through the unsaturated zone and into the top metre or two of the groundwater beneath the basin.
- Much of the leakage water has remained within the top few metres of the watertable and has spread laterally a short distance within this depth zone possibly enhanced by watertable fluctuations.
- Vertical leakage (~30 - 80% of the total leakage) by passes most of the soil matrix beneath the basin and then progresses towards the groundwater pumps.
- The interception drain intercepts little if any leakage (<8%).

Hence, at the Girgarre basin, maybe 50% of the saline leakage water has remained close to the watertable and immediately beneath the basin. However, the leakage that has progressed beyond this zone has reached the shoestring aquifer quicker than expected if piston flow was assumed. In other words, because of preferential flow paths, the lag time for salinisation of deeper aquifers is much shorter than otherwise expected. Also, because leakage from the basin is infiltration limited, and there is little (if any) evidence of a groundwater mound beneath the basin, the interception drain is not operating to intercept leakage. The drain probably intercepts groundwater during periods when regional recharge in the area causes water levels to rise. The salinity of the intercepted water is quite fresh and unlikely to be leakage from the basin.

At the Nehme Basin:

- Leakage from the basin was very high immediately after filling until the soil beneath the basin became saturated.
- There is evidence of leakage water moving laterally from the basin at the surface of the watertable for a distance of close to 20 m after the first year of operation.
- Lateral movement is not via piston flow. Diffusion and mixing of leakage with existing groundwater results in an extensive "mixing zone" extending from the basin, Figure 19.

Nehme basin is behaving similarly to many basins in the Riverine Plain. Although initially unsaturated beneath the basin, high rates of leakage quickly resulted in the soil becoming saturated and a subsequent decrease in leakage rates. Once saturated conditions were established, the leakage was basically "expansion limited" with a significant component of leakage reaching beyond the interception channel close to the top of the watertable.

The lateral movement is likely to be rapid (20 m in one year for Nehme basin) but not via piston flow. In the case of the Nehme basin, and other basins with tile drainage, this component is likely to be intercepted, at least in part, by the subsurface drainage system in the farm area.

Water balance calculations for the basin and the interception channel suggests that ~50% of the leakage is not intercepted by the drain around the basin. For other basins in the Riverine Plain (excepting the Girgarre Basin), the interception drain intercepts from 25 – 80% of the leakage. In the early stages (possibly the first year), the salinity of the intercepted water is likely to be less than the water in the basin due to the lag-time for leakage to reach the drain and mixing with existing soilwater and groundwater. In subsequent years, the intercepted water will have salinity levels similar to the water in the basin.

Despite the considerable differences in the mechanism controlling leakage at the Girgarre Basin and Nehme Basin and the duration of operation, there are similarities in the leakage plume from the basins. For both basins, the highest salinity occurs in the top metre or so of groundwater (or soilwater and groundwater at the Girgarre basin) beneath the basin. This is the only place where piston flow, or flow close to piston flow, is observed.

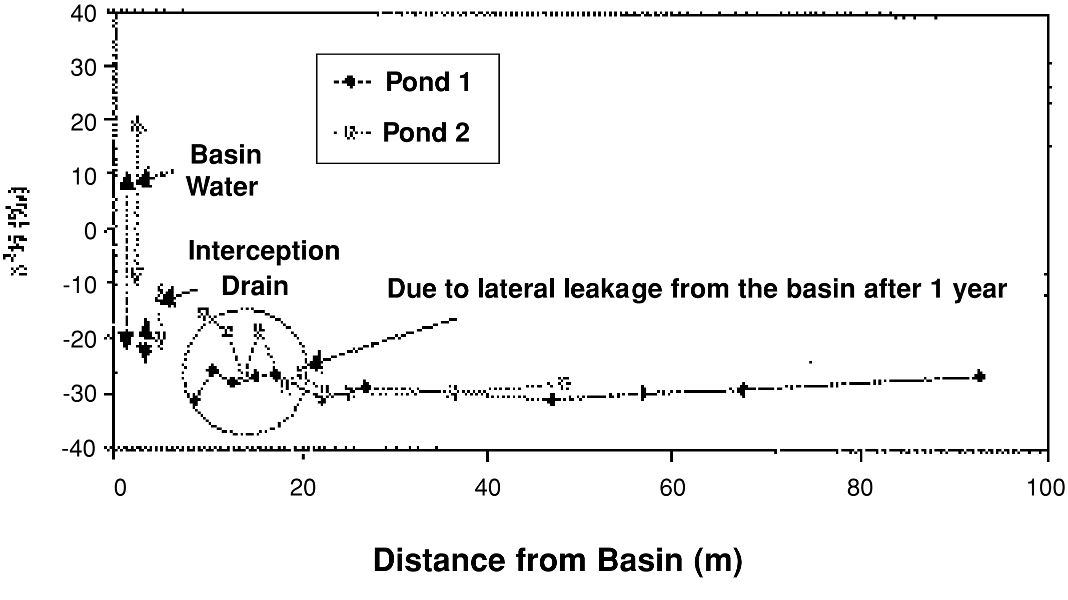


Figure 19. ^{2}H composition of shallow groundwater transect at Nehme basin

Water in the basin is enriched in ^{2}H compared to that in the local groundwater (i.e. at distances >20 m from the basin). There is evidence from the enriched ^{2}H signature in the shallow groundwater at distances up to 20 m from the basin (shown in circle) that a component of leakage from the basin passes beyond the interception drain.

At both sites, a component of the saline leakage plume moves laterally from the basin relatively quickly resulting in an increase in the salinity of the groundwater close to the watertable. The lateral spread occurs much faster than one would expect if piston flow is assumed. The leakage mixes and diffuses with existing groundwater, resulting in lower groundwater salinity than would otherwise be the case (Figure 20).

