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

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

GUIDELINES FOR BASIN USE

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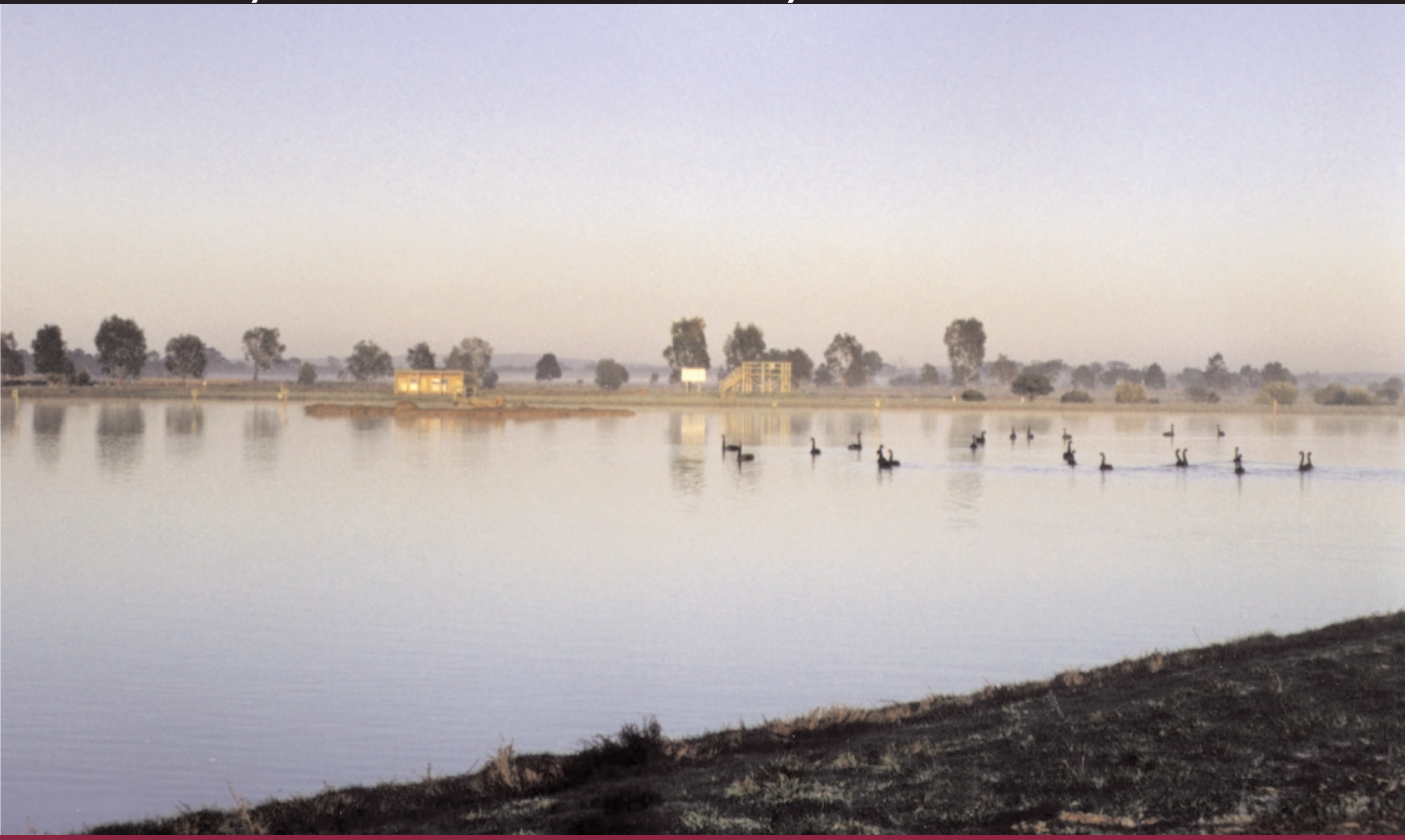

CRC FOR CATCHMENT HYDROLOGY REPORT 00/7
CSIRO LAND AND WATER TECHNICAL REPORT 12/00

December 2000

Foreword

The medium to long-term viability of large irrigated areas in the Riverine Plain region of Victoria and NSW is closely linked with management of high water tables. The Murray-Darling Basin Salinity and Drainage Strategy has imposed restrictions on the export of salt from the area where it originated. These restrictions have resulted in an increase in the number of local-scale on-farm and community salt disposal basins in irrigation areas. The existing design and management of both types of basin vary widely as they have been developed under different administrative frameworks. Until this report, there have been no generic guidelines for the use of local-scale salt disposal basins that could be applied across varying settings and administrative boundaries.

For the last three years, CSIRO Land and Water, in collaboration with the CRC for Catchment Hydrology, the Murray-Darling Basin Commission (Strategic Investigation and Education Program, Project I7034 Managing Disposal Basins for Salt Storage Within Irrigation Areas) and other agencies, has been investigating the siting, design and management conditions under which local-scale basins can be successfully used by individual or groups of landowners. The biophysical and other technical information obtained in this project have already been used to define a robust set of principles that define the overall framework for the responsible use of these types of disposal basins in the Riverine Plain. The guidelines presented in this report provide more detailed information and methods by which the use of these basins can be implemented whilst adhering to the underlying principles adopted by this project.

Glen Walker
Leader, Salinity Program

About This Report

This report describes general **guidelines** for the effective and environmentally safe use of local-scale salt disposal basins. They are specific to the irrigation areas of the Riverine Plain of the Murray-Darling Basin. They build upon a set of underlying **principles** (Christen *et al.*, 2000a) which set the overall framework for the use of these types of basins. While it is not possible to account for every combination of the complex array of soils, geology and land use in areas where local-scale disposal basins may be used, it is possible to provide generalised **guidelines**. The non-prescriptive **guidelines** presented in this report can assist those charged with ensuring the responsible siting, design and management of local-scale salt disposal basins. The audience for these **guidelines** is land and water management planning groups, catchment management authorities, resource and technical staff in government organisations and irrigation companies, and engineering and planning consultants.

It is important to note that these guidelines have been developed by the authors, in consultation with a broad group of stakeholders, as a basis for regional or local planning controls. However, they should not be considered as regulation or law as they have not received endorsement from any of the jurisdictions they encompass.

The report is broken up into several parts, preceded by background material outlining the scope of the report and detailing the issues surrounding the disposal of saline irrigation drainage water.

Part 1 describes how salt disposal basins function, in particular the factors that define their capacity to dispose of saline water.

Part 2 describes the appropriate use of saline disposal basins (through a set of concise **principles**), how any risks to the surrounding environment, infrastructure, and human and other activities can be minimised, and how basins may be made more financially attractive by the concurrent use of other enterprises.

Part 3 deals with strategic assessment for *Land and Water Management Plans (L&WMPs)* and the differences between the two types of local-scale basins (on-farm and community).

Part 4 consists of the **guidelines** themselves. It provides advice on selection of an appropriate site, determining the volume of drainage requiring disposal, assessing the size of basin required, and deciding on an appropriate basin design. It also discusses assessment of the financial considerations associated with the use of a basin, and details the basin management and monitoring required to ensure its long-term safe and efficient operation.

The following reports contain much of the information used to develop these **guidelines**:

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Acknowledgements

The Managing Disposal Basins for Salt Storage Within Irrigation Areas Project received funding and in kind support from the following investment partners: CSIRO Land and Water, the CRC for Catchment Hydrology, Murray-Darling Basin Commission, Goulburn-Murray Water, MIA Council of Horticulture Association, New South Wales Department of Land and Water Conservation, Victorian Department of Natural Resources and Environment, and the Flinders University of South Australia.

The authors would particularly like to thank the following people who provided significant feedback on early drafts of this report:

Peter Alexander	Murray-Darling Basin Commission, Canberra
John Blackwell	CSIRO Land and Water, Griffith
Ari van der Lely	Dept. of Land and Water Conservation, Leeton
Sandy Robinson	Murray-Darling Basin Commission, Canberra
Mike Williams	Dept. of Land and Water Conservation, Sydney

Glossary of Terms

Basin area: The total area of the basin including the evaporative area and the area required for associated infrastructure (such as banks, interception works and buffer zones).

Buffer zone: The area between the basin and its interception works and the surrounding land. Often contains trees or other vegetation to improve the aesthetics of the basin.

Community basins: Local-scale basins that are shared by a small group of properties and are either privately or authority owned.

Design disposal capacity: The amount of drainage water that a disposal basin can dispose of if the recycled water intercepted by the drainage system is equal to that leaked from the basin. May be given in volumetric units (m^3/day or ML/yr) or per unit area (mm/day or ML/ha/yr).

Drainage system: An engineered network of horizontal pipe drains (also referred to as tile drains), horizontal open drains, or groundwater pumping from bores (also called tubewells, spearpoints or wells) used to manage water tables and thereby control waterlogging and the build up of salt in the plant root zone.

Drainage water: Water that passes beyond the root zone as a result of rainfall and irrigation.

Evapoconcentration: The increase in salinity of water in the basin as it evaporates. A non-linear decrease in evaporation rate is observed as the water salinity increases.

Evaporative area: The area of the basin usually covered by water and therefore the area over which evaporation takes place.

Expansion limited: Describes basins where the rate of leakage is determined by the rate at which water can move laterally and vertically away from the basin. Leakage is therefore determined by the differences in depth between the water in the basin and the groundwater, and the hydraulic conductivity of soil, aquifers and aquitards around the basin.

Infiltration limited: Describes basins where the rate of leakage is determined by factors that impact at the base of the basin. Leakage is therefore determined by the depth of water in the basin, and is moderated by the permeability of the basin floor.

Interception works: Horizontal drains or open drains placed close to disposal basins to intercept leakage from the basin. They are usually sited within 2-20 m of the outer bank and at a depth close to the mean winter regional water table.

Lateral flow: Radial leakage away from a basin that occurs at shallow depth, top 4-5 m of soil.

Leakage: The process by which water from the basin moves through the floor of the basin to the soil below.

Leakage rate: The amount of water that leaks from a basin in a given time. Leakage rate may be given in volumetric units (m^3/day or ML/yr) or per unit area (mm/day or ML/ha/yr).

Local-scale basins: Basins sited within the irrigation district where the drainage is generated.

Net leakage: The amount of leakage that passes beyond the interception drain (= leakage – interception).

Oasis effect: This refers to the increase in evaporation rates when water bodies are surrounded by dry regions. This effect results in larger basins having lower rates of evaporation (evaporation factor 0.7 - 0.8) than smaller basins (evaporation factor close to unity).

On-farm basins: Local-scale basins that occupy parts of individual properties and are privately owned.

Piston-flow: The process by which leakage from the basin displaces all soil water and groundwater from areas into which it flows. No mixing or diffusion with existing water is considered to take place.

Potential disposal capacity: The total amount of drainage water that a disposal basin can dispose of per unit of time. May be given in volumetric units (m^3/day or ML/yr) or per unit area (mm/day or ML/ha/yr) and includes the effects of evaporation, rainfall, leakage and interception. It does not consider recycling of shallow lateral or vertical flow.

Preferential flow: The process by which leakage from the basin does not pass through the entire soil matrix. Sometimes referred to as bypass flow.

Regional-scale basins: Basins that accept drainage water from multiple farms and irrigation districts and/or sited outside the districts themselves.

Saline disposal basins: Man-made or natural shallow depressions used for the disposal of saline water. Often referred to as evaporation basins.

Salt export: The process in which saline water is transported outside the irrigation area in which it originated.

Vertical flow: Leakage away from a basin that occurs vertically through the underlying groundwater.

1. Introduction

1.1
Aim and Scope of the Guidelines

The aim of these **guidelines** is to describe the technical and financial issues that need to be considered for the effective and environmentally safe use of local-scale saline disposal basins on the Riverine Plain of the Murray-Darling Basin. While some aspects of these **guidelines** may be of use in other areas, specific modifications for those areas will be required prior to their application. The **guidelines** are underpinned by a set of sound **principles** that provide a general overarching philosophy for the use of local-scale basins (Chapter 5). They are supported by technical information obtained from research carried out in this project and previous studies of basins in the Riverine Plain. They do not encompass social and political issues associated with these basins, as these are generally specific to individual situations and are more appropriately handled by the communities concerned, their land and water management planning groups, and local authorities.

It is important to note that the authors, in consultation with a broad group of stakeholders, have developed these principles and guidelines. However, they should be considered as proposals only as they are not yet part of an agreed policy framework and as such have not received endorsement from any of the jurisdictions they encompass.

1.2
Intended Audience

The intention of these guidelines is to provide information for an individual or group, faced with the responsibility of implementing local-scale basins, which can assist them to make the most appropriate siting, design and management decisions for their situation. The intention is not to provide prescriptive recipes, as the site-specific nature of basin siting, design and management renders this impossible, but to provide overall guidance and to ensure that the reader is aware of all the potential issues that may arise with disposal basins. The intended users of these guidelines are:

- land and water management planning groups;
- catchment management authorities;
- resource and technical staff in Federal, State and Local Government agencies, and irrigation companies; and
- engineering and planning consultants.

1.3 Planning Considerations

Any development of disposal basins should be carried out within the framework of the Salinity and Drainage Strategy of the Murray-Darling Basin Commission (MDBC, 1999) and catchment *Land and Water Management Plans (L&WMPs)*. It is imperative that long-term (100-200 years) salt disposal strategies be prepared as part of all *L&WMPs*. It is very important that the community, local government, environmental protection and other regulatory and catchment management authorities are involved in the planning of the use of local-scale basins that fit into these strategies. A procedure for land and water management planning for local-scale basins is shown in Figure 1.1.

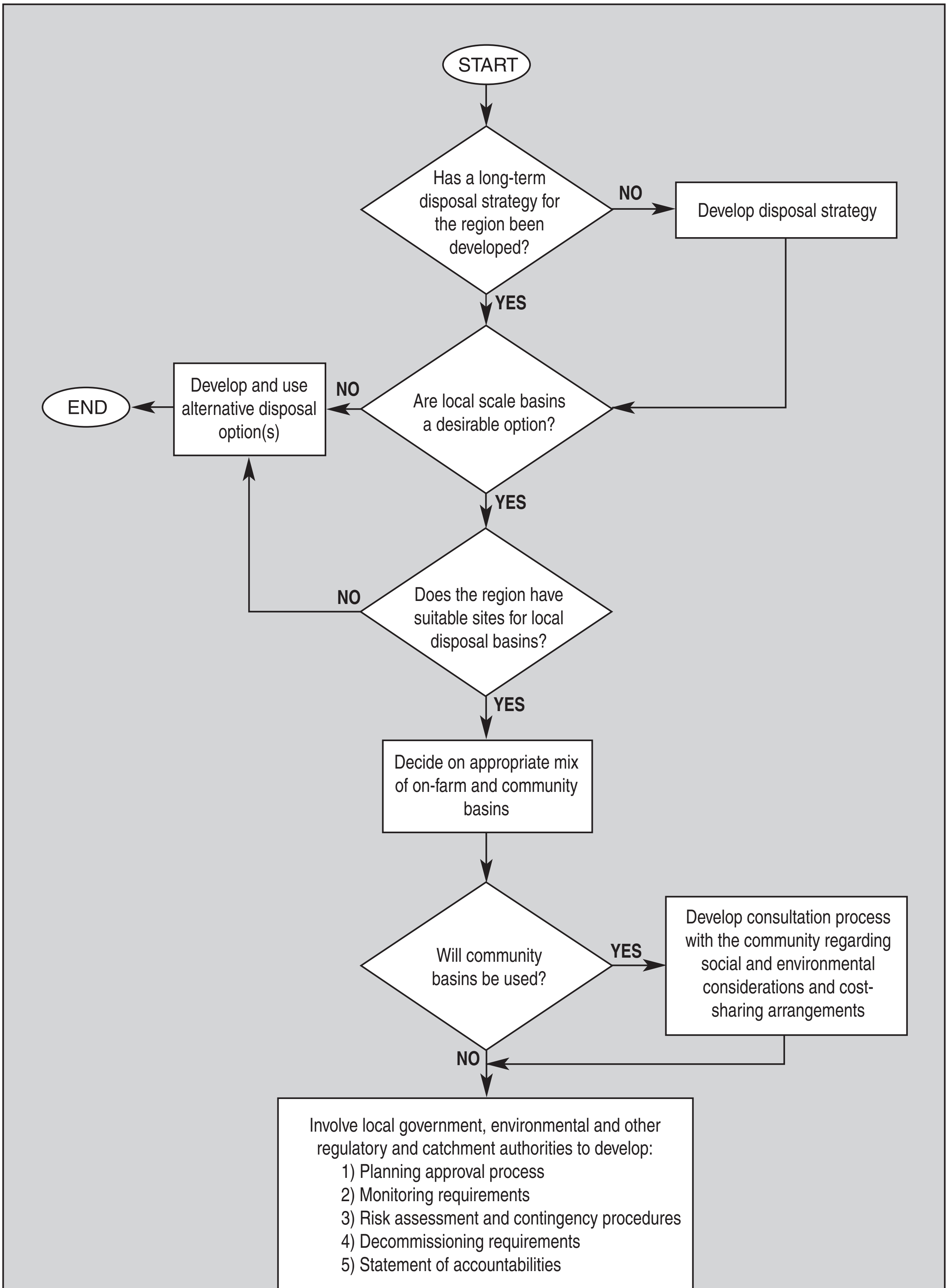

Figure 1.1 Strategic assessment for land and water management planning for local scale disposal basins.

1.4
Legal Compliance

At the time of writing, there is no legislation at Federal, State or Local Government level which specifically deals with the use of local-scale saline disposal basins. However, various aspects of disposal basin siting and use may fall under a range of legislation, regulation and by-law (e.g. VIC EPA, 1994; NSW EPA, 1997). It is therefore important that during the planning stage of a basin, a thorough investigation of the statutory responsibilities is carried out to ensure legal compliance. This is in addition to compliance with all local government planning rules appropriate to the area.