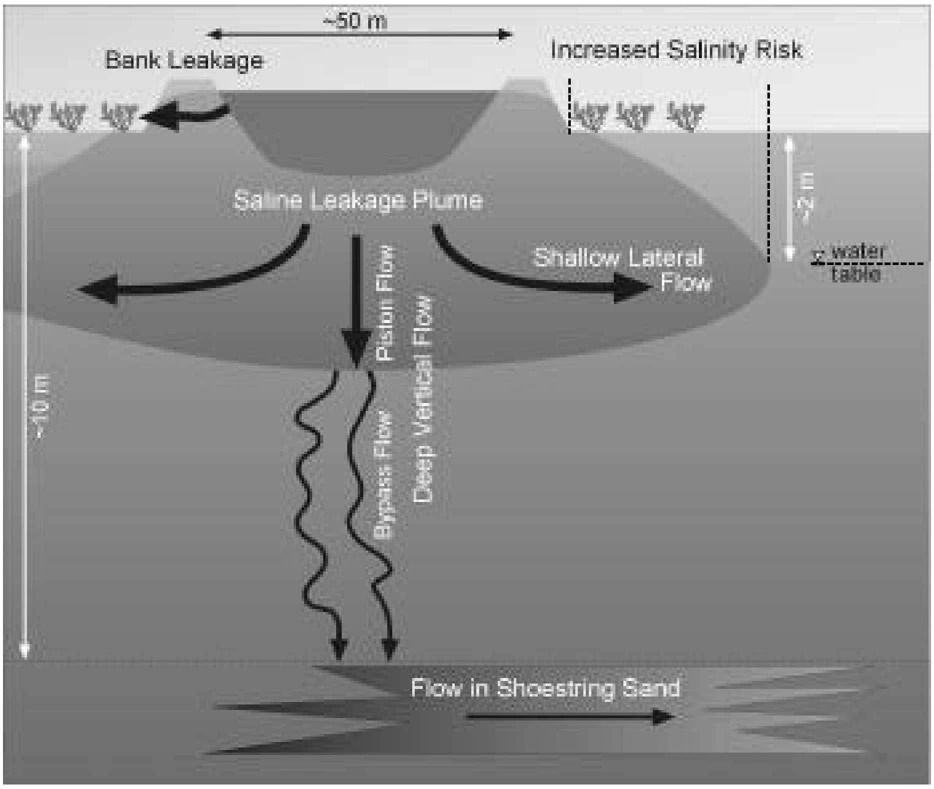


Figure 20. Schematic of the generalised leakage plume beneath a disposal basin.

In general, the most saline groundwater (and soilwater if an unsaturated zone is present) is located immediately beneath the basin. The plume is ellipsoid and only a few metres thick. The lateral progression beyond the basin is greater for basins where leakage is expansion limited compared to those where leakage is infiltration limited. Vertical flow to aquifers of higher hydraulic conductivity is primarily via preferential flow.

Further evidence that lateral flow from disposal basins may exceed vertical flow for basins in the Riverine Plain where leakage is expansion limited is seen from the relationship between the leakage rate (mm/d) and the area of the basin. As discussed earlier (Chapter 2), the relationship seen, (Leakage rate (mm/d) = 5.36 x $A^{-0.51}$) is consistent with leakage being confined to predominantly lateral flow by an impermeable layer at a reasonably shallow depth beneath the basin (i.e. Leakage rate (mm/d) μ $A^{-0.5}$).

There is evidence of a smaller component of flow reaching aquifers of higher conductivity (eg shoestring aquifers), particularly if watertable control is via groundwater pumping. Although this component is considerably smaller than the lateral flow (particularly when leakage is expansion limited), it may become apparent earlier than anticipated because much of the heavier textured soils is bypassed.

5.2

Summary of the Development of Leakage Plumes Under Disposal Basins

Evidence gained from studies of disposal basins in the Riverine Plain suggests that, in the initial stages following filling of a basin, leakage from disposal basins obey hydrological rules that are intuitively obvious. Providing there are no impediments to flow, the initial leakage from basins will be predominantly vertical and the unsaturated zone will gradually fill with water. These basins are termed, "expansion limited" as discussed in the first chapter of this report.

If the unsaturated zone is deep, initial leakage rates will be high. In most irrigation areas in the Riverine Plain, a deep unsaturated zone is the exception rather than the rule. However, as we found at the Nehme site, if a basin is sited in an area with deep clay soil that has not previously been used for irrigation, the watertables may be much deeper than those in nearby irrigation areas (even if the irrigated areas with shallow watertables are less than 20 m away).

For expansion limited basins, once the unsaturated zone beneath the basin is filled, leakage is predominantly controlled by the spread of the groundwater mound and hence leakage rates slow down. Movement of leakage is predominantly lateral for all of the basins studied except the Girgarre Basin. Piston type flow is confined to a 1-3 m zone immediately beneath the basin. Leakage extends laterally via diffusion, mixing with existing groundwater and possibly preferential pathways.

As a result of this, there is likely to be evidence of leakage water moving considerable further laterally than expected using piston flow calculations. This movement is beyond the interception drain with interception drains intercepting an average of 50% of the leakage. The remaining 50% needs to be collected and recycled to ensure there are no detrimental off site effects from leakage from the disposal basin. Basins sited within the drainage system have the best possibility for interception and hence, containment of the saline leakage. Basins sited on the edge or away from the drainage system run the risk of not containing the saline leakage, which may migrate to neighbouring farms and to surface water features. For infiltration limited basins, such as the Girgarre basin, lateral leakage is less apparent and interception drains less efficient.

There is evidence from studies at the Girgarre basin for a component of vertical flow to by-pass much of the soil beneath the basin. The component of deep vertical leakage was estimated to be approximately 30-80% of the overall leakage at the Girgarre basin. It is anticipated that, in areas where watertable control is via groundwater pumping, vertical flow will be induced more than in areas where groundwater control is via near surface tile drains. Unfortunately, there have been no long-term monitoring programs in place in tile drain areas to support this. It is possible that vertical leakage may also be enhanced in hyper-saline basins as a result of density induced flow (Simmons and Naryan, 1996). For reasons explained previously, these are usually large regional basins with low rates for overall leakage and are not the main focus of this report.

For basins that are treated to reduce the hydraulic conductivity at the base of the basin, leakage from the basin may be infiltration limited. For these basins, the leakage rate will be lower and there will probably be less evidence of a groundwater mound beneath the basin. If this is the case, the interception drain will probably not intercept a lot of leakage from the basin. Hence, the costs incurred in compaction of soil at the base of the basin to reduce leakage will probably be slightly offset by lesser pumping costs for recycling water from the interception drain to the basin. We recommend the use of interception drains for all basins and interception drains and soil compaction for all small basins.

6. Conclusions

Most of the basins in the Riverine Plain are *"expansion limited",* because the rate at which water can leak from the basin is determined by the hydraulics associated with expansion of the leakage plume. Only one basin studied, Girgarre was *"infiltration limited"* (i.e. leakage is determined by hydraulic conductivity at the base of the basin and the infiltration rate through the basin base).

As a result of these investigations into the operation of disposal basins in the Riverine Plain, we suggest that it is technically feasible to use on-farm and community basins for the disposal of saline drainage while also ensuring that detrimental off-site effects are kept to a minimum. In order to do this, there will always be a balance between maximising the disposal capacity while minimising the off-site detrimental effects in the design of basins. This balance will primarily be decided by the amount of leakage from the basin. If leakage is prevented, then the disposal capacity of the basin, under most situations, will decrease markedly; the cost of disposal will rise accordingly. We suggest that effective leakage rates of 0.5-1.0 mm/d are desirable and achievable for most basins in the Riverine Plain for this balance.

In order to achieve the desired leakage rates of 0.5 – 1.0 mm/d, it may be necessary to design, treat and manage some basins to reduce the effective leakage. The most effective way of reducing effective leakage, particularly for small basins is by using interception drains. We recommend the use of interception drains for all basins in the Riverine Plain. For all basins, we recommend compaction of soil used when constructing the sides of basins. For smaller basins, we also suggest that the soil at the base and sides of basins is compacted.

The main purpose of disposal basins is to dispose of saline water and store salt in, around and under the basin. For basins to function optimally, the basins need to evaporate as much water as possible. Basins that are empty do not evaporate water and develop preferential leakage pathways. We recommend that disposal basins are managed such that the floors of the basin are always covered with water.

A prerequisite, when determining the required size of a basin for a farm or a group of farms, is the *disposal capacity* (i.e. the amount of water that can be disposed into the basin). We recommend the use of the design disposal capacity, when determining the farm area. The *design disposal capacity* assumes that a volume of water, equivalent to that of leakage, is intercepted and recycled into the basin. For basins that are expansion limited, the best way to intercept leakage is by the use of an appropriately designed and managed interception drain. The interception drain, plus the farm or community subsurface drainage system, provides the infrastructure to ensure containment of saline leakage over a time frame of several decades. For basins that are infiltration limited, interception drains are less efficient and interception is via the subsurface drainage system.

Whether or not the use of disposal basins to dispose of saline drainage will be economically viable has not been addressed in this report although the results from this study will provide prerequisite information for these economic decisions.

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Appendix 1. Estimating Leakage From Disposal Basins in the Riverine Plain

Methods

Whole of Basin Estimates (Water and Chloride Balance Approaches)

By far the most common method used to estimate leakage is a simple water balance. Estimation of leakage, L, using water balance calculations has been made for several evaporation basins in the Riverine Plain. Estimation of leakage using the water balance of a basin involves estimating input to the basin by measuring the amount of water pumped into the basin, P, and that entering as rainfall, R. This is balanced with output from the basin that consists of evaporation, E, and leakage, L, and with the change in basin volume, DV. Mean leakage rate is estimated for the time period of the water balance.

Evaporation is estimated from pan evaporation, either measured on site or at the nearest suitably equipped meteorological station. Conversion of pan evaporation data to that for the basin involves calculating a pan factor. There are several approaches available to estimate the pan factor depending on the availability of data such as humidity, water temperature, wind speed. In general, the average pan factor reduces from near unity for very small (< 2 ha) to ~0.8 for large regional basins. Leakage is determined for any time interval using the equation

$$L = R + P + \quad V - E \qquad [8]$$

The major difficulty in using the water balance as the only method of measuring leakage is that an error in any of the parameters will result in an error of equal magnitude in the leakage estimate. This is not a major problem if leakage is a large component of the water balance but, as the method is a difference method, the error becomes proportionally larger as leakage decreases.

A possible way of minimising the error in leakage estimation using a water balance approach is to conduct the water balance experiment at night. The advantage with this method is that the evaporation component of the equation is close to zero and, if there is no input into the basin, the change in volume of the basin is theoretically equal to leakage. Unfortunately, because the experiment is conducted overnight, very precise estimates of the volume change in the basin need to be made. Also, if there is a small amount of evaporation during the night, it will result in a large error in leakage estimation. Hence, as per longer term measurements of water balance, this method is more suitable to basins with high leakage rates.