1.5
Using the Guidelines

As stated in Section 1.2, the guidelines are neither prescriptive nor all encompassing, and for any given situation, other information and issues will need to be considered (i.e. social, political and legal impacts). The emphasis of these guidelines is on general technical and economic decisions that need to be made when planning the use of local-scale saline disposal basins in an area. These guidelines are intended as an initial framework for the planning and implementation of basins. Review of local information and consultation with local experts is necessary to complete basin design and assessment for any particular area.

1.6
Outline of the Report

The report is broken up into four major parts preceded by two chapters of background material. Chapter 1 provides an outline of the report. Chapter 2 assists the reader in understanding the context in which the use of disposal basins has become a recognised option for the control of saline water discharge from irrigation areas. This information can be used to help decide whether local-scale basins are desirable for a region.

Part 1 describes how salt disposal basins function, in particular the factors that define their capacity to dispose of saline water. It is comprised of Chapters 3 and 4 that provide a simple conceptualisation of how disposal basins function on the Riverine Plain. They introduce the potential environmental risks associated with disposal basins and the necessary requirements for disposal basins to provide long-term disposal.

Part 2 describes the appropriate use of saline disposal basins and minimising environmental risk. It is comprised of Chapters 5 and 6 which provide the guiding principles for disposal basin use, which should ensure that disposal basins are effective and environmentally acceptable, and provide an overall guide to minimising the environmental risk of using disposal basins. It also includes Chapter 7, where some potential ventures for improving the financial viability of disposal basins by using them for aquaculture or other enterprises are described.

Part 3 is concerned with strategic assessment required for L&WMPs in regions considering the use of small-scale basins. Chapter 8 discusses strategic assessment to ascertain to what extent any region in the Riverine

Plain is suitable for the siting of disposal basins. This analysis considers general factors such as groundwater quality, soils, water table depth, surface water features and areas to be avoided for basin siting. This allows a general understanding of the suitability of the region and the likely difficulty or ease in finding suitable basin sites. Chapter 9 deals with the issues associated with the use of on-farm (single landholder) or community (multiple landholder) basins. The differences between these types of basins are physical as well as social and economic. The choice between using the different types of basins, or a mix of both, for a particular region should be made in close consultation with the community.

Part 4 consists of the guidelines themselves. Chapters 10 to 15 provide the guidance to develop appropriate siting, design and management procedures for the use of disposal basins in a region. The sequence of assessment followed in these chapters is:

1. The drainage volume that is to be disposed of to any site needs to be determined. This depends upon the type and extent of the drainage system and factors such as irrigation efficiency, regional groundwater conditions and the level of water table control required (usually depends upon crop type and groundwater salinity).

2. Having determined the required drainage volume, the appropriate disposal basin area to cope with that drainage needs to be determined. The evaporative area depends upon climate, soil types, groundwater quality and the level of disposal reliability required (dependent on crop value and its sensitivity to waterlogging). Understanding the functioning of a basin and the factors affecting disposal capacity are important in this analysis. The total disposal basin area is comprised of the evaporative area plus the area required for infrastructure such as banks, interception measures and buffers to the surrounding land use.

3. A particular site will be associated with an area where waterlogging and salinity is a problem. The basin site will preferably be as close to or within the area being drained. The suitability of a particular site and the safeguards required in the site selection to minimise the risk of negative environmental impacts need to be determined. If a particular site is found to be unsuitable then further sites will need to be assessed in the vicinity, if the whole locality is unsuitable then sites further afield will need to be found.

4. Having determined the site location and basin area, the physical design of the basin can be undertaken. This requires decisions regarding shape, number of cells, depth, freeboard, floor compaction, interception of lateral flow, and aesthetic improvements.

5. Decision making will need to take financial impacts of disposal basins on the farming enterprises into account. This can be conducted after an assessment of siting and design is made or it may be useful to undertake some preliminary analysis earlier in the process. For instance, after the regional analysis has found that suitable sites are likely to exist for disposal, then preliminary economic impact analysis on the local farming enterprises may be useful.
6. Once the basin is sited and designed, a management and monitoring policy is required to ensure that the basin functions effectively and its impact on the environment and community is contained. Monitoring provides an opportunity to reassess the design assumptions and help anticipate future problems

The key siting, design and management decisions, and the chapters where information of assistance can be found is given in Table 1.1.

Many of these decisions will require a range of expertise in fields such as soil, drainage, geotechnical and construction engineering, agriculture, pedology, hydrogeology and financial planning. Advice in these areas may be sought from State agencies, catchment management authorities, local government, consultants and research organisations.

Table 1.1 Site specific decisions for local-scale basin use.

Key Decision Required	**Chapter**	**Outcome**
1. Maximise irrigation and drainage efficiency.		drainage minimised
2. Select most suitable site.	12	site selected
3. Determine the volume of drainage water for disposal.	10	____ ML/yr
4. Determine the disposal capacity of a basin at this site.	4	____ ML/yr
5. Determine the required basin area.	11	____ ha
6. Decide on appropriate basin design.	13	shape / cells / interception works
7. Develop management and monitoring plans.	6 & 15	leakage / water quality plans
8. Determine impact on the financial viability of farm enterprises.	14	construction cost / enterprise viability
9. Assess other possible productive enterprises for the basin.	7	Possible enterprises
10. Prepare contingency, decommissioning plans.	6 & 15	Contingency / decommissioning plans

2. Saline Water Disposal Issues

The Murray-Darling Basin is one of Australia's most important water and land resources.

2.1
Importance of Irrigation on the Riverine Plain of the Murray-Darling Basin

Approximately 73% of all water used for agriculture and human consumption in Australia is harvested from the Murray-Darling Basin (MDB) (Fleming, 1982). Approximately 80% of lands irrigated in Australia (1.8 million hectares) are located within its boundaries. About 90% of cereal, 80% of pasture, 65% of fruit and 25% of vegetable production in Australia is derived from irrigated agriculture within the Basin (MDBMC, 1987a). The estimated annual value of irrigated agriculture in Australia is approximately $6 billion, of which around 65% is derived from the MDB (W. Meyer, pers. comm.). The majority of this irrigation occurs on alluvial soils in the south-central part of the Basin known as the Riverine Plain (Figure 2.1).

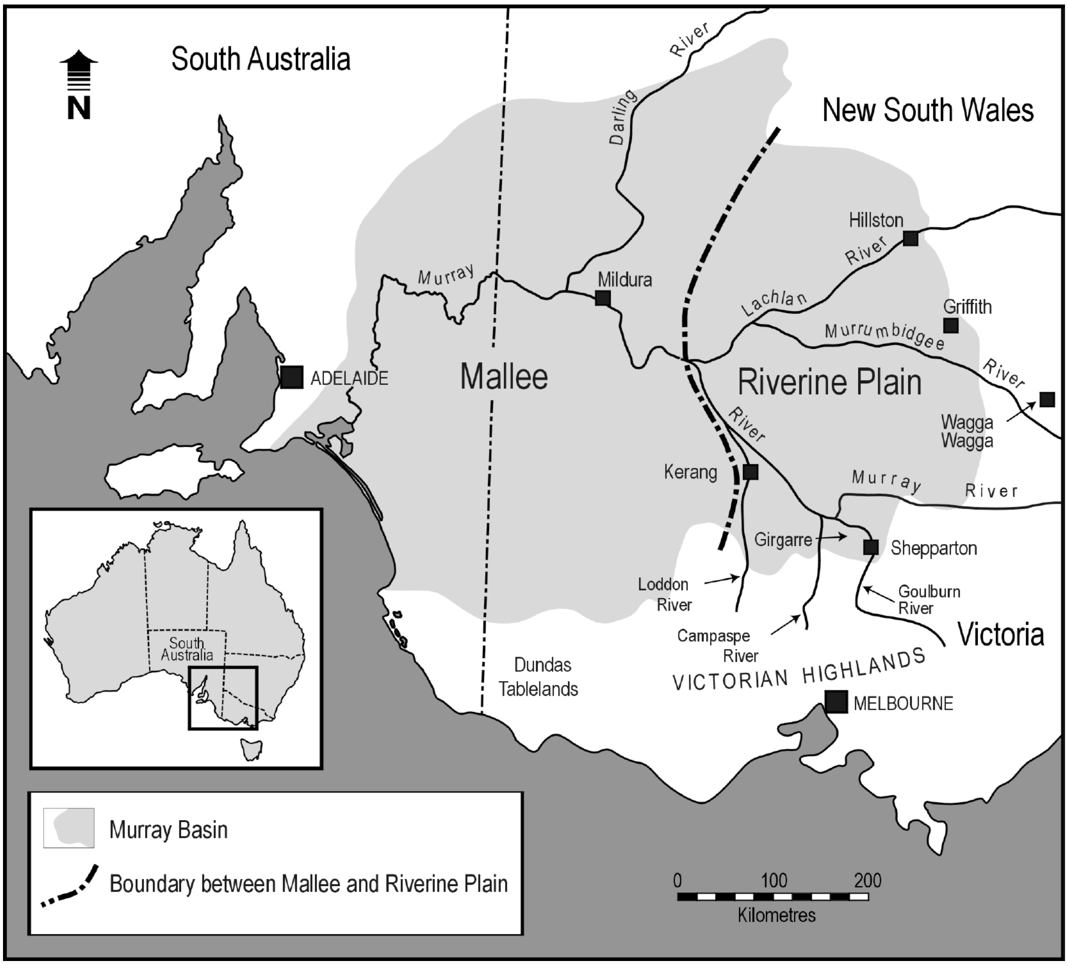

Figure 2.1 Map showing location of the Riverine Plain of the Murray Basin

2.2 Soil Salinisation and Waterlogging

Even in its pre-European state, the MDB contained a vast amount of salt, which was stored in its 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 water tables to rise throughout the Basin. This has resulted in mobilisation of the stored salt and when the water table comes close to the soil surface, soil salinisation and waterlogging result, with detrimental effects on agricultural production and ecological systems. Raised water table levels can also increase hydraulic gradients between the groundwater and surface water resources, leading to increased movement of salt to drains, streams and rivers.

For productive irrigation farming to continue, adequate leaching and drainage (to remove salt left in the root zone after transpiration of irrigation water) is necessary (Hoffman, 1985). The natural drainage capacity of the soils and groundwater systems in irrigation areas is usually insufficient to remove water that has infiltrated in excess of crop requirements; and so engineered drainage is often necessary to prevent waterlogging and salinisation of the crop root zone (Tanji, 1996). Surface drains, sub-surface drains, and groundwater pumps act to remove water from the soil profile and allow leaching of salts from the root zone of plants. Drainage can also be used to alleviate high water tables beneath urban areas, and intercept groundwater flowing into streams.

2.3 The Drainage Dilemma

As the salinisation of irrigated areas has become increasingly more serious and widespread, a growing awareness of the link between local catchment and regional salinity issues has led to a re-evaluation of salinity management strategies. In particular, linkages have been made between the use of engineered drainage to reduce and manage the impact of salinisation on local irrigated farmland, and the adverse effects of drainage disposal on the downstream water resources. Such management concerns highlight the need to account for local, catchment and regional salinity issues in any assessment of the costs and benefits of irrigated agriculture.

Changing political and community attitudes has increased pressure to minimise the impacts of large volumes of drainage from irrigation areas on downstream users and the riverine environment. As a consequence, drainage disposal into the river system can no longer be viewed as a overall solution to the problems of waterlogging and salinisation in irrigation areas. The costs of rising river salinity in downstream areas need to be balanced against the benefits of upstream irrigation drainage disposal into the river system. To help minimise impacts on the river system, land disposal of drainage to disposal basins has recently become more prevalent. Regional basins have been most commonly used in the past. However, the use of local-scale community and on-farm basins is increasing.

2.4 The Disposal Issue

Drainage disposal is one of the most important components in the L&WMPs of irrigation areas in the Riverine Plain. However, some types of drainage (surface drainage, rainfall and irrigation runoff) are suitable for re-use and disposal basins will only be viable for disposal of highly saline water because of the high cost of basin construction and loss of productive land. Furthermore, the role of disposal basins in a given L&WMP will depend on the regional context, in particular its salt export situation. For example, the use of basins in a region which has existing external drainage disposal but plans new drainage development will be different to a region which must dispose of all of its drainage to basins.

One of the primary drainage management objectives is to minimise disposal volumes by implementing improved irrigation practices and promoting the re-use of drainage water wherever possible. However, because of the need to prevent salt accumulation in the root zone by maintaining an adequate leaching fraction, **saline drainage will always be a consequence of irrigation.** It is important to note that all methods of drainage disposal can have negative impacts on the environment. It is therefore important to choose disposal options that minimise the negative environmental impacts and to ensure, as far as possible, that the beneficiaries of drainage pay for its disposal.

These guidelines focus on the use of local-scale disposal basins for disposal of farm-derived, sub-surface drainage, in the Riverine Plain. They do not deal with the use of local-scale basins to dispose of:

- ***surface drainage and runoff***
- ***sub-surface drainage from urban salinity control***
- ***groundwater from interception schemes to protect stream salinity.***

2.5 Areas of Land Salinised or Waterlogged

It was estimated in 1987 that 96 000 ha of irrigated land in the Murray-Darling Basin were visibly affected by soil salinisation and that 560 000 ha had water tables within 2 metres of the surface (MDBMC, 1987b). By the year 2015, it was predicted that 869 000 ha of irrigated land would be salinised or waterlogged due to high water tables. This represents about 60% of the land presently irrigated in the Basin (1.47 million ha; MDBC, 1999). However, recent surveys in New South Wales suggest that these predictions may be too high (A. van der Lely, pers. comm.).

2.6
Volumes of Drainage Disposal Required

It is difficult to get an accurate assessment of the total volume of saline drainage produced in the Riverine Plain by water table control measures. L&WMPs for the various irrigation areas of the Riverine Plain provide some information but the data are inadequate to provide an accurate overall estimate.

Nevertheless, it has been predicted that by the year 2040, between 335 000-608 000 ML/yr of groundwater in the Riverine Plain will require disposal (GHD, 1990). The lower value is based on a groundwater extraction rate 0.7-0.9 ML/ha/year (partial water table control), whereas the higher value considers a groundwater extraction rate of 1.4-1.6 ML/ha/year (full water table control – i.e. maintain the water table deeper than 2 m). It was also estimated that if the drainage was concentrated to one eighth of its volume, and no other means of disposal was available, 29 300 ha (partial water table control) to 53 200 ha (full water table control) of disposal basins would be required. These represent between 9 and 16 times the current area of disposal basins in the Riverine Plain (see Section 2.8). It is important to note that these are probably overestimates as sub-surface drainage is unlikely to proceed in many areas of the Riverine Plain due to the poor viability of drainage (A. van der Lely, pers. comm.).

2.7
Disposal Options: Past and Present

The main drainage disposal options which are in use or have been considered are:

- by local or regional re-use - with dilution as required;
- to streams and rivers on an opportunistic basis – used in most irrigation areas;
- to disposal basins - in use in some irrigation areas; and
- by a pipeline to the sea - feasibility studies conducted.

Some saline water is currently disposed of into river systems in periods of high flows and thus exported downstream. However, the salinity of pumped groundwater and drainage effluent is such that continuous unmanaged disposal to rivers and streams may result in unacceptable impacts on the environment and downstream users. The Salinity and Drainage Strategy of the Murray-Darling Basin Commission (MDBC, 1999) imposes constraints on the amount of river disposal possible. Moreover, there appears to be declining political and community tolerance of continued disposal to river systems.

Export of saline drainage to the sea via a pipeline is an option which has been considered a number of times in the past (SRWSC, 1978; Earl, 1982; GHD, 1990). However, these studies have each indicated that this option was relatively uneconomic when compared to other available disposal options. Moreover, the impacts of this option on the marine environment remain unclear.

Saline disposal basins (also referred to as evaporation basins) have been an important option and will continue to be so into the future, at least in the short to medium term (50 years). As was shown by Evans (1989), saline disposal basins are the lowest cost option for disposing of high salinity drainage water.

In the past, use of **regional-scale basins** has been a common approach. These accept drainage water from multiple farms and irrigation districts, and may even be situated outside the districts themselves (hence salt is exported from the area in which it is produced). In many instances, regional basins were developed on the most convenient sites from an engineering standpoint, sometimes with detrimental environmental, socio-economic and aesthetic impacts. In many cases, this has led to poor community perceptions of regional disposal basins. Furthermore, there is a view in some quarters that there is a need to depart from the existing *export the problem* mentality and that the beneficiaries of irrigation should be responsible for their own drainage management. The assumption being that this would encourage more efficient irrigation and drainage management and hence minimise the environmental and other impacts of disposal basins and irrigation on downstream users.

The above concerns have led to the use of **local-scale basins.** These can be in the form of on-farm basins that occupy parts of individual properties and are privately owned (such as those being used for new horticultural developments in the Murrumbidgee Irrigation Area). They can also be in the form of community basins that are shared by a small group of properties and are either privately or authority owned (such as the Girgarre Basin near Shepparton). **It is these local-scale on-farm and community basins which are the subject of these guidelines.** While it is clear that basins can be an attractive means of disposing of saline drainage water, it is important to note that they may not be suitable for all areas. As will be shown later, strict siting and management criteria govern the environmentally safe use of basins. When properly sited and managed, local-scale basins can also be important environmental assets (Roberts, 1995). However, in some instances, there may not be sufficient suitable land available, and so these types of basins may not be the most appropriate disposal option.

2.8
Existing Basins in the Riverine Plain

Hostetler and Radke (1995) collated all available hydrogeological, engineering and operational data on more than 150 existing basins in the Murray-Darling Basin. While the data for many basins is incomplete, the study provides a summary of available information:

- 107 basins were reported as being active, with a total area of >15 900 ha, a total storage capacity of >113 342 ML, and an annual disposal volume of >210 044 ML/yr.

- Of the 107 active basins, 90 were reported as being used for drainage disposal (i.e. not for groundwater interception schemes or groundwater discharge), with a total area of >14 531 ha, a total storage capacity of >113 074 ML, and an annual disposal volume of >181 495 ML/yr.
- Of the 90 active drainage disposal basins, only 9 (representing 3338 ha) were located on the Riverine Plain, the rest being concentrated mostly in the Riverland (SA) and Sunraysia (Victoria) regions.