Another method for estimation of leakage from a basin is by using a salt (or preferably chloride) mass balance. Prior to this study, it had not been used in any of the studies on disposal basins in the Riverine Plain despite its relative simplicity and advantages when compared to the methods above. It should be used in conjunction with water balance calculations as it allows a semi-independent estimate of leakage to be made. A description of the method and example of its use is given in Leaney and Christen (2000).

As discussed in the appendix, the overall amount of chloride entering the basin (predominantly as input from pumped saline water) must balance the amount of chloride in the basin and that present in the leakage water. If it does not, there is a problem with the input data or the leakage estimate from the water balance.

Leakage rates from individual bays can be estimated if temporal data is available for changes in bay salinity for the life of the basin. This method was used at the Girgarre basin as discussed in the following section.

Tracking basin water salinity compared with the drainage water salinity provides another gross measure of leakage. This works best over long periods when there is little change in storage. The salinity of the pumped and basin waters need to be regularly monitored over the selected period. The average pond salinity for that period is divided by the salinity of the drainage water to give the concentration factor. The average daily net evaporation (evaporation minus rainfall) is calculated for the same period. Dividing this by the concentration factor gives the leakage rate over that time. This very simple procedure can give a relatively accurate assessment of leakage rates. In overall terms for basins in the Riverine plain this procedure can be used as a check of probable leakage rates and is a fundamental method in tracking long term changes in basin behaviour. Also importantly basin leakage can be modelled.

Point Estimates (Tracer Techniques, Seepage Meters)

The above methods determine leakage from the basin as a whole. Other methods have been used to determine leakage rate at a particular location in the basin. These so called "point estimates" include tracer techniques to identify how far leakage has moved from the basin and water loss from a small area in the basin using leakage meters such as the "Idaho leakage meter".

The best natural tracer to use is the chloride ion because it is conservative and usually only present in low concentrations in soils (except as halite in discharge areas). When water is ponding, and thus evaporating (as in an disposal basin), the water which remains in the basin will be highly concentrated in most salts including chloride. The chloride concentration of the water leaking from the basin will reflect the concentration in the basin.

One method to determine the chloride concentration in the leakage water is to sample soil beneath the basin and determine the soil-water chloride concentration at discrete depths below the basin floor. From the profile obtained by plotting the soil water chloride concentration as a function of depth, it is possible to recognise how far the water from the evaporating pond has travelled in the unsaturated zone or in the saturated zone.

If we assume piston flow occurs, the amount of water in the soil and groundwater to the depth where chloride concentrations change from high (representing leakage) to low (representing original water) is approximately the amount of water that has leaked since the basin was commissioned. The estimate may not be correct if watertable fluctuations cause the soil-water to disperse or in situations when the horizontal conductivity exceeds the vertical conductivity and causes the leakage water to move laterally.

Seepage meters consist of a solid tube tapped into the soil at the base of the basin. The tube extends out of the water for the conventional seepage meter and attaches to a bladder for the Idahoe seepage meter. The aim is to ensure that the water in the tube is kept at the same pressure as the water in the basin to ensure there is no additional head of water increasing leakage from the tube beyond that of the basin. Evaporation from the tube is negligible for both types of leakage meter. The amount of water lost from the tube (conventional) or by the bladder (Idaho type meter) for any time period is equal to leakage over the area of the pipe.

The greatest difficulty with using leakage meters is ensuring that the tube seals well with the soil without compacting it. This plus other problems, such as blockages or puncturing of the bladders are technically achievable if care is taken. Using point source estimates of leakage allows an evaluation of the spatial variability but there are rarely enough measurements to get an overall estimate of leakage from the basin.

Previous Studies and Results

Estimating leakage from disposal basins is difficult. This is especially the case for larger and opportunistically located basins that may have considerable temporal changes in size and limited inflow data. As a result, many of the previous studies have used a combination of whole of basin and point estimates for leakage. In the following discussion, we summarise these studies commencing at the largest basins and progressing to the on-farm basins in the Riverine Plain.

Wakool

The Wakool disposal basin is a constructed basin consisting of several individual bays (total area 2,100 ha) which receives saline drainage water from the Wakool/Tullakool subsurface drainage scheme. The leakage study was conducted during a 6 day period in late 1988 in Bay 13 of stage 1 of the basin (White and Denmead, 1989). Seepage measurements using floating capillary scale seepage meters were less than 0.1 mm/d. Leakage estimates from water balance studies were less than 0.2 mm/d.

The study appeared to have numerous practical difficulties stemming from the fact that leakage is such a small fraction of the overall water balance and the experiment was conducted over a short period of time. A major source of error is the determination of a pan factor to convert potential to actual evaporation from the basin. Nevertheless, the results from the whole of bay and the point estimates are consistent and clearly suggest low estimates of leakage for this bay in the Wakool basin.

Girgarre

The Girgarre basin is a 30 ha community basin located near the township of Girgarre in the Shepparton Irrigation Region (SIR). It was one of the first constructed basins and, apart from the practical reasons for its development, it was to be used as a demonstration basin. Hence, following the commissioning of the basin, a long-term monitoring and field investigation program was established so that maximum information could be gained as to whether or not such basins were a long-term method of salt storage in the area.