Since the publication of the Hostetler and Radke (1995) report, at least another 10 on-farm basins have been constructed on the Riverine Plain in the Murrumbidgee Irrigation Area (MIA).

2.9

Salt Export and Responsibility

The degree to which salt is exported from the drainage area depends upon the siting of the disposal basin:

- *On-farm basin* - salt is stored in the drained area and so there is no export. However, if long-term containment is not completely effective then salt export to adjacent farms may occur through the groundwater system. Examples of this type of basin can be seen in the MIA of New South Wales.

- *Community basin within the drainage area* - salt is stored within a drainage area that protects several farms. Salt is exported from some farms but not from the drainage area. The Girgarre Basin near Shepparton in Victoria is an example of this type of basin.

- *Community/Regional basin close to the area of drainage* – salt is exported from several farms protected by drainage but remains adjacent to the drainage area and within the irrigation region. An example of this type of basin is the Wakool Basin in southern New South Wales.

- *Regional basin some distance from the drainage area* – this is complete salt export from the drainage area and irrigation region to a remote site. This type of basin is not very common on the Riverine Plain but has been widely used in other irrigation areas of the MDB. Noora Basin in the South Australian Riverland is a good example.

Changing from *no export* to *complete export* represents a decreasing level of responsibility for those producing drainage. Hence, there is also decreasing incentive to improve irrigation efficiency and drainage management (unless the full cost for drainage disposal off-farm is levied). However, it is important to recognise that all types of basins have potential negative environmental and community impacts. What differs between them is the degree of risk and who or what is exposed to the risk.

On-farm basins pose a potentially greater risk of failure, as there is less opportunity to select appropriate sites and lesser controls on their design and management. However, the consequences of individual failures may be more contained as they are likely to mainly affect just the landowner and his local environment (or at worst those of the immediate neighbours). Implementing appropriate controls based on the application of these guidelines can reduce the risk.

Conversely, regional basins pose a potentially lower risk as there is greater availability of suitable sites and they are most likely to be managed by agencies with experienced staff. However, the potential environmental and community impacts of these larger types of basins are likely to be on people and environments not directly involved in the generation of the saline drainage (which can be significant if not well sited, designed, constructed and managed).

It is clear that no one type of basin suits all situations, and careful consideration should be made for each individual circumstance. Local-scale disposal basins represent an expensive long-term commitment, and are also terminal storages for salt. For these reasons, the desired basin is one which meets community and environmental standards, is economically viable and results in the least salt export.

2.10 Summary

1. There is a range of possible basin options, each with advantages and disadvantages.
2. There is a need to site, design, construct and manage basins to minimise the detrimental environmental effects from the basin and from the disposal of saline drainage water overall.
3. Minimising the export of salt should be the preferred option. For various reasons such as the lack of suitable land, and economic or social factors, local on-farm basins or community basins may not be feasible.

part one

Disposal Basins and Their Function

3. How a Disposal Basin - Drainage System Functions

3.1 What is a Disposal Basin?

Disposal basins are engineered structures used to evaporate sub-surface drainage water and store the remaining concentrated salt. The salt must be stored within the basin or in the soils and groundwater in a defined location beneath and around the basin. For the purposes of this report, they are not intended for the collection of surface run-off and, apart from rainfall directly on the basin, receive only sub-surface drainage water as input. The key factors that govern the operation of a disposal basin are water loss through **evaporation** and by **leakage** beneath the basin (Figure 3.1).

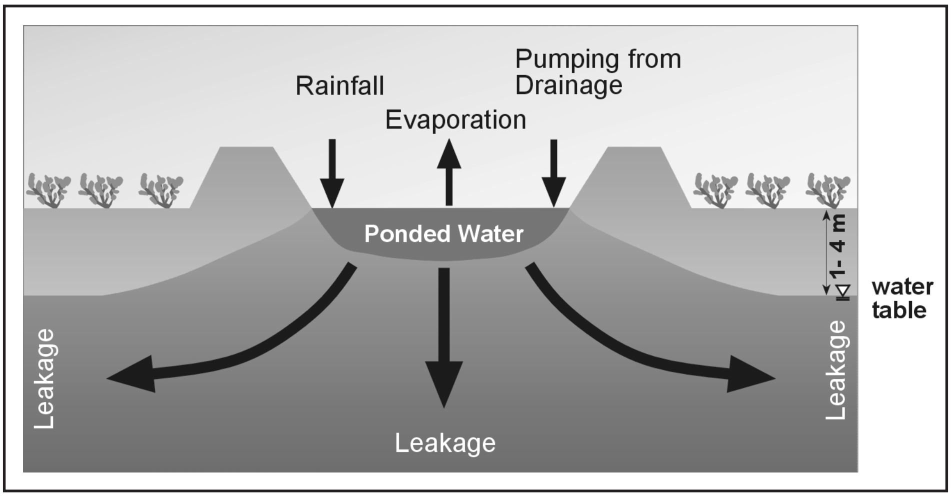

Figure 3.1 Conceptualisation of a disposal basin water balance.

3.2 Key Components of a Disposal Basin / Drainage System

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 (Figure 3.2, and see Chapter 13). 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.

In these guidelines we only consider constructed basins.

Drainage System

The aim of a drainage system is to manage water tables, thereby controlling waterlogging and reducing the build up of salt in the plant root zone. Control of shallow water tables 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.

The area served by a horizontal pipe drainage system is generally more easily defined than the area served by a groundwater pump. Although there may be *edge effects* around a horizontal pipe drainage system, the primary area served is clearly defined by the drainage installation itself. In the case of groundwater pumping, drainage is provided by lowering groundwater levels in the underlying aquifer to allow salt leaching from the irrigated area. The area served (for a given extraction capacity) is largely defined by the hydrogeology of the site, particularly the:

- shape, size and conductivity of the aquifer; and
- thickness and conductivity of overlying layers.

The nature of the groundwater level drawdown around any pump is such that areas very close to the pump have much greater drawdowns (and hence better drainage) than more remote areas. Moreover, there is no sharply defined boundary to the area of influence of the pump, which can also vary with seasonal conditions and pump operation. Because of the nature of the drawdown surface, groundwater pumps are most efficient in providing drainage when installed as a network with overlapping areas of influence. This can ensure that all of the area within the pump network receives some minimum groundwater level drawdown (and resulting drainage service). In practice, the effectiveness of any pump (or network of pumps) in providing drainage can only be assessed on the basis of detailed site testing.

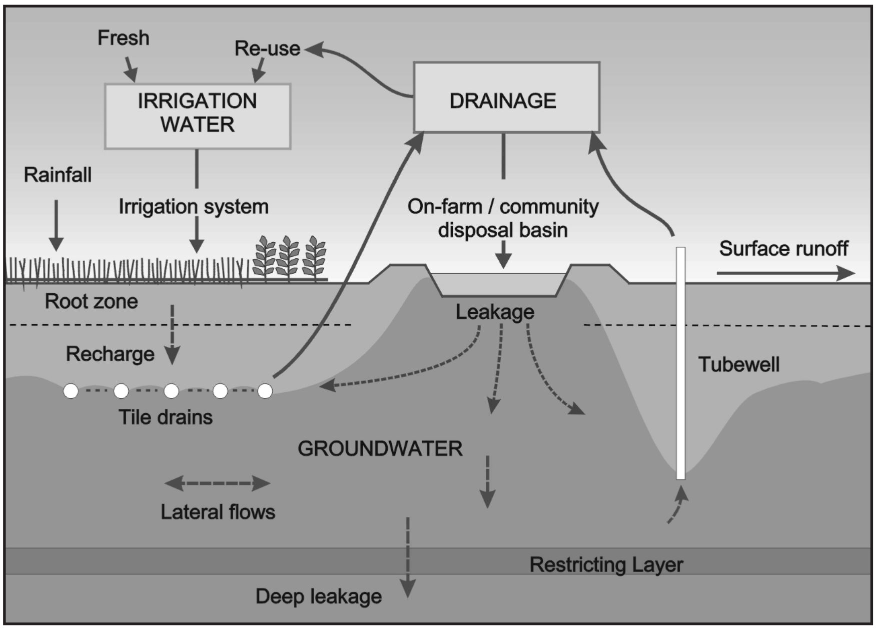

Figure 3.2 Conceptualisation of the main water movement processes associated with a disposal basin – drainage system.

Evaporation

The evaporation rate from a basin is affected by several interacting physical factors. These include the salinity of the basin water (more salinity = lower evaporation rate), size of the basin (larger basin = lower evaporation rate), basin water temperature (higher temperature = higher evaporation rate), as well as the overall evaporative demand as determined by climate.

The evaporation process removes water leaving salt in the remaining water, thus increasing the salinity of the remaining water. This can, if not managed, affect the disposal capacity of the basin in the long-term.

While some of these factors are specific to a particular site, others can be incorporated in basin design to increase the evaporative losses from a basin (see Chapter 13).

Leakage

Leakage refers to the process by which water from the basin moves through the floor of the basin to the soil below. The rate at which this occurs is determined by the differences in elevation between the water in the basin and the groundwater, and is moderated by the permeability of the basin floor *(infiltration limited)*, and any shallow aquifers and aquitards *(expansion limited)*. The flow of leakage water from the basin is predominantly vertical if the soil beneath the basin is unsaturated. 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. Lateral flow is considered to be a shallow, 4-5 m thick radial component of flow beneath the basin (Figure 3.3).

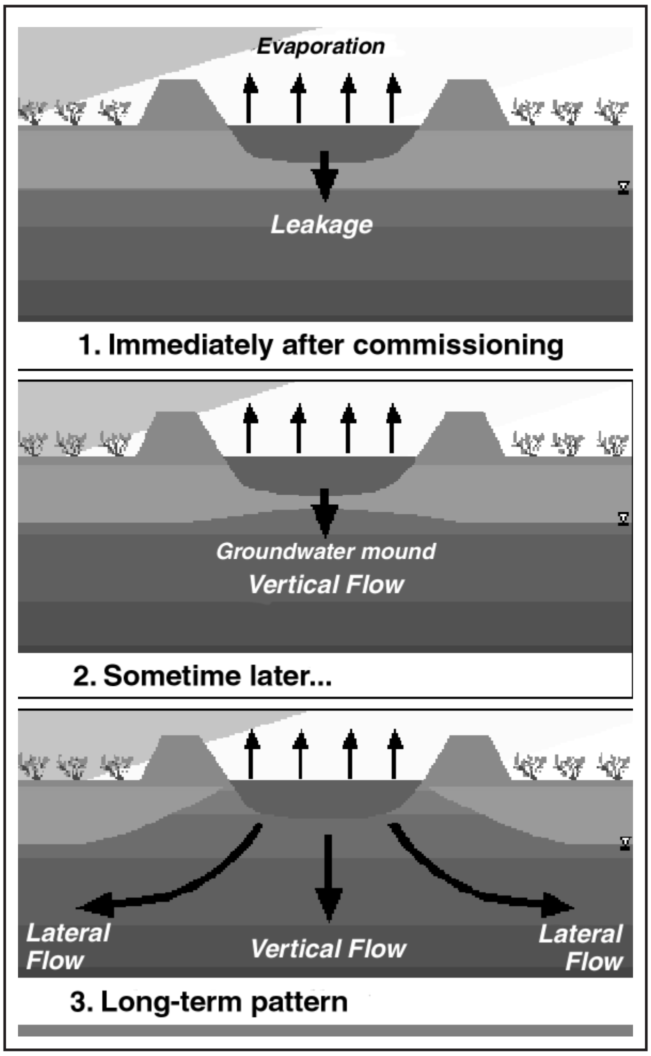

Figure 3.3 *General indication of the groundwater flow pattern under a disposal basin for three time steps.*

Our research suggests that, for the heavy textured soils of the Riverine Plains, large basins are generally *expansion limited* and leakage is primarily controlled by the perimeter/area relationship and is less than 1 mm/day (see Chapter 4). Small and moderately sized basins may be either expansion or *infiltration limited.* Leakage rates will be dependent on factors such as soil hydraulic conductivity, soil compaction and basin management. If the soil at the base of small basins has a light texture, is not compacted and/or the basins are allowed to dry out (preferential flow enhanced), leakage rates may be 3 mm/day or more.

Basins should have an interception drain sited close to the basin (see Chapter 13). Interception drains have been shown to intercept up to 80% of leakage from small basins, hence reducing the *net leakage* (leakage – intercepted leakage) to manageable levels.

Net leakage from small and moderately sized basins may be further reduced by compaction of the soil in the basin floor (and hence reducing the hydraulic conductivity) and by maintaining a year-round cover of water in the basin. Such practices may reduce leakage to ~0.5-1 mm/day in heavy soils.

It has been hypothesised that the use of groundwater pumping for control of water tables may induce deep or vertical flow from basins (and an overall increase in leakage rate for basins within the pumps' zone of influence). This would be particularly the case if leakage from a basin is *expansion limited,* rather than *infiltration limited.* Unfortunately, there are no data available from studies on the Riverine Plain to support or refute this hypothesis. The Girgarre Basin, one of the more comprehensively studied basins with groundwater pumping, does not show excessively high leakage rates above what would normally be expected (see Chapter 4). However, as leakage from this basin is *infiltration limited* (the soil beneath the basin is unsaturated), results from this are not applicable to *expansion limited* basins.

3.3

The Saline Leakage Plume

Limited amounts of leakage allow disposal basins to function longer and with a smaller area (see Chapter 4). However, the plume of saline leakage can lead to contamination of groundwater and soil salinisation surrounding the basin. It is important that groundwater with existing or potential beneficial use is not contaminated and that the leakage plume is contained within the area of influence of the drainage system (or within a specific containment area if the basin is located outside the drainage system). It is also important to recognise that, in most cases, any shallow groundwater below and adjacent to the basin is likely to be a result of recharge from irrigated areas (i.e. effectively sub-surface drainage water). As such, it is likely to be very sensitive (in terms of both quantity and quality) to changes in land use and irrigation practice. Hence, its real resource value is unlikely to be as great as the value of the larger and more distributed groundwater resources which may exist at much greater depth.

The shape and speed of movement of the leakage plume is dependent on the saturated vertical and horizontal hydraulic conductivities of the soil, and on the type of flow processes (*piston-flow* and/or *bypass/preferential flow*) which predominate (Figure 3.4). Studies in the Riverine Plain area suggest that:

- *piston-flow* occurs for only a few metres directly beneath the basin (in the zone of shallow lateral flow);
- where leakage is *expansion limited,* most of the leakage moves as shallow lateral flow (although 50% or more may move as vertical flow when deep bores are used to intercept and recycle the leakage water);

- in general, the laterally moving leakage plume mixes and diffuses with the groundwater in a shallow 4-5 m thick layer below the surface of the water table (see Figure 3.4). Vertical diffusion/mixing outside the layer will decrease the rate of spread while horizontal diffusion/mixing will increase the rate; and
- the impact of saline leakage in areas with shoestring sand aquifers (a hydrogeological feature of many parts of the Riverine Plain) may be considerably quicker than expected, due to vertical *bypass/preferential flow* caused by secondary porosity (cracks, holes, root channels), in the soils underlying the basin. It is important that the existence of secondary porosity is examined during site geotechnical investigations.

The leakage plume for a basin is likely to move laterally away from the basin following the predominant hydraulic gradient. In flat land with low hydraulic gradient, this leakage will move in a uniform radial pattern from the basin. If groundwater pumping is used for drainage, then the pumps will modify the movement of the plume once it enters their zones of influence.

As the leakage plume progresses from the basin, it mixes with the local groundwater. The degree to which this mixing occurs is determined by the operation of the adjacent sub-surface drainage system. In this way, much of the leakage from the basin will be recycled via the sub-surface drainage system to the basin. In order for this to effectively occur and to minimise the risk of the leakage plume moving laterally out of the drainage area, the basin needs to be sited well within the drainage area.

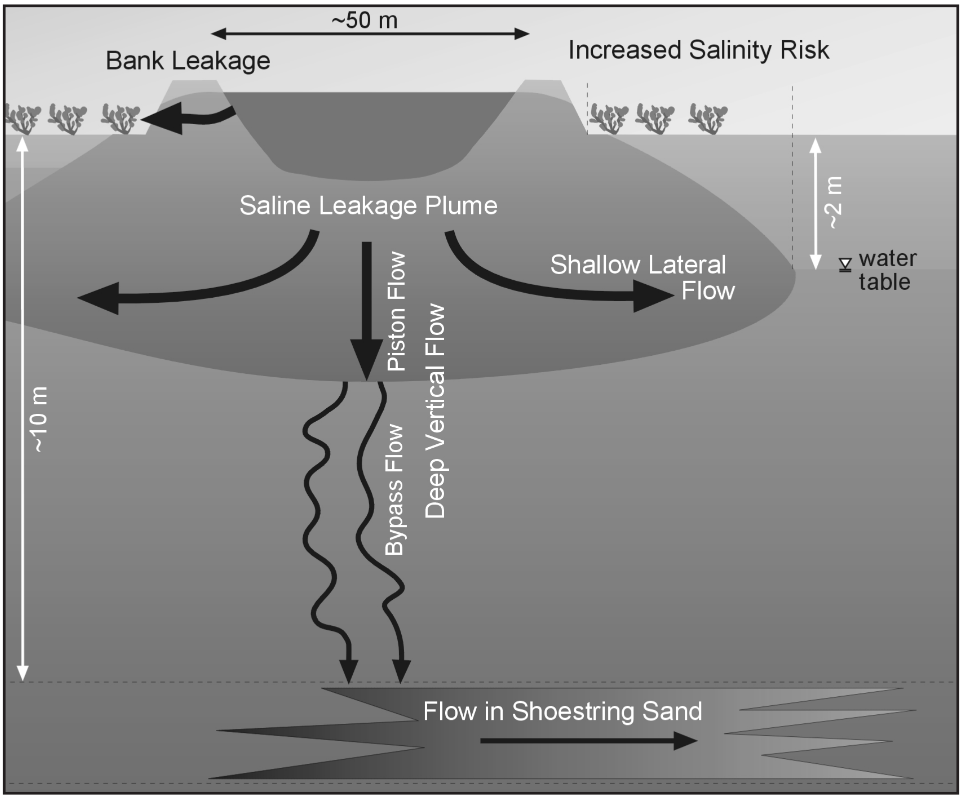

Figure 3.4 Conceptualisation of the main water movement processes associated with disposal basin leakage.