Leakage estimates were made using water balance techniques for the period from 1987 to 1994. Considerable care and effort was taken to ensure that the components of the water balance were measured as accurately as possible. This included regular calibration of the volumes of water pumped into the basin and the installation of on site evaporation pans. Pan factors (PCF #'s) were calculated monthly and ranged from ~0.7 to ~0.9 (mean 0.8). The mean estimated leakage for the monitoring period was 1.8 mm/d. However, monthly leakage rates ranged from negative values to 8 mm/d. The authors believe that this was due mainly to difficulties in measuring the storage change (V component) and that while month to month estimates may be in error, the estimated overall leakage rate would be close to the correct value.

As part of this current project, leakage was measured using a chloride balance for each of the individual bays. Results from this study suggested that leakage for the first and second bays (Bays A and B) was 1.5 mm/d from 1987 to early 1993 and 0.7 mm/d from early 1993 to 1999 (Leaney and Christen, 2000). The reduction in leakage rate at this time is consistent with estimates using water balance calculations alone. Leakage from the terminal bay (Bay C) was constant at 0.7 mm/d from 1987 to 1999.

Overall, for the period 1987 to 1994, the mean leakage rate estimated using a chloride mass balance for the basin was ~1.3 mm/d, approximately 40 % less than that suggested using the water balance alone. The reasons why the leakage rate decreased after 1993 in the first two bays is not clear. It was observed that a failure with the pumping system at this stage resulted in all bays approaching dryness. However, why this should result in a reduction in leakage for the next 5 years to values close to those seen in Bay C is not known.

Point estimates of leakage were made using chloride concentrations and deuterium (^{2}H) concentrations of basin water as tracers of leakage into the soil-water and groundwater beneath the basin (Leaney and Christen, 2000). Using these methods, the point estimates of leakage range from 0.1 to 0.5 mm/d. These estimates are 60-85% less than leakage calculated from whole of basin studies.

Point estimates of leakage were also made in all of the bays using seepage meters installed for periods of approximately three months (Leaney and Christen, 2000). Seepage metres were installed directly into the soil (sludge) or were installed after removal of the black sediment at the bottom of the basin (no sludge). Seepage measurements for sites with the sludge present ranged from 0.0 to 2.6 mm/d (average 0.5 mm/d). These were considerably less than leakage measurements when the sludge was removed (0.0 to 11.3, average = 3.8 mm/d).

The mean value for the seepage measurements (0.5 mm/d) agrees with the estimate for whole of basin leakage using the chloride mass balance approach for the corresponding time period (0.7 mm/d). However, given the limited number of valid measurements, this is more likely the result of good fortune than a statistically sound observation.

In addition to the longer term field monitoring of the large bays, one month tests were conducted on the individual bays and several smaller trial bays (~0.04 ha) in August/September for the years 1988 - 1994 (excluding 1993). Flow between the bays was stopped during the trial and leakage estimated from water balance calculations. Treatment for the bays and trial bays was as follows:

Bay A	untreated (natural vegetation and existing pasture)
Bay B	ripped and compacted 'A' horizon (topsoil stripped and removed)
Bay C	ripped and compacted 'B' horizon (topsoil and 'A' horizon stripped and removed)
Bay T1	salt crust attempted by filling/drying cycle (not successful)
Bay T2	compacted 'B' horizon (as for Bay C)

Bay T3	compacted 'A' horizon (as for Bay B)
Bay T4	control no treatment (as for Bay A)
Bay T5	woven plastic lining
Bay T6	bentonite clay liningsurface stripped before 5 mm thick blanket added (then covered with topsoil.
Bay T7	compacted 'A' horizon (as per bays T3 and B)
Bay T8	plastic lining (0.5 mm PVC sheet)

Results for the one month leakage estimates were are shown in the Table 6 .

Table 6 Leakage estimates for trial bays at the Girgarre Basin (Goulburn-Murray Water and Sinclair Knight Merz,1995)

	Leakage Rates (mm/d)						
Bay	**1988**	**1989**	**1990**	**1991**	**1992**	**1994**	**Average**
A	1.82	3.42	3.6	n.m	1.84	0.93	2.32
B	0.47	1.31	1.11	n.m	-0.34	-0.14	0.48
C	0.04	-0.04	-0.05	n.m	-0.39	-0.39	-0.17
T1	0.86	1.38	0.71	0.4	0.41	0.22	0.66
T2	0.61	0.96	0.68	0.28	0.46	0.25	0.54
T3	0.56	0.7	0.37	0.24	0.32	-0.07	0.35
T4	0.78	2.64	0.76	0.89	1.7	0.48	1.21
T5	0.75	0.42	0.37	0.07	0.32	-0.29	0.27
T6	0.71	1.08	1.65	0.39	0.42	0.20	0.74
T7	n.c	n.c	0.63	0.06	0.56	0.19	0.36
T8	n.c	n.c	-0.23	-0.46	-0.47	-0.44	-0.4

n.c. not constructed till 1990 n.m not measured in 1991

There is clearly a significant range in the leakage estimates from year to year with leakage estimates as low as –0.5 mm/d (suggesting that the basin is gaining rather than losing water). The range in values is probably due to the limitations in the water balance method for leakage estimation (negative values suggest there may be a bias to low values). Nevertheless, there is evidence from this data that compacting either of the A or B horizons (Bays B, T3, T7, C and T2) reduces leakage rates significantly when compared to no pretreatment (Bays A and T4). Plastic lining (or to a lesser extent Fabricon lining) reduces leakage rates to basically zero although this is dependent on maintaining the integrity of the barriers. From this data, the use of Bentonite lining is less efficient at reducing leakage than compaction of the soil. There is also a trend towards lower rates of leakage as the basin ages. This is particularly obvious from the 1994 leakage estimates.