3.4 Safe Leakage: Balancing Disposal Capacity and Leakage

For any basin, there will always be a trade-off between maximising the disposal capacity (reducing the farm area sacrificed for the basin) and minimising the risk associated with leakage from the basin. The risk can be reduced significantly by preventing leakage from the basin by lining the basin. However, this practice is not generally economically feasible because of the costs associated with lining the basin and, equally importantly, the reduction in evaporative disposal capacity as a result of higher salinity levels in lined basins. The amount of leakage required to maintain evaporative capacity is discussed in Chapter 4.

Controlled low rates of leakage give the potential for **leakage that is contained and thus is safe** thereby ensuring longevity of the basin – as it prevents the basin water becoming too saline, a factor that causes a decline in evaporation in the short term. Furthermore, it provides a much larger long-term salt storage volume than just the basin itself. It is recommended that basins be allowed to leak at a low controlled rate and that the drainage system, including an interception drain, is designed to intercept most of the leakage. This may require the installation of dedicated seepage interception works if the basin is not placed inside the drained area.

In determining the basin disposal capacity, and hence, the design area, the leakage of water can be considered as a water loss from the basin. After a few years, a large proportion of this is likely to be balanced by interception and recycling. Only in the early time of basin filling after construction, will leakage from the basin act as additional disposal capacity, i.e. until the groundwater mound is fully developed under the basin.

Some leakage may not be intercepted/recycled, as some may move to the deep aquifer systems. However, in the long-term a large proportion will be recycled. The leakage losses from the basin may also be balanced by water inflows to the drainage system from surrounding areas. Thus, in overall terms it is best not to consider leakage from a basin as additional disposal capacity, but as a means of maintaining high evaporation rates, at least in the short to medium term. Disposal capacity is discussed in more detail in Chapters 4 and 13.

3.5 Lifetimes of Basins

If basins are designed correctly salinity build up in or around the basins is unlikely to be the major factor that determines the basin’s lifetime. However, disposal basins will not have an indefinite lifetime. Other factors relating to the economics, technical (long-term bank wall stability) and the development of alternative (and more economical) disposal systems are more likely to result in shortening the basin life.

3.6 Summary

1. A disposal basin is an engineered structure used to evaporate sub-surface drainage water and store the remaining concentrated salt in a defined location within the basin and in the soils and groundwater beneath it.
2. A disposal basin is part of an overall system aimed at controlling water tables and disposing of the drained water and storing the salt in a contained area.
3. Evaporation and leakage are the key processes that govern the behaviour and effectiveness of a basin.
4. For basins that are *expansion limited*, shallow lateral flow of a leakage plume exceeds vertical flow. In the case where basins are *infiltration limited*, vertical flow is enhanced and, when groundwater pumping is used, vertical flow may account for 50% or more of the total leakage.
5. *Preferential flow* paths may result in vertical flow *bypassing* much of the soil matrix beneath the basin and saline leakage water may reach zones of higher hydraulic conductivity (e.g. shoestring aquifers) sooner than expected, if the mechanism was by *piston-flow*. Geotechnical investigations should include an assessment of the existence of secondary porosity that may facilitate *bypass* flow.
6. A small amount of controlled leakage from the disposal basin is required to maintain evaporative disposal capacity. Wherever possible, basins should be sited in the drained area, in a position that minimises the leakage rate and maximises the possible time for the leakage plume to escape the drained area. Basins sited outside the limits of the drainage system should be located within a specific salt containment area equipped with effective interception and recycling works.
7. Basins, particularly smaller on-farm basins, should have interception drains/channels close to the basin to reduce *net leakage* to manageable levels.

4. Disposal Capacity of a Basin

4.1 Definition

The total amount of drainage water that a basin can dispose of is referred to as its *potential* disposal capacity. This capacity includes the effects of evaporation, rainfall and leakage (see Figure 4.1) on the amount of drainage water that can be disposed of into a given basin but does not consider interception and recycling of shallow lateral or vertical flow. *Design* disposal capacity refers to the amount of drainage water that can be pumped into a disposal basin if the recycled water intercepted by the interception drain and drainage system is equal to that leaked from the basin ie. water loss from the basin is taken as only that due to evaporation.

The *design* disposal capacity, when matched to the required drainage for an irrigated area, determines the area that needs to be reserved for disposal basins. This is important as the area occupied by basins does not have an economic return, unless there are opportunities for other uses (see Chapter 7).

This chapter discusses particular factors that have an influence on the *design* disposal capacity for basins in the Riverine Plain. We also present estimates of probable *potential* disposal capacities for basins in the Riverine Plain based on field evaluation of the individual effects of the factors. However, local variations in these factors at any particular site are likely to result in a range of disposal capacities.

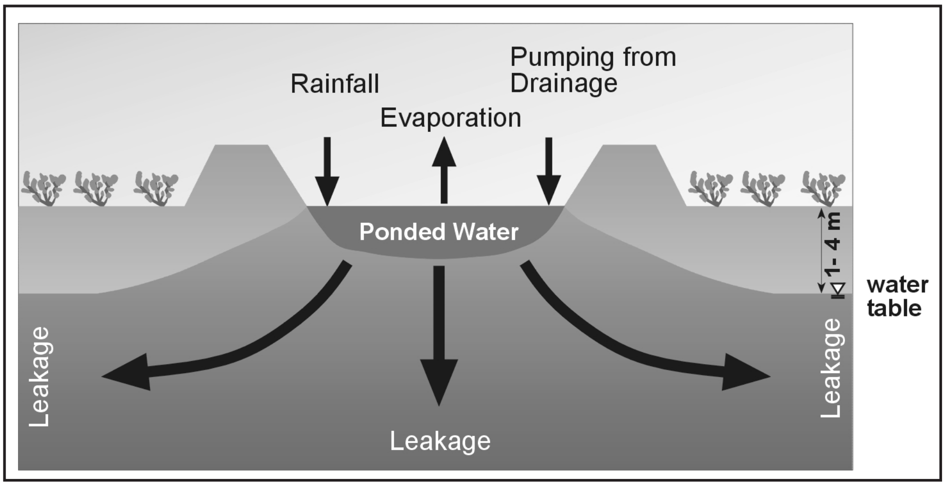

Figure 4.1 Conceptualisation of a disposal basin water balance.

4.2
Factors Controlling the Disposal Basin

A range of physical factors controls the volume of water that can be disposed of in a disposal basin. This includes both direct water balance terms (rainfall and evaporation), and conditions within the basin itself. Leakage amounts, climate, soil properties, salinity of the disposal water, and the area of basin are all important factors. The complex interaction of these factors determines the potential and design disposal capacity of a basin.

Climate

This has a direct effect on the disposal capacity of a basin. Rainfall is water-added, while evaporation is water-removed. Consequently, increased rainfall lowers the disposal capacity, while increased evaporation raises it.

Leakage

Increased leakage below a basin leads to a direct increase in the *potential* disposal capacity. However, the effect of leakage on the *design* disposal capacity is not included as it is safer to assume that all of the leakage is recycled. Leakage has another effect on both the *potential* and the *design* disposal capacity. If leakage is zero or very low, evaporative concentration will increase the basin water salinity, reducing the evaporation rate and hence the disposal capacity of the basin (see next paragraph). This may result in a considerable reduction in both the *potential* and *design* disposal capacity. However, as discussed in Chapter 3, high leakage rates lead to contamination of groundwater and soils surrounding the basin because of difficulties in recycling the saline leakage water.

Basin Salinity

There is a relationship between the salinity of water and the rate of evaporation. As the salinity increases, there is a corresponding decrease in the free water molecules that are not bound to salt particles. The reduction in evaporation rate is also affected to some degree by the type of salt and by the humidity of the atmosphere. This relationship can be accounted for by calculating an evaporation factor, which lowers the evaporation rate based on the basin salinity.

Basin leakage, even at low rates (<1 mm/day), will moderate this effect of evapoconcentration and allow the basin to continue to function at near the maximum evaporative capacity. Without leakage, the size of basin required to dispose of a unit volume of drainage will be governed, in the long-term, by the rate of evaporation from a saline brine solution that is at, or near, the stage where salts start precipitating. Evaporation rates will continue to decline further as different salts precipitate from solution (see Figure 4.2).

Thus, depending on the relative magnitudes of the rainfall and potential evaporation of the site and the degree of *oasis effect* (see below), basins without leakage will need to be at least 40% larger than basins that leak.

An example of this effect on the *design* disposal capacity for a hypothetical 1 ha basin at Hillston is shown in Figure 4.3. Depending on the input water salinity, the *design* disposal capacity may be reduced by 60-70% for a lined (zero leakage) basin as opposed to a basin with a leakage of between 0.5 and 1 mm/day. In situations with low input salinities (<10 000 mg/L) high *design* disposal capacities can be maintained with leakage rates less than 0.5 mm/day, however it is generally not practical or beneficial to reduce leakage rates below this level. Similarly, the increase in *design* disposal capacity is less marked for leakage in excess of 1 mm/day, and so there is little benefit to be gained by allowing leakage rates much higher than this.

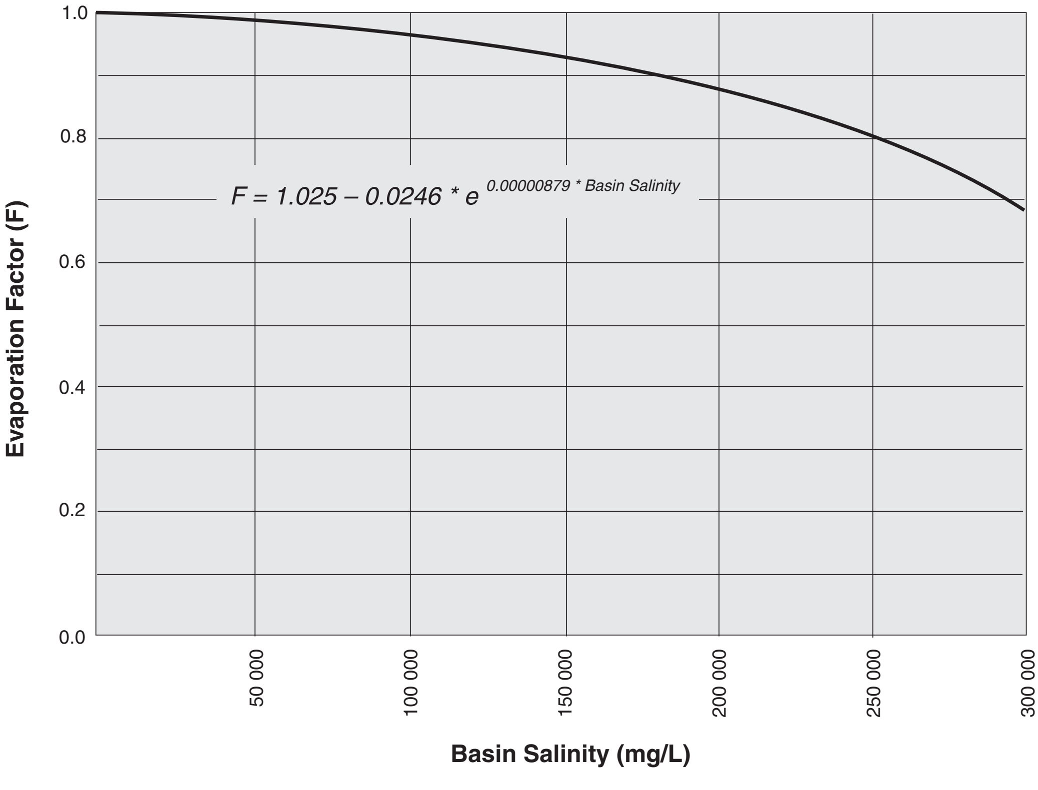

Figure 4.2 Effect of basin salinity on basin evaporation. The relationship uses a curve fitted through the data of Bonython (1969) and Turk (1970).

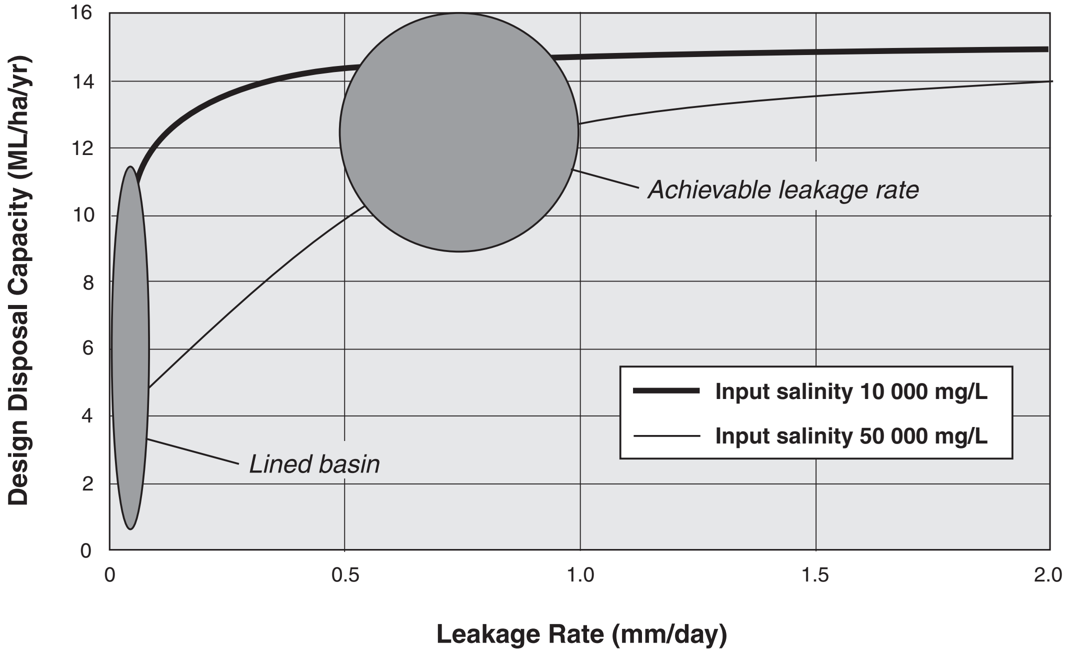

Figure 4.3 Design disposal capacity for hypothetical 1 ha basin at Hillston with varying leakage rate.

Basin Area

There are two main effects that influence the disposal capacity of a basin that are related to its size.

1. The *oasis effect* where larger basins tend to develop their own microclimate, resulting in increased humidity above the basin – and hence less evaporation (Figure 4.4). The magnitude of this effect is also affected by the humidity of the surrounding area. The effect will be greatest where there is no (or very little) irrigation occurring in the upwind areas.

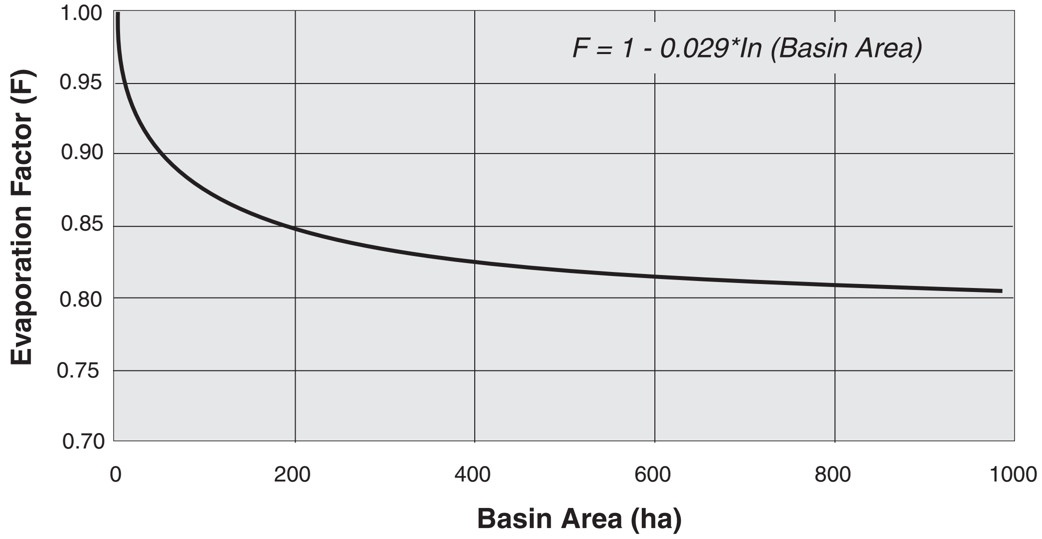

Figure 4.4 Oasis effect of basin area on basin evaporation.

2. Larger basins tend to have less leakage than smaller basins when placed in areas with similar site conditions. This is explained by the relationship between observed leakage and perimeter/area (P/A) ratio under existing basins on the Riverine Plain in shallow water table areas. In these areas, much of the leakage is shallow lateral flow away from the basin (see Chapter 3). This means that basins which have a larger perimeter compared to their area can have higher leakage rates – larger basins leak less than smaller basins. Figure 4.3 shows the relationship between observed differences between estimated leakage rate and P/A ratio for ten existing basins in the Riverine Plain.

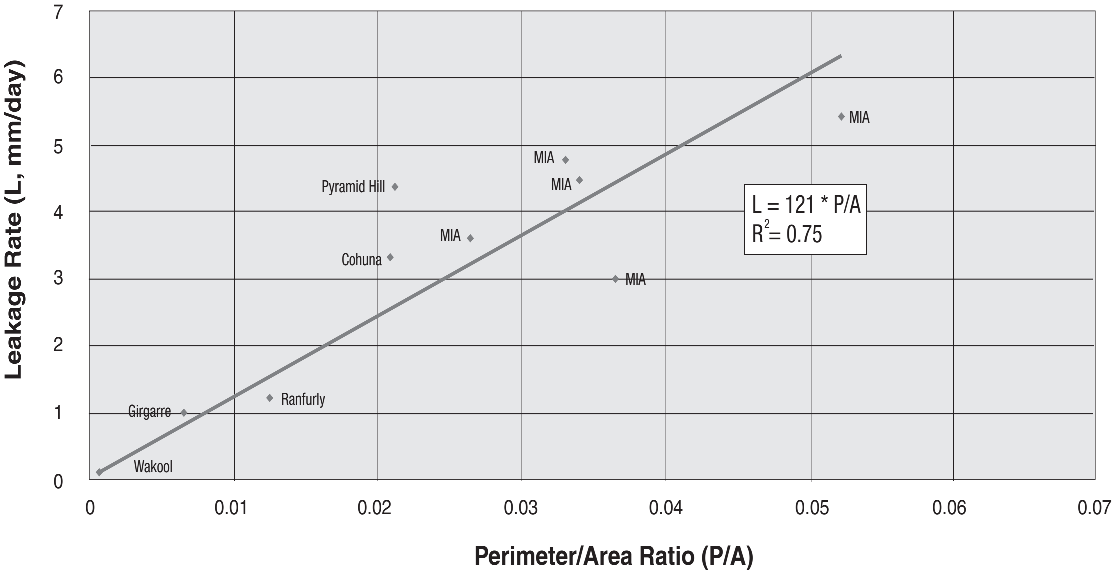

Figure 4.5 Effect of basin size (Perimeter/Area ratio) on the basin leakage rate. Where P is the perimeter of the basin (m), and A is the area (m^2).

4.3 Modelling the Disposal Capacity

A spreadsheet model has been developed which combines the factors influencing the disposal capacity of a basin (Leaney and Christen, 2000a). Model input includes the size of the basin, the climatic record (evaporation and rainfall estimation from the nearest meteorological station), the leakage rate under the basin, and the salinity of the incoming drainage water. The model has the option of a single basin, or a multiple cell basin. It takes into account all of the effects discussed earlier in this chapter.

It is assumed that water in the basin will be fully mixed – field observations at the Wakool Basin suggest minimal salinity stratification at the basin salinity levels recommended in this report (Leaney and Christen, 2000b). The model can be used to predict the *design* and *potential* disposal capacity of a new basin in a particular area (Leaney and Christen, 2000a). It can also be used to calculate the leakage rate from an existing basin from the changes in basin salinity with time (see Chapter 15).

Table 4.1 summarises average disposal capacity for the period 1957-1996 for basins of different size and input salinity at a number of sites on the Riverine Plain.

4.4 Multiple Cell Basins

The disposal capacity in Table 4.1 refers only to single-bay basins. Simulations of disposal basin behaviour using the spreadsheet model predict that there is likely to be only a negligible reduction in disposal capacity when a single-bay basin is replaced with a three-bay basin system with equivalent basin area (Leaney and Christen, 2000a). This finding encourages the use of multiple cell basins, where the most saline bay is completely surrounded by the fresher cells, thus reducing the impacts of the most saline leakage on the surrounding area (see Chapter 13).

4.5 Recommended Leakage Rates and Design Disposal Capacity

From observations of existing basins, together with the modelled behaviour of hypothetical basins, it is considered that net leakage rates of 0.5-1 mm/day should be considered as desirable and achievable for basins located at suitable sites in the Riverine Plain. At these rates of leakage, there is likely to be only a small loss in evaporation potential (Figure 4.3). To achieve such rates, basins less than 100 ha in area will need to have their floors compacted and maintained with a year-round cover of water and have a properly designed interception drain (see Chapter 13). In general, we recommend the use of *design* disposal capacity (all leakage recycled to the basin) when determining the area of the basin (Chapter 12). However, it is important to make allowance for the additional operating costs incurred by complete recycling of leakage.

More detail on the factors controlling disposal capacity, recommended leakage rates, and case studies can be found in Leaney and Christen (2000a).

Table 4.1 Calculated values for mean disposal capacity for selected sites in the Riverine Plain 1957-1996.

Site	**Leakage mm/day**	**Basin Area ha**	**Disposal Capacity**						**Pan E-R ML/ha/yr**
			Input Salinity Potential ML/ha/yr			**Input Salinity Design ML/ha/yr**			
			A	**B**	**C**	**A**	**B**	**C**	
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	9.5	9.3	7.3	9.5
	1	1	13.3	13.1	12.2	9.5	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

A	*input salinity 10 000 mg/L ((Cl) = 5 500 mg/L)*
B	*input salinity 20 000 mg/L ((Cl) = 11 000 mg/L)*
C	*input salinity 50 000 mg/L ((Cl) = 27 500 mg/L)*

4.6 Summary

1. Disposal basins function more effectively if they have some limited leakage. Without leakage, salinity in the basins becomes excessive, reducing the evaporation from the basin to inefficient levels. The higher the salinity of input water the greater this effect will be.
2. For heavy textured soils with some compaction of the basin floor, year-round coverage of water, and a properly designed interception drain, net leakage rates in the Riverine Plain should be reduced to ~0.5 to 1 mm/day, values which are still sufficient to maintain evaporation rates. Leakage is often limited by the capacity for shallow lateral flow in underlying aquifers. For similar site conditions, smaller basins will leak at a much higher rate than large basins, and therefore will need more attention to floor compaction and siting of the interception drain.
3. Smaller basins can dispose of more water per unit area than larger basins due to higher leakage rates that maintain lower basin salinity and higher net evaporation rate (i.e.. the *potential* disposal capacity is higher). The *design* disposal capacity however is only slightly higher for smaller basins. The higher leakage rates become especially significant and potentially detrimental when basins are to be sited above relatively fresh groundwater systems where contamination is to be avoided. Large basins, when placed on a similar site, will leak less and therefore present a lesser threat of groundwater salinisation per unit of water disposed (although they may cause much more significant problems locally because of their size).
4. Simulations of disposal basin behaviour predict that there is likely to be only a negligible reduction in disposal capacity when a single-bay basin is replaced with a three-bay basin system with equivalent basin area. This finding encourages the use of multiple cell basins, where the most saline bay is completely surrounded by the fresher cells, thus reducing the impacts of saline leakage on the surrounding area.

part two

Appropriate Use of Disposal Basins and Minimising Environmental Risk

5. Principles of Disposal Basin Use

5.1 Background

The intention of the following set of **principles** is to define desirable objectives for basin siting, design and management. Rather than being prescriptive, **principles** provide a general over-arching philosophy for the effective and environmentally responsible use of basins. They should apply in most situations unless there are compelling reasons to move away from them, and required social and environmental standards are satisfied. However, it is recognised that in some instances they may contradict each other and so consideration will need to be made as to which is the most important **principle** in a given situation. This chapter presents only a brief summary and justification of each **principle**, a far more detailed description of the **principles** and the philosophy behind them can be found in Christen *et al.* (2000a).

The most desirable outcome in the use of disposal basins should be achieved by adhering to these **principles**. This report aims to provide sufficient information and practical **guidelines** to ensure that future disposal basins in the Riverine Plain adhere to these **principles**. However, in many aspects this report can only provide guidance on the likely issues and their importance. The reader will need to develop the optimal solution to many factors concerned with the use of disposal basins in their region. These **principles** should be used as the overarching framework for doing this.

5.2 Principle 1

Evaporation basins should only be used for the disposal of saline drainage effluent, after all potential productive uses have occurred or the water is shown to be economically and environmentally unsuitable for use.

This **principle** has been developed in order to minimise the volume of disposal, thereby minimising the basin size and cost; and to ensure the best use of water as a resource.

5.3 Principle 2

Salts remaining in a basin due to evaporation may be stored in the ponded water and also in the soil and aquifer system below and adjacent to the basin.

This **principle** has been developed in order to maximise and maintain disposal capacity by allowing a small amount of leakage to the groundwater. (Any adverse impact of this leakage needs to be assessed and minimised - see Principle 4)

5.4
Principle 3

Salt stored below the basin should remain in the area of influence of the drainage system, or within a specific salt containment area around a basin located outside the limits of a drainage system.

This **principle** has been developed in order to encourage the retention of salt within the drainage area benefiting from the drainage water disposal.

5.5
Principle 4

Leakage from a basin should not pollute groundwater with existing or potential beneficial use.

This **principle** has been developed in order not to pollute usable groundwater resources. It is potentially in conflict with **Principle 3** as it is virtually impossible to prevent leakage from basins reaching and polluting groundwater (unless basins are lined with an impermeable material, a procedure generally not economically attractive). Land and water management planning groups will need to develop policies in conjunction with local environmental protection authority and other government agencies to allow defined *attenuation zones* around some disposal basins. Where needed, these *attenuation zones* allow some degradation of groundwater quality around the basins and are seen as necessary trade-offs in order that this method of disposal of saline drainage can be adopted.

5.6
Principle 5

Water stored in disposal basins should not be released to surface drainage systems or other inland water bodies not designed as disposal basins.

This **principle** has been developed in order not to pollute fresh surface water resources.

5.7
Principle 6

Basins should be sited, designed, constructed, maintained and managed to minimise detrimental environmental, socio-economic and aesthetic impacts.

This **principle** has been developed in order to ensure that detrimental impacts of basin use are minimised. Individual land and water management planning groups need to define minimum standards that are acceptable to the community in their region.

5.8
Principle 7

Basin owners are responsible for the consequences of the design, construction, operation and maintenance decisions related to their basin and its associated drainage system.

This **principle** has been developed in order to ensure that the basin owner is completely accountable for the safe management of their basin. For on-farm basins the basin owner will be the landholder, whereas for community basins it could be a group of landowners, an authority, or an investment group. The type of ownership has implications for the approach to ensure accountability.

6. Risk Assessment and Minimisation

6.1 Risks Posed by Basins

Basins are a potential risk to the surrounding environment, infrastructure, and human and other activities. For safe and sustainable use, their off-site impacts must be minimised.

The most important first steps in risk minimisation are to:

- ***adhere to the principles listed in Chapter 5;***
- ***employ experienced engineering/scientific experts (who preferably adhere to a quality assurance system) for basin siting, design, and preparation of management, monitoring, contingency and decommissioning plans;***
- ***ensure that clear design standards and implementation guidelines are in place; and***
- ***employ well supervised and experienced personnel for construction.***

The most serious **environmental** risk is that of basin leakage, as this may contaminate groundwater below the basin, and the resultant leakage plume may move to adjacent properties or surface water features (e.g. streams, lakes, channels). As discussed in Chapter 3, key factors which influence the extent to which a leakage plume can form and move include:

- the permeability of the basin floor, with or without compaction;
- the permeability and depth of the soil beneath the basin which determines the rate of leakage to the aquifer;
- the depth to groundwater which affects the leakage rate and overall hydraulic impact on the surrounding area; and
- the permeability and flow processes in the aquifer (*piston flow* and/or *bypass/preferential flow*) and groundwater gradient which controls the movement of the plume away from the basin.

Leakage can also cause local salinisation of land around the basin and impact on surrounding **infrastructure** such as roads and railways (through increased waterlogging and soil salinity that can affect the stability of their foundations). Buildings and other engineered structures may also be affected by leakage from disposal basins.

There are various possible impacts on **humans** such as insects (especially mosquitoes and midges), aesthetics, odours, and the blowing of salt dust. These problems with some basins have led to a poor public perception of disposal basins in general.

Other risks associated with disposal basins include their attractiveness to bird populations, leading to possible damage to adjacent crops and impacts on aircraft safety (around aerodromes). There are also risks to nearby irrigated crops and pastures, both from local salinisation around the basin and from waterlogging due to inadequate basin size (hence limited disposal capacity) and bank failure due to inadequate design.

6.2

Determining the Level of Risk and its Minimisation

The requirements for site investigation, design and management for a particular basin vary depending upon the suitability of the site, knowledge of the local hydrogeology and the level of risk the owner of the disposal basin and its drainage system is prepared to bear. The level of risk also depends on the scale of the project and possible economic and environmental impacts. Key factors that are associated with levels of higher risk include:

- large basins with high associated infrastructure costs and potentially high economic cost and/or environmental impact of failure;
- areas where there is a high level of uncertainty regarding the likely leakage rates and hydrogeology;
- investigation, design and construction carried out by inexperienced personnel;
- management carried out by those by those with little knowledge and skill;
- poor management plans and unclear accountability;
- high toxicant levels in drainage water; and
- proximity to environmentally sensitive features, infrastructure, or residential areas.

Lower levels of risk occur where:

- basins are small, with relatively low associated infrastructure costs and potentially low economic costs and/or environmental impact of failure;
- there is a good general understanding of the geotechnical, hydrogeological and biophysical systems of the site;
- management is carried out by accountable agencies with appropriate resources and experience;
- good management plans, including monitoring, contingency and decommissioning plans, are prepared, implemented and regularly reviewed; and
- investigation and design is carried out to a minimum specification, and construction is carried out by well supervised and experienced personnel.

Table 6.1 shows the factors that should be considered when determining the level of risk posed by a proposed basin, and therefore the extent of risk minimisation required.

Table 6.1 Factors determining possible risk for disposal basin sites.

Factors	Low Risk	High Risk	Unacceptable
1. Locality assessment	Detailed	Simple	None
2. Investigation and design	Locally developed guidelines and professional input	Site specific with no local guidelines available	Layperson
3. Construction	Well supervised person with specific basin construction experience	Poorly supervised person with no basin construction experience	Unsupervised person with no earthwork storage construction experience
4. Potential effects of leakage	Confined to drained area	Impact outside drained area	Impact on major infrastructure and environment
5. Other environmental impacts	Good community acceptance	Partial community acceptance	No community acceptance
6. Capital investment	Small	Large	N/A
7. Geotechnical	Well documented and meets site suitability criteria	Uncertain but expected to meet suitability criteria	Unknown, or does not meet suitability criteria
8. Management plans (monitoring, management, contingency, decommissioning)	Good plans, implemented and regularly reviewed	Poor plans or implementation and not reviewed	No plans
9. Management accountability	Covenant on land title, bond, insurance	Responsibility unclear or not adhered to	Not considered
10. Toxicants	Regular testing of basin water	Irregular testing of basin water	No testing of basin water

6.3 Strategic Assessment

From a regional viewpoint there is also a need to assess the total risk posed by various combinations of large and small or on-farm and community basins. Land and water management planning groups need to take a strategic approach when developing their preferred position in relation to the available options across any catchment. This will require careful consideration of the overall costs and benefits of drainage and salt disposal. Important in the consideration of local-scale basins for disposal is a clear understanding of the relationship between basin size and potential production losses resulting from a lack of disposal capacity. Other forms of basin failure include bank failure from inadequate design, construction or management, and excessive contamination of groundwater due to poor siting. It is also important to take into account the expected impacts of more frequent failures or part failures of a significant number of on-farm basins. This is compared to the risk of relatively rare failure of a community basin, which may nevertheless have a major impact on the community and environment in that locality. Further information on the issues related to the choice between on-farm and community basins can be found in Chapter 9.

Another key issue in risk assessment is identifying who bears the risks. This then has implications for the requirements that might apply in different cases. For example, if a small basin site serves a single landholder and is located centrally in a large property, both the economic and environmental risks associated with failure of the basin to meet the preferred **guidelines** might lie predominantly with the landholder. Land and water management planning groups may choose to allow the landholder to work to lower standards in these situations (e.g. the buffer distance around the landholder's house may be less than would generally be required). In cases where the risks are greater and are likely to be borne by other landholders or the wider community, this option would not be allowed.

6.4 Regulatory Framework

It is essential that basins be continually monitored by their owners or by an experienced agent. All basins should have management, monitoring, contingency and decommissioning plans that have been developed in consultation with and approved by a regulatory agency (see Chapter 15). Management and monitoring plans describe how the basin will be managed over its life and the monitoring that will be carried out to ensure that basin operation conforms to its management objectives. Contingency plans describe actions in response to excessive leakage, salt movement and overtopping of basin banks. They need to include containment of surface water in the local area and notification of adjacent landowners and regulatory authorities should such circumstances arise. Decommissioning plans describe how issues such as management of leakage plumes and clean up of salt and toxicants in basin sediments will be dealt with, in the event that the basin is no longer required. In addition to these plans, all basins should be registered and assessed by regulatory agencies on an ongoing basis to ensure compliance with the agreed plans.

6.5 Summary

1. The most important first steps in risk minimisation are to adhere to the principles developed in this study (Chapter 5), employ experienced engineering/scientific experts for siting, design, construction and management advice, and ensure that clear design standards and implementation guidelines are in place.
2. There are number of key factors which determine the level of risk for a disposal basin site, as set out in Table 6.1; an assessment of these should be carried out for any proposed basin.
3. Land and water management planning groups need to take a strategic approach when developing their preferred position in relation to the available options for siting and use of disposal basins across any catchment. This will require careful consideration of the overall costs and benefits of drainage and salt disposal with due consideration to identifying who bears the risks.
4. All basins should have monitoring, management, contingency and decommissioning plans that has been approved and regularly reviewed by a regulatory agency.

7. Other Potential Uses for Disposal Basins

The primary purpose of saline disposal basins is to evaporate sub-surface drainage water and store the remaining concentrated salt in a defined location. Other concurrent uses may improve financial viability of the basin, but may compromise its effectiveness for disposal.

7.1 Introduction

Apart from their primary purpose, there are a number of potential concurrent uses for local-scale disposal basins, which, if successful, could make basins more financially attractive. Three that have been attempted or proposed to date are **aquaculture, salt production** and **salt gradient solar ponds.** With the exception of one small salt production operation (near Pyramid Hill in northern Victoria), they are all **still in the research and development phase**, and should be **considered as potential uses** at this stage. A review of these possible uses is contained in RWC (1992). In addition, Lawrence (1996) provides a good summary of aquaculture options, in particular the farming of fish, crustaceans and molluscs. Information from these publications is briefly summarised in this chapter.

While the above uses may be appropriate, it is stressed that under no circumstances should saline disposal basins be used for disposal of other types of waste. Evaporation will concentrate whatever contaminants are in the basin water (see Chapter 10), and leakage will transport them into the underlying soils and groundwater. Moreover, in the event of overtopping or failure of the basin (due to poor design and/or management or an exceptionally large flood) the concentrated contaminants could escape to surrounding areas and the surface water system. This could have potentially serious consequences for the environment and the health of humans, animals, and crops.