Lake Ranfurly

Lake Ranfurly commenced operation as a disposal basin in 1980. It has been divided into two "bays" called Lake Ranfurly West (the larger and more saline) and Lake Ranfurly East (smaller and fresher). Originally, the lake was to be used as a balancing storage by reducing peak outflow rates (and hence pipe costs for disposal to the Wargan basin). However, high salinity levels in the west bay meant that the water was too saline to be transported by pipe to the Wargan basin.

Lake Ranfurly is not sited on the Riverine Plain but has a layer of clay (~3m thick) between the basin and the Parilla Sands aquifer. Leakage from Lake Ranfurly was estimated at 1.4 mm/d using a water and salt balance method similar to that described in this paper (Dyer, 1991). However, difficulties with the estimation of some of the input parameters limited the reliability of this value. Naryan and Armstrong (1995) used a value of 1.2 mm/d when modelling flow from the basin (including a density induced flow component).

Cohuna

This study was conducted from 1974 to 1977 on a newly constructed 3.3 ha basin placed in a depression approximately 9 km from Cohuna in Victoria (Girdwood, 1978). Saline groundwater was pumped into the basin from a pump located ~ 800 m from the basin. Leakage was measured using a water balance with pan evaporation measured at the site using a floating pan to equilibrate pan water temperature with that in the basin. A constant value of 0.75 was used for the pan factor to convert pan evaporation to evaporation from open water. In hindsite, this value may have been too low and a more appropriate value may have been about 0.9.

Depending on the value used for the pan factor, leakage from the basin is probably between 3 and 3.5 mm/d. Approximately 25% of the leakage was intercepted in the 0.4 m deep interception drain placed several metres outside the basin. The depth of water in the basin ranged from 0.3 to 0.9 m throughout the study. The authors found that leakage increased markedly at depths greater than 0.7 m. This may be the result of the additional head of water or alternatively may reflects problems with soil compaction near the top of the basin walls.

Pyramid Hill

The Pyramid Hill tile drain and disposal basin complex was set up ~10 km west of the township of Pyramid Hill in the Tragowel Plains (McConnachy, 1991). It was established as a trial facility by Goulburn-Murray Water to study the effectiveness of sub-surface drains to lower the watertable and increase crop production and to study the effectiveness of evaporation basins for disposing of saline water in an environmentally sensitive manner.

The experiment was conducted from November, 1992 to August, 1993 when it was stopped because of technical difficulties in providing enough water to keep the basin filled. The mean leakage rates during this time, as determined from water balance calculations, was 5.1 mm/d. However, the authors point out that these estimates are very approximate given the short term operation of the basin and difficulties in measuring evaporation from the basin. As with the Cohuna study, ~25% of the leakage was intercepted by the interception drain around the basin.

On-farm basins in the MIA

Nehme basin

This basin was on a 50 ha vineyard in the MIA, 30 km north of Griffith. It was a newly constructed triangular 2 ha evaporation basin split into two bays. The vineyard was established in 1994 after previously being used to grow rice up until 1989, and vegetables until 1994. This site was chosen because the newly constructed evaporation basin enabled measurement of initial soil and hydraulic conditions under the basin, and initial rates of infiltration.

The farm was flood-irrigated using broad based furrows. Irrigation occurred around every 12 to 18 days and took 2 to 3 days to complete. Subsurface pipe drainage using 100 mm corrugated pipe with gravel envelope was installed with lateral drain lines 1.8 m deep at 36 m spacing with a sealed collector main running to the sump. All subsurface drainage was pumped from the sump into the evaporation basin.

The evaporation basin was an above ground construction consisting of 2 bays of 1.07 and 1.04 ha, with a maximum capacity of 10.8 ML and 10.4 ML respectively. Drainage water was pumped into the first bay via a 150 mm PVC pipe from the pump, and overflowed into the second bay through a pipe between the bays. Water only left the basin by evaporation, vertical leakage and lateral leakage. There were no arrangements for overflow. Once the basin was full, pumping of drainage water was stopped. The basin was sited in a disused part of the farm, which was unsuitable for irrigation due to its elevation and triangular shape. This portion of land had never been irrigated and the watertable was below 7 m when piezometers were inserted before the basin was filled.

An interceptor pipe drain to collect shallow lateral seepage was installed about 1.5 m below ground level around the perimeter of the evaporation basin, at a distance of about 10 m from the inside bank. This drain was connected to a subsurface drain line in the farm that returned any intercepted leakage to the main pump sump. Two inspection pits were inserted into this interceptor drain line, which enabled measurement of the quantity and quality of lateral leakage.

A detailed salt and water balance was conducted for the basin over a period of two years. A detailed description of the basin, measurements and results can be found in Leaney and Christen (2000).

The initial vertical leakage of water from the basin was extremely rapid, water entering the 7 m piezometer only 18 days after basin filling commenced. This can be equated to a mean leakage rate over that period of about 77 mm/day if the volumetric soil water content moved from field capacity ~0.22 to saturation ~0.42 and if there is no preferential flow to the deeper piezometers. This assumption is questionable and hence the leakage estimate using this calculation should be considered a maximum value. Nevertheless, the rate is very high and can be attributed to the dryness and well developed structural properties of the soil before basin filling.

A summary of all the leakage measurements from the basin over time and for different techniques is given in Table 7.

Table 7. Leakage summary for Nehme basin

Period	Technique	Leakage rate (mm/d)
Initial 18 days after filling	Filling of 7 m deep piezometer.	Up to 77 (probably considerably less)
Months 2 –4 after filling	Water and salt balance	6-7
Months 4-14	Water and salt balance	2.9 –3.0
Refilling after 6 months dry	Water and salt balance	2.6
Months 2 – 13	Concentration factor	3
Months 6 - 9	Seepage meter	0.4 – 5.2 (Av. 1.3, S.D. 1.6)

Subsequent salt and water balance estimates found that basin leakage stabilised at about 3 mm/day.