7.2 Aquaculture

Aquaculture is the farming of aquatic plants and animals for human consumption. It is often highly specialised and is an enterprise that can carry high risks. Aquaculture will be difficult to implement by individual landholders and may best be carried out under co-operative arrangements with specialist producers. Sammy (1986) provides some general **guidelines** on the factors that should be considered when planning an aquaculture venture. Organisms that are farmed in aquaculture fall into two categories, those that are self-sustaining and those that require sustenance.

Self-Sustaining Organisms

These do not require added food as they use photosynthesis to manufacture carbohydrates, vitamins and essential oils. They are predominantly macro-algae, micro-algae and animals containing symbiotic micro-algae. Macro-algae are used primarily for agar production with the oceanic species of *Euchuema* and *Gelidium*, and the estuarine species of *Gracillaria* the most commonly grown. Many different species of micro-algae are cultured as feed (essential polyunsaturated fatty acids) for hatchery fish and crustaceans. A particular micro-alga, *Dunaliellia salina*, is cultured for the production of beta-carotene, an important food colouring. Animals containing symbiotic micro-algae include giant clams, sponges and soft corals.

Organisms Requiring Sustenance

The main organisms potentially suitable for saline basins are molluscs, crustaceans and fish. Two oyster species, S*accostrea commercialis* (Sydney Rock Oyster) and *Crassostrea gigas* (Pacific Oyster), are commercially farmed in Australia. The latter is a possible candidate for disposal basins provided that the water is clean and has the right mixture of micro algae bloom and a method for oxygenating the water is available. Brine shrimps (*Artemia* spp.) are widely grown by aquaculture and are used as feed for aquarium fish and fish and crustacean mariculture. They can tolerate high salinities, with an EC of around 160 000 µS/cm being optimum. They require a constant feed supply of yeast, powdered algae, rice bran and/or live *Dunaliellia* algae. The basins need protection from predatory wading birds and should have a bottom algal mat to supplement the diet of planktonic micro algae. Bethune *et al.* (1997) report attempts which have been made to grow a number of fish species, with the most promising being *Salmo salar* (Atlantic Salmon). One of the potential difficulties in growing fish in saline basins on the Riverine Plain is that water temperatures get too high in summer for possible commercial species. This could be overcome by using deeper basins, however this will have other design consequences (see Chapter 13).

7.3
Salt Production

Salt production is a complex process requiring specialist expertise to produce high-grade salts. It requires the use of multiple basins in series in order to precipitate the different salts present in the water. For precipitation to occur, leakage from the basins needs to be prevented, necessitating the use of expensive lining materials (usually heavy-duty PVC). In addition, large volumes of highly saline water are required to produce commercial quantities of high-grade salts. For these and other reasons (such as highly competitive markets), salt production from existing regional basins has been very limited. It is our view that salt production *per se* from small disposal basins will probably be beyond the capability of most landholders. However, if there is a nearby specialist salt producer, there may be some scope for harvesting low-grade salt or concentrated brine and selling it for further refining.

7.4 Salt Gradient Solar Ponds

Salt gradient solar ponds are bodies of water with high salinity water at the bottom, and less saline water at the surface which enable the collection of solar energy as heat. This can then be used to drive an efficient heat engine to produce electricity. Although these ponds initially require a large amount of salt (to form brine), they do not continue to require additional salt, limiting their usefulness for disposal basins.

According to RWC (1992), for basins to be used as solar ponds they would need to be constructed to about 3 m deep, and have a nearby use for the generated heat (<2 km, as it would be uneconomic to pipe the hot water any further). They also require very saline water, preferably a mixture of magnesium chloride and sodium chloride salts, in order to maximise the salinity gradient between the top and bottom layers. Production of brines such as these requires the use of multiple basins that are lined (usually with heavy-duty PVC) to prevent leakage (i.e. similar conditions to those required for salt production). While solar ponds clearly have potential as renewable energy sources, at this stage they are in the research and development phase.

7.5 Summary

1. The primary purpose of saline disposal basins is to evaporate sub-surface drainage water and store the remaining concentrated salt in a defined location. Other concurrent uses may improve financial viability of the basin, but may compromise its effectiveness for disposal.
2. These other uses are mainly in the research and development phase, and should be considered as potential uses only.
3. All these uses require considerable specialised expertise and carry potentially high financial risks.

part three

Strategic Assessment

8. Strategic Assessment for Land and Water Management Plans

8.1 Introduction

As discussed in Chapter 2, possible disposal options include salt export to regional basins or streams, water re-use and local basins. There are constraints on salt exports to streams within the Murray-Darling Basin due to the requirement to comply with the MDBC Salinity and Drainage Strategy and environmental protection authority requirements. We emphasise that there is a need for natural resource managers, as part of their regional *L&WMPs*, identify what the longer-term salt management strategy will be (100-200 years), and to ensure that salt disposal basins which are built are sited such that they fit in with that strategy.

This chapter will:

- discuss issues to be considered for regional scale assessment of suitability for either on-farm or community basins;
- describe a technique which may be useful for coarse regional scale assessment of suitability; and
- discuss economic and financial aspects of local basins.

When land and water management planning groups are developing strategic plans for salinity control, they should consider the following:

- level of service to be provided;
- assessment of drainage volumes to be disposed;
- identification of disposal options and constraints; and
- economic and financial assessment of options.

In relation to the fourth point, it is important to note that disposal basins are costly and will not make drainage more financially viable, rather the opposite. It is unlikely that drainage will be affordable for low value crops, let alone with disposal to a local basin. It is therefore important that land and water management planning groups assess the likely financial viability of drainage for crops in their area very early in the planning process.

In areas suitable for drainage, all opportunities to minimise current and future disposal volumes should be considered, including:

- improved irrigation efficiency;
- water re-use; and
- whether drainage is for control of salinity and waterlogging.

The first two of these issues are an extension of Principle 1. The relationship between irrigation efficiency and area of disposal basin is discussed in Chapter 11. The third issue is discussed in Chapter 10 where it is pointed out that the volume of water to be disposed can be significantly reduced if the drainage system is designed to control salinity rather than waterlogging. In this case the salinity of the drainage water is also likely to be higher. Estimates of the volume of drainage water produced by horizontal pipe drains or groundwater pumps can be made using the methods described in Chapter 10. The volume to be discharged to any disposal basin can then be estimated after allowing for reductions due to any re-use of the drainage water.

8.2 Suitability

Before developing policies for local-scale basins, it is important to have an assessment of those parts of any region where such basins can be constructed with little risk of failure. Not all areas of the Riverine Plain are suitable for local-scale disposal basins. If a site is not suitable, then it will be difficult and expensive to engineer and manage the basin in a safe and sustainable manner. If there are insufficient suitable areas for local-scale basins in a particular region, alternative disposal methods will be required or drainage may not be possible for all of the areas where it is required. However, in the absence of drainage, it can be expected that saline areas and hence salt wash-off will increase (i.e. failure to install drainage will result in some impact on downstream resources).

This section is concerned with the procedure for:

1. determining whether enough suitable area is available; and
2. identifying in general terms where basins can be sited.

While it is difficult on a regional basis to precisely determine suitable locations for individual basins, it is possible from available spatial data to estimate the probability of finding suitable land within a given region, and its general location within a region. The procedure can, in some cases, show areas where on-farm basins are unlikely to be feasible and community basins would be the only available option.

Important: in addition to a regional assessment, detailed site investigation is always required in order to decide whether a particular site is suitable.

A Geographical Information Systems (GIS) based approach is described which uses suitability criteria expected to minimise the off-site effects of basins. As an example, we have used preliminary estimates of thresholds for the suitability criteria to demonstrate the methodology for the main irrigation areas of the Riverine Plain (Dowling et al., 2000). **These threshold estimates are subjective, having been selected on the basis of**

both data quality and experience of the authors. In reality, the decisions on threshold values will need to be made locally, based on community attitudes and needs. The method used is relatively simple and should be able to be applied where there are GIS professionals. The analysis described here uses fairly coarse data-sets, but the method is amenable to finer scale data-sets, if available. The main value of the analysis is to provide a coarse scale ranking of the relative suitability of land within different regions.

8.3
What Defines an Area as Being Suitable for a Basin?

The suitability of an area for a basin is defined by the extent to which the risks described in Chapter 6 are eliminated, or minimised. Suitability criteria, which have this aim, will be site-, region- and community-specific. However, it is possible to identify a range of physical, social and economic factors in a generic way, which defines the suitability of a region for local-scale basins.

The main physical factors are concerned with minimising leakage and its impact. As such, areas with low permeability soil (control leakage), groundwater which is saline (limited use) and shallow (control leakage, minimise hydraulic gradients), and remote from surface water features (streams, lakes, channels) are suitable because these conditions minimise the risk of leakage and its impacts. At the same time, it is recognised that the combination of shallow and saline water tables also introduces a risk of local salinisation if basins are not constructed to acceptable standards.

Social and infrastructure factors associated with off-site effects of basins mean that they should not be placed close to urban areas, community facilities, roads, railways or aerodromes.

There are also many economic factors associated with the use of local-scale basins. These are primarily concerned with the trade-off between the loss of productive area occupied by the basin with the benefits of water table control in the drained area. Moreover, in regions with small properties sizes there may not be sufficient suitable area on any one property. These regions may not be suitable for on-farm basins, so community basins are likely to be more appropriate. The use of community basins also raises economic issues such as land equity and compensation.

8.4
GIS Regional Assessment Methodology

Maps of available spatial data for the above factors can be combined to produce a map of the overall suitability of a region. A Geographical Information System (GIS) framework can be used to carry out the complex manipulation of the digital maps. The methodology is fully described in Dowling *et al.* (2000). In brief, suitability ranges are defined separately for each of the factors, which are then combined according to relative importance (priorities defined by the user) to derive a manageable number of overall suitability classes ranging from optimal to not suitable.

At a regional scale, only a limited number of data sets are presently available. For the entire Riverine Plain, the most uniform and complete data sets are currently only available at the 1:250 000 scale. Using data of this scale means that a regional assessment cannot precisely determine suitable locations for individual basins. However, it is useful for determining the probability of finding suitable land within a given region, and its general location. At this scale, data are available for water table depth, groundwater salinity, infrastructure (roads, railways, urban areas, surface water features), soil landform, and topography (digital elevation model).

While the soil landform map provides some information on soil texture, it is insufficient to provide accurate estimates of leakage (Dowling *et al.*, 2000). Another point to note is that no data presently exists at this scale for property boundaries and land values, and so economic impacts cannot be included in the analysis. It is probable that these types of data will increasingly become available in the future.

8.5 Example of Methodolgy

The following is an example (from Dowling *et al.*, 2000) of the GIS regional assessment methodology applied to the main irrigation regions of the Riverine Plain using the available data at the 1:250 000 scale (250 m grid cell). Areas not suitable for basin siting were defined by criteria based on a combination of proximity to important surface features (e.g. roads, railways, stream, drains, irrigation channels, lakes, swamps, urban settlement and aerodromes) and the following four suitability classes:

- **S1, highly suitable** – impermeable soil *and* shallow saline groundwater
- **S2, moderately suitable** – moderately permeable soil *and* deeper water table *and* less saline groundwater
- **S3, marginally suitable** – permeable soil *and* moderate depth to water table *and* reasonably fresh groundwater
- **N, not suitable** – permeable soil *or* deep water table *or* fresh groundwater

There were no recognised guidelines for the threshold values for each of the factors in these classes and so those used here are considered as a first approximation, based on both data quality and the experience of the authors. **They should be considered only as reasonable examples that demonstrate the methodology.**

To estimate the area around important surface features that is **not suitable**, a combination of *buffer zone* and map grid size were used:

- If a particular 250 m grid cell contained a linear feature (*roads, railways, stream, drains, irrigation channels*), then the entire cell was deemed to be **not suitable** – an effective buffer of 125 m around that feature.

- For l*akes and swamps*, a 50 m buffer zone was first drawn around the feature. The **not suitable** area was then the combined area of any cell within that zone – an effective buffer around these features ranging between 50-300 m.
- A 1000 m buffer was placed around *urban settlement* and *aerodromes*.

Following this, the land suitability was defined by both the above buffer areas and the following thresholds:

- **S1**: water table depth <5 m and groundwater salinity >7000 mg/L
- **S2**: water table depth <5 m and groundwater salinity >3000 mg/L
- **S3**: water table depth <10 m and groundwater salinity >3000 mg/L
- **N**: water table depth >10 m or groundwater salinity <3000 mg/L

The overall suitability maps are shown below for the Shepparton Irrigation Region (SIR; Figure 8.1), Murrumbidgee Irrigation Area (MIA; Figure 8.2), Coleambally Irrigation Area (CIA; Figure 8.3), Murray Irrigation Limited area (MIL; Figure 8.4) and the Kerang/Cohuna area (Figure 8.5).

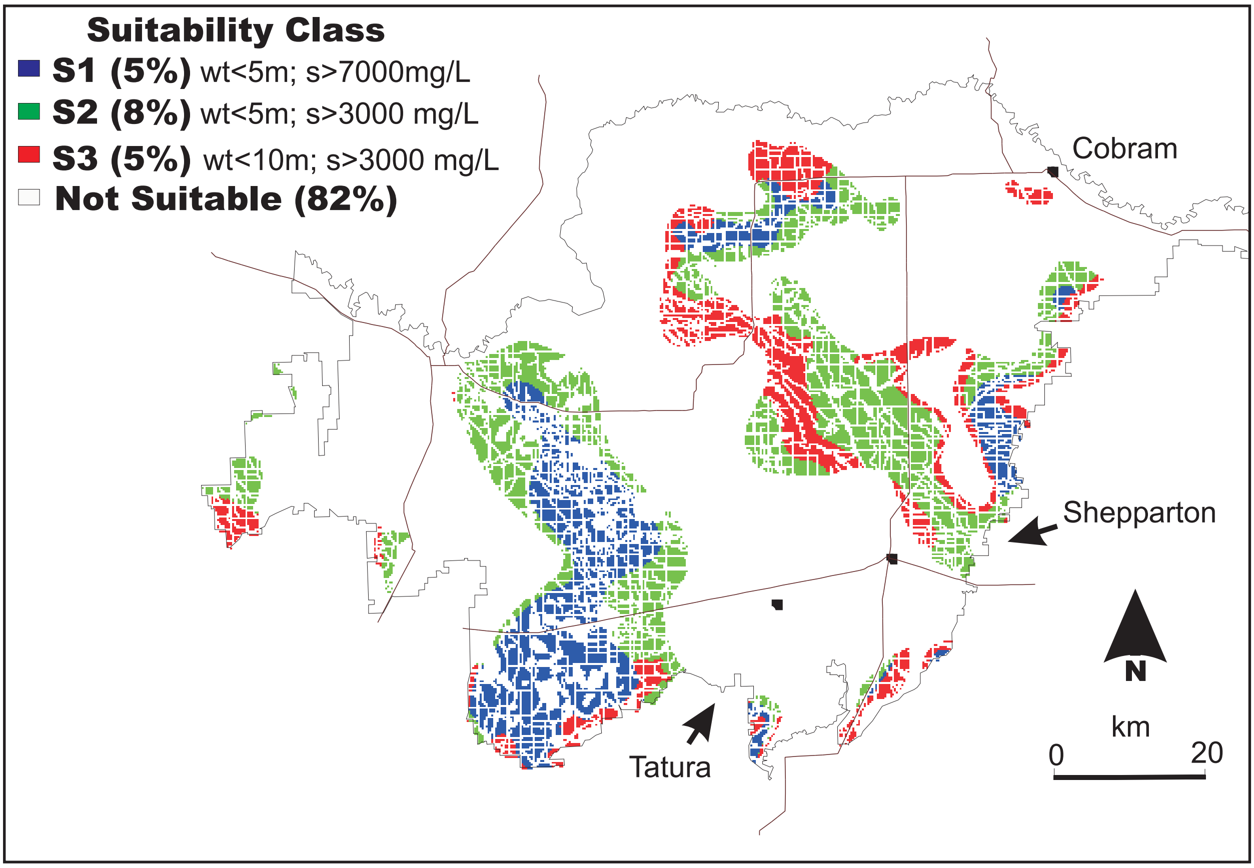

Figure 8.1 Overall suitability of land in the Shepparton Irrigation Region based on infrastructure and surface water features buffer zones, water table depth and groundwater salinity. S1 is the area with optimal conditions, S2 and S3 have water table depth and groundwater salinity relaxed, and N is the area ***not suitable*** *for local-scale basins.*

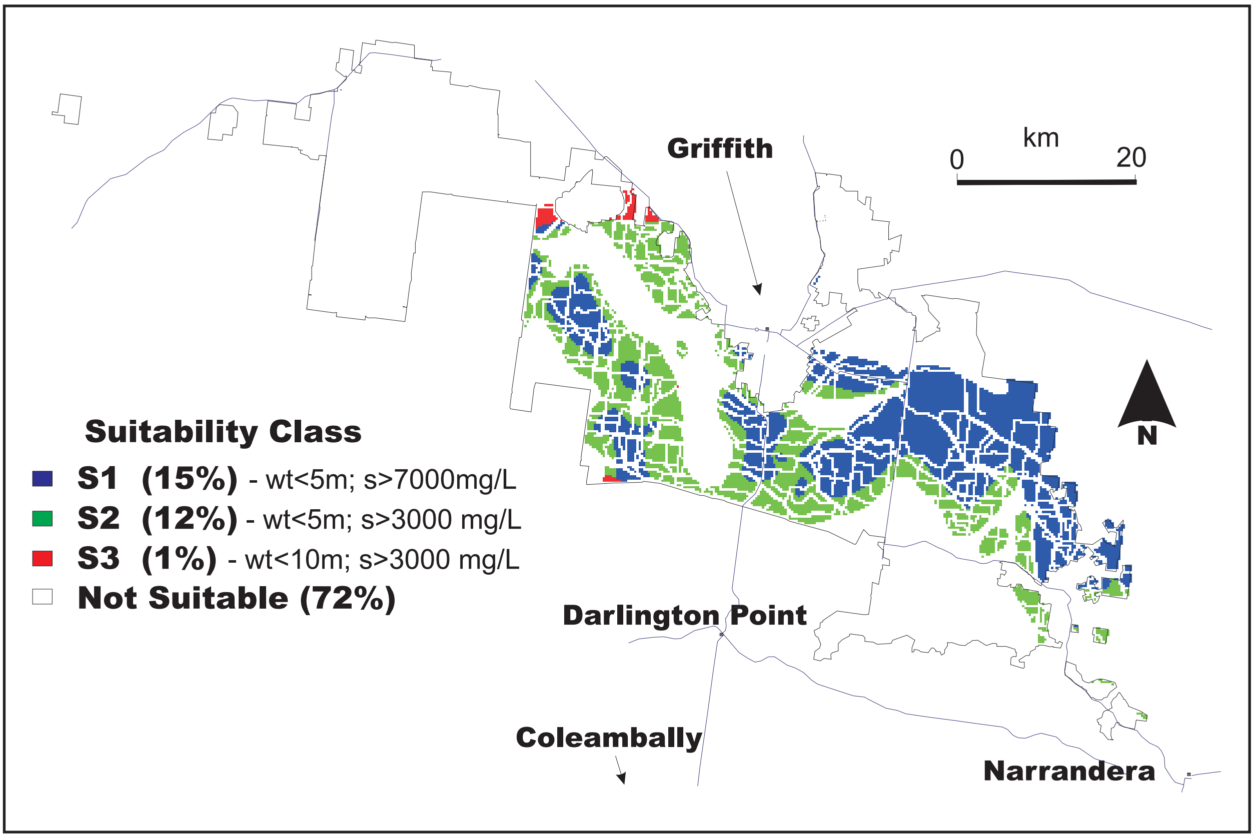

Figure 8.2 *Overall suitability of land in the Murrumbidgee Irrigation Area based on infrastructure and surface water features buffer zones, water table depth and groundwater salinity. S1 is the area with optimal conditions, S2 and S3 have water table depth and groundwater salinity relaxed, and N is the area **not suitable** for local-scale basins.*

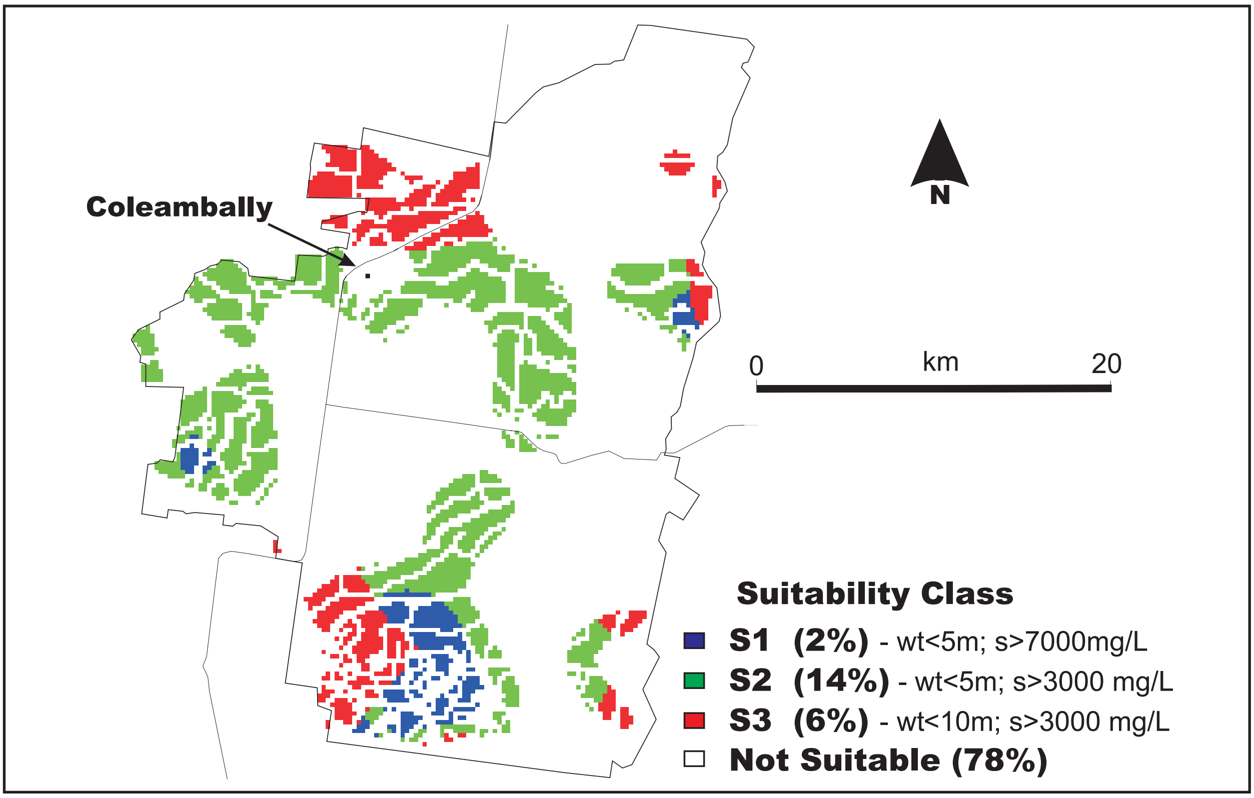

Figure 8.3 *Overall suitability of land in the Coleambally Irrigation Area based on infrastructure and surface water features buffer zones, water table depth and groundwater salinity. S1 is the area with optimal conditions, S2 and S3 have water table depth and groundwater salinity relaxed, and N is the area **not suitable** for local-scale basins.*

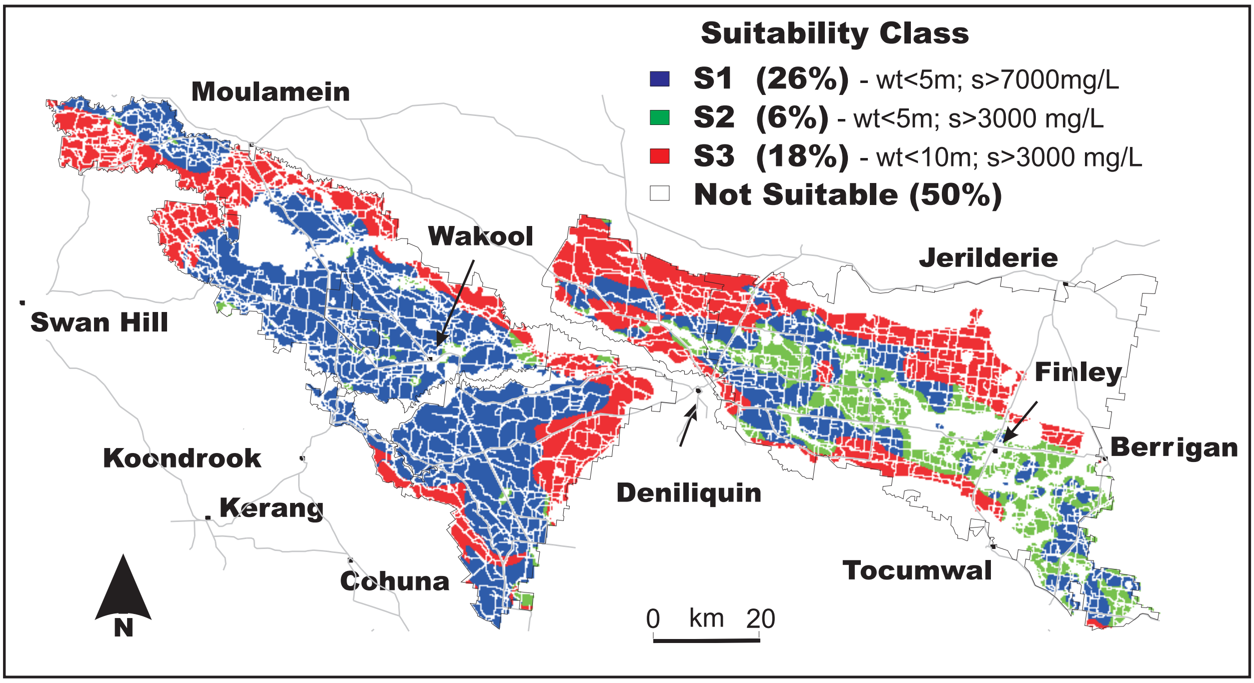

Figure 8.4 *Overall suitability of land in the Murray Irrigation Limited area based on infrastructure and surface water features buffer zones, water table depth and groundwater salinity. S1 is the area with optimal conditions, S2 and S3 have water table depth and groundwater salinity relaxed, and N is the area* ***not suitable*** *for local-scale basins.*

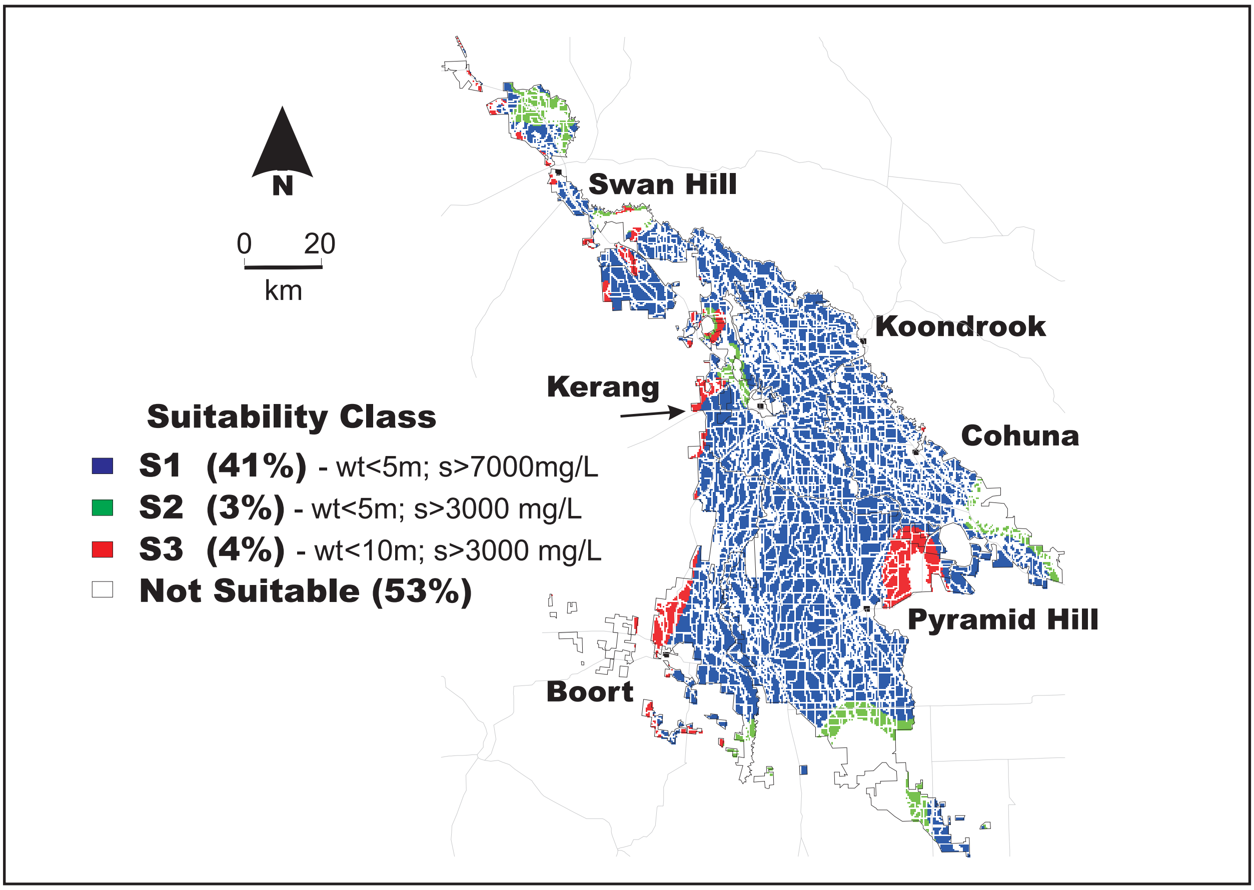

Figure 8.5 *Overall suitability of land in the Kerang/Cohuna area based on infrastructure and surface water features buffer zones, water table depth and groundwater salinity. S1 is the area with optimal conditions, S2 and S3 have water table depth and groundwater salinity relaxed, and N is the area* ***not suitable*** *for local-scale basins.*

Comparison of the proportion of each area that is **not suitable** indicates a grouping of the eastern districts (MIA, CIA, SIR) between 72-82% and another of the western districts (MIL, Kerang/Cohuna area) of 50–53%.

8.6
Implications of Regional Assessment

While the quality of the available data has some limitations, the methodology can provide some valuable planning insights. In particular, it helps identify in broad terms how much land is available for basins and where it is most likely to be found. The estimated amount of suitable land provides some idea of the feasibility of using only local-scale basins to dispose of all of the drainage water from an area. This may be particularly useful for strategic planning at a Riverine Plain level when considering the range of salt disposal options required across all of the irrigation regions.

As discussed in Chapter 11, about 10% of the irrigated land that is drained (probably around 2-5% of the total land area) will be needed for local-scale basins. If sufficient suitable land is not available, then salt may need to be exported outside of the irrigation area to regional basins. The distribution of suitable land provides some idea as to whether on-farm or community basins are more suitable. For on-farm basins to be widely used it is necessary for suitable land to be widely available. There are fewer restrictions for community basins as drainage water can be transported to more suitable areas.

It is important to note that, in the above examples, no information on criteria such as soil hydraulic conductivity, land value, land availability and farm size were used. If these were incorporated, then the proportions of suitable land will be even lower again and the values above represent the maximum values likely. With this in mind, it seems that it could be difficult to store all of the drainage water within the SIR as only 5% of the area appears to be most suitable for disposal basins. Hence, salt export may be required, as was envisaged in the Shepparton Irrigation Region Land and Water Salinity Management Plan (SPPAC, 1989). Similarly, in the MIA, there appears to be only limited areas most suitable for basins, although the proportion of most suitable land appears to be higher (15%). The CIA has the lowest of all in that only 2% are in the most suitable class. The Kerang/Cohuna and MIL districts contrast with the MIA and SIR in that much higher fractions appear to be most suitable for disposal basins (41% and 26% respectively). The reason for these differences appears to be groundwater salinity. For Kerang/Cohuna and MIL, 88% and 67% of the area overlie groundwater of salinity of more than 7000 mg/L, while this is only the case for 8%, 14% and 22% for CIA, SIR and MIA respectively.

These results raise questions as to the type of local-scale basin that can be used to store drainage water. For on-farm basins to be widely used it would be necessary for suitable land to be available everywhere in the area where irrigation is carried out. Irrespective of the criteria thresholds used, this is clearly not the case in the MIA, SIR and CIA. Thus, on-farm basins can only be opportunistically used in these districts, but can be used widely across Kerang/Cohuna and MIL. Conversely, community basins can be used anywhere in these areas where suitable land is available. However, the cost of purchasing good quality land and the costs of transporting water significant distances will be important considerations.

As described earlier, this analysis is only an example of the methodology based on coarse data and threshold values defined by the authors. While the numbers themselves may be queried, the overall trend and the magnitude of the trend appear to be real and so the analysis is identifying important differences between the irrigation districts.

8.7 Financial and Economic Considerations

The analysis described in Chapter 14 suggests that drainage systems with disposal to local basins may not be financially viable in many cases. Successful drainage with local disposal basins is:

- best suited to crops that have high yields and prices and crops that are sensitive to waterlogging as well as salinity;
- more economically viable for existing plantings than new developments, although provision should be made in new developments for future installation of works when required; and
- related to the standards of irrigation management, as these have a major bearing on the need for drainage and the volumes of water for disposal.

In some cases investment in improved irrigation infrastructure will be more financially attractive than investment in drainage works, especially when a basin is required. Furthermore, as discussed in Chapter 9, often there will be little difference in the economic costs and benefits of on-farm and community basins. The decision to construct a community basin rather than a series of on-farm basins is likely to be based, in many cases, on other factors, as is also discussed in Chapter 9.

Land and water management planning groups need to:

- be aware that local-scale disposal basins, whether on-farm or community, may in some cases be neither technically feasible nor financially viable; and
- ensure that all proposals for new basins are:
  - based on property development plans which include a high standard of irrigation infrastructure; and
  - accompanied by a comprehensive financial analysis.

8.8 Summary

1. A regional assessment based on broad scale spatial data can provide an indication of the amount of suitable land and its likely distribution. The examples show that the irrigation areas in the Riverine Plain differ with respect to the use of local-scale basins.
2. An estimate of the amount of suitable land is useful for determining whether local-scale basins alone can dispose of the required volumes of drainage water. In some cases it may be necessary to export salt to regional basins, find other means of disposal or forgo some drainage works.
3. Information on the spatial distribution of suitable land can provide a guide to the most appropriate parts of a region where local-scale basins are to be implemented.
4. Regional assessment is suitable for strategic planning purposes but is not appropriate for the precise siting of local-scale basins, and a specific site investigation will always be required.
5. Disposal to local-scale basins is not likely to be financially viable in cases of poor irrigation efficiency, small farm sizes and low-value crops.
6. There is no obvious difference in economic costs and benefits between on-farm and community basins.
7. Proposals for new basins should be accompanied by property development plans, which include a high standard of irrigation infrastructure, and a comprehensive financial analysis.

9. On-Farm or Community Basins?

9.1 Differences

The choice between on-farm and community basins is governed by factors such as site conditions, environmental risk, landholder preferences, and regional planning objectives. The key difference between the two types of basins is that community basins are shared by a number of farms, while on-farm basins are not. In the context of these **guidelines**, both on-farm and community disposal basins can be large or small and have the same basic function. With a community basin the subsurface drainage system may also be shared to provide protection for more than one farm, as is usually the case with groundwater pumps that have a large area of influence. Alternatively, a number of individual farm drainage systems may share a community basin, which is more likely to be the case for horizontal pipe drainage systems. A community basin may be owned and operated by either an authority or investment group operating under a service agreement, or by a group of landholders.