Point estimates by seepage meter were extremely variable, ranging from 0.4 – 5.2 mm/d. During the same period the water balance estimates were that leakage was 3.0 mm/d. This indicates that leakage is highly variable across the basin which was supported by a sixfold variation in apparent soil conductivity from EM38 survey.

The water balance method estimated leakage to average 3.7 mm/d. However, this does not account for the initial very high leakage period. The leakage by water and salt balance account for 1,439 mm of leakage, not including the first 24 days of basin filling. The soil sampling suggests a total leakage of 1,594 mm. The 155 mm difference may be due to initial leakage before intensive water balance analysis started, and, if so, the leakage over this 24 day period would equate to about 6.5 mm/d leakage. This is similar to the 5 –9 mm/d measured by salt and water balance in the first three months.

Lateral leakage is taken as that measured in the interceptor drains. These however are unlikely to collect all the lateral leakage as indicated by the stable isotope analysis of shallow groundwater outside the interceptor drains.

Initially, during the period when the groundwater mound was developing below the basin, the component of total leakage that was collected in the interception drains was about 23%. Subsequently, the total leakage decreased but lateral leakage remained at similar levels. As such this accounted for about 50% of total leakage. The changes in flows in the interceptor drain are strongly related to the head of water in the basin when the groundwater mound id fully developed under a basin.

Over the period of monitoring the mean disposal rate to the basin was 5mm/d, of this it would appear that 0.5 –1 mm/d was water from the interceptor drains, representing 10-20% of the total input to the basin.

The volume of groundwater that has been influenced by leakage from the basin appears to be about 5m depth below the basin (by soil water chloride analysis) and about 20 m from the edge of the basin in the shallow groundwater (by deuterium analysis). Thus overall it would appear that under the 2 ha of basin the groundwater has been affected to 5m, and about an additional 1 – 2 ha has been affected around the basin in the shallow (1-2 m deep) groundwater. The depth of the leakage effect (plume) around the basin is not known.

Other basins in the MIA

In the MIA there are at present 14 on-farm evaporation basins. These vary markedly in shape, size, drainage water salinity and management, Table 8. However, they are all sited on clay soils and receive water from subsurface pipe drainage schemes and all have interceptor drains around their perimeter. Leakage for the 6 basins was estimated by water balance using electricity readings from the pumps and also by salt balance on the basis of salt additions and change in salt stored. A further gross estimate of leakage was made using the concentration factor method (Leaney and Christen, 2000) which took average drainage and pond salinities with the pan evaporation and rainfall measured at Griffith for 560 day period (Table 9).

Table 8. Summary of on-farm evaporation basin characteristics in the MIA.

	Average	**Minimum**	**Maximum**
Basin area (ha)	4	0.6	14
Drained area (ha)	80	22	257
Percent of drained area	4	2	9
Percent of basin area utilised	37	0	100
Drainage water salinity (dS/m)	12	2	25
Basin water salinity (dS/m)	23	6	80

Table 9. Summary leakage data from 5 MIA on-farm basins

Farm	**Leakage by water balance (mm/d)**	**Leakage by salt balance (mm/d)**	**Concentration factor**	**Leakage by concentration factor (mm/d)**	**Intercept or drain flow (m^3/d/m)**	
A	5.9	3.5	1.30	3.8	2.9	0.09
B	7.5	4.4	1.26	3.9	3.9	0.11
C	7.9	4.8	1.01	4.8	NA	NA
D	6.3	5.4	1.14	4.3	NA	NA
Average	6.9	4.5	1.2	4.2		
Nehme	3.7	3.0	1.45	3.0	1.5	0.05

Appendix 2. Wakool Sampling for Stratification

Introduction

In evaporation basins used for salt making, stratification of the water according to salinity is the normal operating situation. When this occurs, the less saline input water ‘floats’ over the more dense higher salinity water already in the basin. In order to assess whether this may occur in evaporation basins for drainage water disposal, samples were taken at Wakool basin.

Method

Three bays, an inlet bay, a middle salinity bay and a terminal bay (highest salt concentration) were sampled at the Wakool basin on 12/10/99. Each bay was sampled at two points. The samples were taken from the water surface and at 0.05, 0.1, 0.2, 0.3, 0.4, & 0.5 m deep for the inlet bay (1 m deep) and at the surface 0.05, 0.1 and 0.2 m deep for the other bays (0.2 m deep). The sampling was done with a special apparatus using a syringe that enabled water sampling without disturbance. The weather conditions at sampling were cool and windy creating choppy waves except where the water was sheltered by banks. The samples were then analysed for electrical conductivity and, for total dissolved solids, by evaporation to dryness.

Results

Figure 21 and Figure 22 show salinity and total dissolved salts results, respectively, from the three bays (two sampling sites in each bay). The results from EC measurements suggest that there is little evidence of stratification for any of the sites except perhaps at the most sheltered site in the terminal bay. These results are quite different from the TDS measurements where there is a considerable salinity range at one of the sites in each of the terminal and intermediate salinity bays. Due to the limited samples, it is difficult to make any firm conclusions from this data.

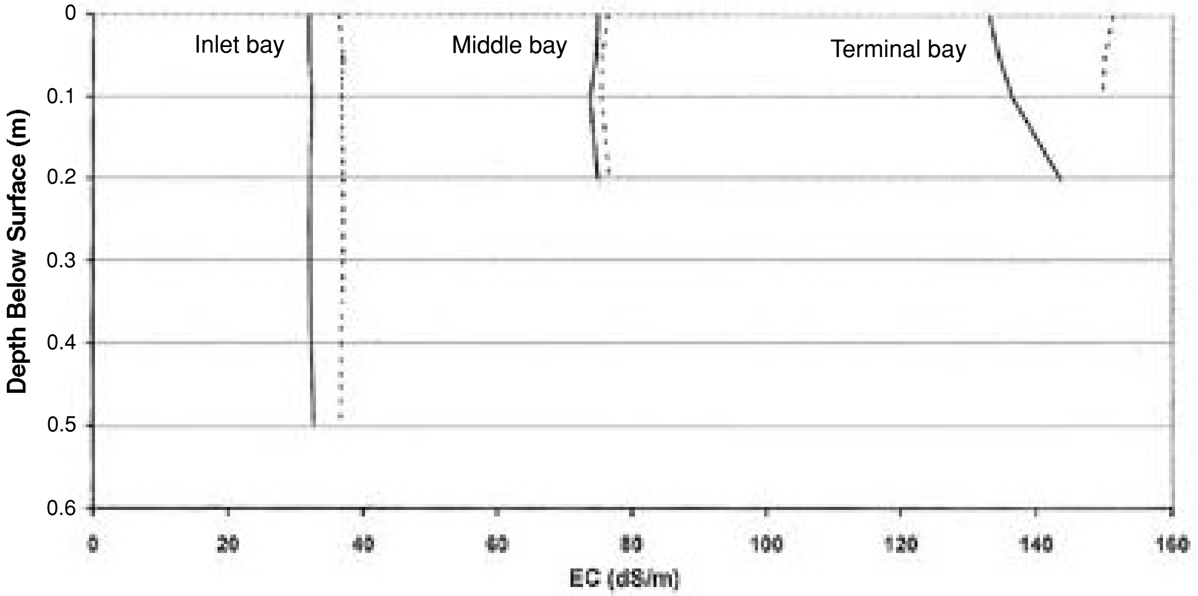

Figure 21. Profiles of EC measurements with depth for sites at the Wakool Basin.

There is little difference in EC measurements with depth at each site except for the most saline site where the EC for the water at the base of the basin for one of the profiles is 7% greater than at the surface.

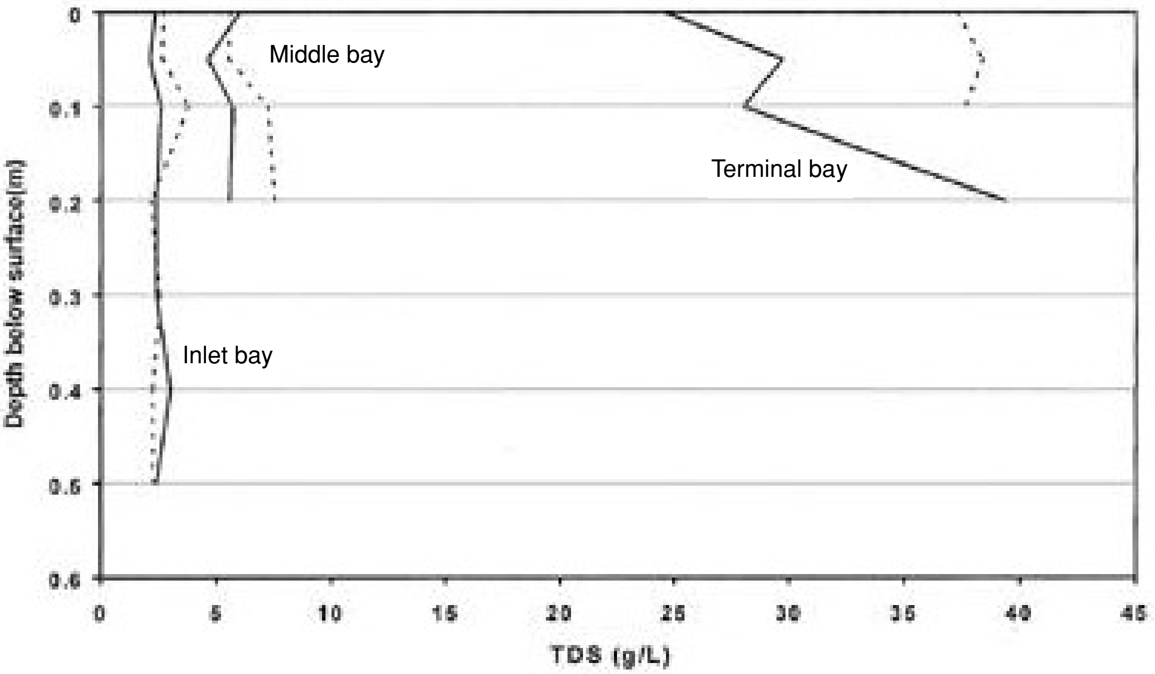

Figure 22. Profiles of TDS measurements with depth for sites in the Wakool Basin (two samples per site)

TDS measurements show greater variation than EC measurements. TDS variation may be 50% or more at the same site.

Conclusions

The results from this preliminary study are inconclusive. It is likely that there is a small potential for stratification in saline water in disposal basins. The amount of stratification will depend on the salinity, whether or not the bay is sheltered and wind strength during the preceeding few days or possibly weeks. It is unlikely that basins, if not designed or managed to promote stratification, will be able to maintain stratification for much of the year. Further work is required to confirm this. We, therefore, consider it safer to consider that evaporative capacity will be reduced due to the salinity of the basin water (as indicated in the main text) rather than assume a higher evaporative capacity that would apply should stratification take place.