Scale

The design, siting and construction for on-farm and community basins are both affected by the processes discussed in Chapters 3 and 4. The main difference being that of scale as the community basin area for the disposal of water from any particular drainage scheme will be approximately the sum of the individual on-farm basin evaporative areas. However, since a community basin will be larger than the individual on-farm basins, the community basin will tend to have lower leakage due to the lower perimeter to area ratio and lower evaporation due to the *oasis effect* (see Figure 4.4). This therefore means that the evaporative area of a community basin will need to be slightly larger than that of the sum of the on-farm basins. However, because of factors such as buffer areas and bank widths, multiple small basins actually require more land for a given evaporative area. The difference in total area required will need to be determined on a case by case basis, as it will depend on the number and size of basins planned.

Drainage Water Transport

The other main difference between on-farm and community basins is that, for a community basin, a system of pipes is usually required to transport the drainage water from the groundwater pumps or horizontal pipe drainage scheme to the basin. For smaller existing community basins, such as Girgarre

(30 ha), the groundwater pumping is in the close vicinity of the basin (<1 km) serving only a few farms. In this case the water is pumped over relatively short distances. In very large community schemes, such as Wakool, many farms are served and the drainage water is pumped several kilometres to a very large basin (~2000 ha). The transport of drainage water to a community basin can represent a significant cost. This is discussed more fully in Chapter 15.

Drainage water is usually transported in pipes because open channels have problems with leakage from the channel, and because groundwater and surface runoff may flow into the channel. The use of the existing surface drainage networks is usually not possible because the basin would then need to dispose of surface run off water also. This is undesirable because the surface run off water usually has a much lower salinity than the subsurface drainage and should not be disposed of into the basin (Principle 1).

Siting and Cost Sharing

In the case of on-farm basins, the overriding physical constraint is whether there is an appropriate site on the farm where the basin can be located (see Chapter 12). There may also be financial reasons such as the farm size or land availability (in terms of sale price or opportunity cost) that makes an on-farm disposal basin unviable (Chapter 14). In the case of a community basin, there is a wider area available for site selection but the positioning of a basin may be restricted by socio-political considerations. Getting community consensus on the best basin site may be difficult due to competing interests. It is unlikely that landholders will be happy to have a basin on or near their property due to the perceived risks.

Cost sharing for a community basin also requires careful consideration so that there is equity between those involved. Issues such as these may be resolved in some situations by authority ownership of the land and the basin. A user pays charging system for on-going management and maintenance costs is required, in order to encourage landholders to minimise their drainage. This requires that drainage volumes are monitored. For example, where groundwater pumping is used, it may be possible for land and water management planning groups to set rates according to the level of drawdown on each farm after a pumping test, as is presently done in the SIR Land and Water Salinity Management Plan (SSPAC, 1989). For on-farm basins, the above complications do not arise as the beneficiary of the system also has to bear all the costs and inconvenience.

Management

The management requirements for community and on-farm basins are likely to be quite different. The volume of water in on-farm basins tends to closely reflect the irrigation management and climatic conditions prevailing on the farm at that time. This is especially the case with horizontal pipe drainage systems where the area of influence is limited and water tables can rise and fall rapidly. Farmers tend to adjust their irrigation and drainage management practices in accordance with the volume of disposal available in their basin. In this way, the basin provides direct visual feedback on the farm's water management situation. This can encourage farmers to improve their irrigation management practices, even to the extent of no longer using all the cells of their basin.

Community basins tend to be maintained at a near constant water level. This is in part due to the larger buffering capacity of a community basin, but to a greater extent because they have generally been associated with groundwater pumping drainage systems. With groundwater pumping the system is usually pumped for long periods of time resulting in a gradual drawdown of water tables. This process tends to be lengthy (months) and only reflects on-farm productivity over the long-term as salinisation and waterlogging is reduced. For horizontal pipe drainage systems disposal volumes are likely to be much more seasonal. Given the requirement for year-round coverage of water in basins (to help maintain low leakage rates, see Chapter 4), very careful management of the contributing drainage systems will be imperative. A community basin will also need clearly agreed protocols for:

- drainage access to the basin (if more than one pump or horizontal pipe drainage system is disposing to it);
- operating rules and responsibilities; and
- cost-sharing.

These issues will be less important if the basin is managed by an authority or investment group (operating under a clearly defined service agreement) than if the basin is operated by a group of landholders. If community basins are to be managed by landholder groups it is desirable that relevant land and water management planning groups provide model agreements to facilitate the process and encourage consistency in operations and cost sharing.

9.2
On-Farm Basins

In general, the **advantages** of on-farm basins are:

1. All costs of designing, operating, monitoring and maintaining the basin are borne by the primary beneficiaries of the drainage development.
2. The ownership and responsibility for the basin remains with the primary beneficiaries.
3. There is a direct cost incentive for the landholders to improve irrigation efficiency and drainage management so as to reduce drainage volumes.
4. The physical presence of the basin on-farm has a strong psychological impact on farmers irrigation management as the results of over irrigation or over drainage are immediately visible.

5. The environmental and human impacts of the basins are generally restricted to primarily the landowner.
6. There is no export of salt from the place of extraction.

In general, the **disadvantages** of on-farm basins are:

1. It may be difficult to find suitable sites.
2. These basins will generally be smaller and so leakage rates will be potentially higher. The basins have to be placed somewhere on the farm and so there is a higher probability of using unsuitable sites.
3. There are greater construction costs per basin area and larger buffer areas per basin area (due to small basins having large perimeter to area ratios).
4. They pose a potentially higher environmental and human risk due to the probability of lesser controls on their siting, management and monitoring.
5. Large numbers of on-farm basins complicate long-term regional planning and may be very difficult to decommission if a better salt disposal or storage method becomes available in the future.

9.3
Community basins

In general, the **advantages** of community basins are:

1. They provide a better opportunity to find suitable sites.
2. Leakage rates will be generally lower due to larger basin sizes and the lower probability of using unsuitable sites.
3. The construction costs and buffer areas are less per basin area due to the generally larger basin sizes.
4. They pose a lower environmental and human risk due to better siting and probable better quality of management and monitoring.
5. Salt production or aquaculture are potentially more feasible as more water is available and inflows are more regular.
6. Smaller numbers of larger community basins make long-term regional planning simpler and will be easier to decommission if a better salt disposal or storage method becomes available in the future.

In general, the **disadvantages** of community basins are:

1. There is a need to get community agreement to the scheme and cost sharing arrangements. There are serious questions of what to do with the minority of landowners who don’t want the scheme but may benefit anyway.
2. Compulsory acquisition to provide appropriate siting may lead to land equity and other legal disputes.

3. The distribution of site purchase, construction, operating and monitoring costs to beneficiaries may be complex and difficult (although ownership of the land and basin by an authority or investment group can overcome this).
4. Monitoring of drainage, in terms of quality and quantity, is required in order to ensure that the drainage water is of an acceptable quality (pesticides especially) and in order to distribute costs (which should be on a *user pays* principle).
5. Since the disposal of the drainage water is remote from the farm and shared between a number of farmers, the measuring of and charging for drainage water must be sufficiently sensitive that it ensures a high standard of water management. This will ensure the basin does not have to be over designed.
6. They require high levels of construction, management and monitoring expertise due to their greater technical complexity.
7. Construction and operating costs may be higher in some situations due to need to transport water greater distances.
8. A long-term commitment on the part of the beneficiaries is required (for reasons outlined above).
9. While they pose less risk to the environment and the community, it may be difficult to obtain community acceptance due to the perception that *big is bad.*
10. There is export of salt from the place of extraction (but not necessarily from the irrigation region).

9.4 Cost Comparisons

The key difference between the 2 types of basin in financial terms is in the establishment cost. For a community basin, the water is transported from the farms or shared groundwater pumps to the basin, while for on-farm basins there is minimal transportation required. However, there is some trade-off because the construction cost of a large basin is cheaper per unit area than a small basin because of the relative bank length and the need for compaction in smaller basins.

Analyses carried out in this project (see Singh and Christen, 2000c) showed that the construction cost of a community basin was 21-36% lower than on-farm basins for the same horizontal pipe drainage scheme. However, this was balanced by the transportation cost that added to the total cost of a community basin by about 24-30%. Overall, the community basin cost was 3-12% less than individual on-farm basins under conditions of land trading between the farms to optimise the basin siting. Whilst in other cases the community basin cost was about 10-25% higher due to increased costs for additional land purchase and drainage water transportation.

The cost to some individual farmers with a community basin increased considerably above the on-farm cost, despite the fact that the overall cost of community basin was less than on-farm basins considered together. These individual variations in costs were due to variation in the drainage transport cost according to the position of the farms.

An analysis of the existing Wakool Basin compared to hypothetical replacement with 16 smaller community basins or 48 on-farm basins, found that there was negligible difference (2-8%) in the *NPC* between each option. The increasing basin construction costs as the basins get smaller is almost balanced by the decreasing drainage transportation costs.

In both the MIA and Wakool analyses the cost differences between community or on-farm basins were marginal. Thus, in deciding between on-farm, small community or large community basins other environmental and/or social considerations should outweigh the negligible economic differences.

9.5
Making the Choice

The selection of the most appropriate type of basin for a given drainage development will depend on a range of physical, economic and human factors. Community basins may be adopted where on-farm basins are not feasible, the community prefers that option, or they provide clear economic or environmental advantages. A key issue in the adoption of a given community basin will be resolving all equity issues with regard to siting and cost sharing arrangements. Community basins should be considered where a suitable site exists within a reasonable distance and other economic and socio-political considerations can be satisfied. If no suitable sites exist for either on-farm or community basins, then export of salt to a regional basin should be investigated. If this is not possible then the drainage development should not proceed unless alternative disposal can be justified and agreed.

Another consideration is that management and monitoring of a single large basin is likely to be significantly easier than the management and monitoring of an equivalent area of multiple single basins. This is likely to affect the ongoing costs incurred by regulatory authorities. Moreover, from a regional decommissioning perspective, it may be better to have fewer community basins rather than numerous small on-farm basins. This would make final disposal of salt by a pipeline to the sea much easier, should it ever become economically viable.

9.6 Summary

1. The choice between on-farm or community basins should consider physical, environmental and social-political issues as well as cost. Economic analyses suggest that there will generally be little cost difference between the two options.
2. Community basins require careful decisions with regard to siting and cost sharing, to ensure equitable distribution of costs among those landholders that benefit.
3. A community basin may be owned and operated by either an authority, investment group, or by a group of landholders.
4. If community basins are owned and managed by an authority, then they should have a clearly defined service agreement with its customers. If community basins are to be managed by landholder groups, it is desirable that relevant catchment planning groups provide model agreements to facilitate the process and encourage consistency in operations and cost sharing.
5. From environmental risk management, monitoring and regional decommissioning perspectives, it would be better to have fewer large community basins than many small on-farm basins.

part four

Siting, Design and Management Guidelines

10. Disposal Requirement

10.1 Introduction

An important step in the planning of a new drainage project is to determine the disposal requirements for the proposed land use. For disposal basins, this involves the assessment of the likely quality of the drainage water and the volumes of drainage that will require disposal.

10.2 Determining Drainage Volume

General Considerations

In determining drainage volumes, it is necessary to consider whether full water table control is required or whether a minimum leaching fraction, which will maintain an acceptable long-term rootzone soil salinity, is sufficient. If full water table control is required, then the design needs to allow for drainage rates that will keep the root zone adequately aerated. This will result in more drainage water than for a long-term salt balance based on drainage of the minimum leaching fraction.

Drainage Volume for Long Term Salt Balance

This is the simplest drainage volume calculation and is suitable, as discussed above, for crops where waterlogging is not a major threat such as perennial pasture. This method does, however, also provide the baseline (absolute minimum) value for other crops that can then be increased to deal with waterlogging. It should be noted, that with very good irrigation management and proper surface drainage, this may also be considered the appropriate drainage volume for waterlogging sensitive crops. To determine the drainage volume for salinity control the following steps are required:

1. Determine mean annual volume and salinity of irrigation water for each crop.
2. Assess crop sensitivity to salinity. Thresholds for soil salinity causing yield decline are widely available for most crops and soil type and allow the determination of an appropriate drainage salinity and thus leaching fraction (Rhoades, 1974; FAO, 1976; and Rhoades and Loveday, 1990). Typical leaching fractions that provide safe salinity control for most crops on most soils of the Riverine Plain using surface water are in the range of 5-10% of the irrigation water applied. Irrigation using more saline water will need higher leaching fractions.
3. Assess the area of the drainage system and different crops to provide a land-use area weighted volume.

This gives a total volume of water to be disposed of per year. In horizontal pipe drained horticulture this could vary from 0.2-0.6 ML/ha/year for wine grapes to 0.6-0.8 ML/ha/year for citrus. Drainage volumes produced by groundwater pumping are more difficult to determine, but can be estimated based on local experience to derive *rules of thumb*. In the case of the SIR extensive experience suggests that average groundwater extraction rates in the range of 0.5 to 1 ML/ha/year are needed if a grid of pumps is to provide an adequate level of sub-surface drainage. For a specific site the volume to be disposed would be based on the results of site testing to determine both the potential site capacity and the capacity required to serve the area to be protected. This would require an extended pump test (over at least 3 weeks), with monitoring of both pump output and groundwater level responses across a significant proportion of the area to be protected.

Allowing for Local and Regional Groundwater Flows

The above methods are based on the premise that water tables are not extremely shallow (i.e. they are >1 m) and there is not significant lateral groundwater inflow or upward leakage from deeper aquifers. Both of these will cause higher rates of capillary upflow and salinisation. If the area has shallow water tables due to lateral or upward inflows, then the drainage volume will need to account for these. Assessment of these volumes is not easy, but has been estimated in at least two studies. In the Kerang region a horizontal pipe drainage system was found to drain 0.8 mm/day (~2.9 ML/ha/year) to control upward leakage from deeper aquifers (Smith *et al.*, 1985). In the MIA, there is no upward leakage from deeper aquifers, however horticulture developments with horizontal pipe drainage are being sited in areas surrounded by rice growing and broad acre cropping, leading to potential inflows to drainage systems. An analysis by van der Lely (1993) showed that 20 ha horticultural development using horizontal pipe drains in such a situation could experience groundwater inflows of up to 1 ML/ha/year.

Drainage After Rainfall

Apart from groundwater inflows, the effect of rainfall on the design drainage volume needs to be considered. Rainfall and subsequent waterlogging at certain periods of the year can have a significant impact on crop growth or threaten productivity (e.g. in early spring for deciduous crops and at harvest time for all crops). At other times of the year, rainfall may have little impact (e.g. mid summer rainfall is unlikely to cause significant waterlogging and mid winter waterlogging may have little effect on a dormant crop such as grapes). Irrigation method and management also affect drainage volumes resulting from rainfall. Poor irrigation management will lead to greater drainage from rainfall and good irrigation management may result in very little. Figure 10.1 shows how rainfall and irrigation interact.

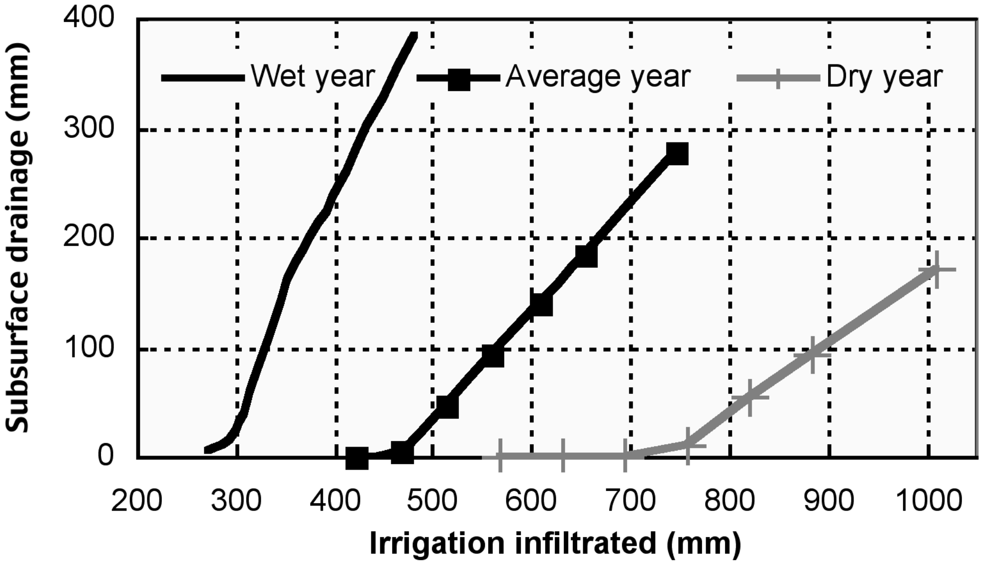

Figure 10.1 Increasing drainage volume with increased irrigation, for modelled citrus in MIA.

Drainage After Irrigation

Irrigation induced waterlogging can result in significant yield loss. However, to design a drainage system and its disposal basin for poor irrigation practice is not justifiable. The costs of the system will increase significantly with inefficient irrigation as the drainage volume increases, and the basin will need to be much larger. Moreover, allowing such an *over-designed* system that permits poor irrigation management does not promote better water use practices. Experience with on-farm disposal basins in the MIA has shown that disposal basins that are designed for high levels of irrigation efficiency work successfully. This is because farmers have dramatically improved their water use efficiency as a result of the restriction a disposal basin has imposed on their ability to drain.

In horizontal pipe drained horticulture in the MIA, the drainage volume is in the order of 0.8 ML/ha/year in a dry year and around 1.6 ML/ha/year in an average year for farmers without a disposal basin. Studies of farmers with a disposal basin have been found to drain about 1.1 ML/ha/year in an average year. Thus, as long as an appropriate drainage volume is selected which will protect crops in the long-term, farmers tend to adjust their practices to comply with that requirement.

A Suitable Compromise

A simple practical solution to ascertaining a suitable drainage volume is to determine a suitable leaching fraction (based on the irrigation water quality and the crop sensitivity to soil salinity) and apply that to the average irrigation amount as a base level. In addition, 10-20% of the average annual rainfall, or the total average rainfall during critical periods of crop growth, can be added. This will result in a reasonable drainage volume that will primarily provide salinity control, with some additional waterlogging control. In dry years, the leaching fraction component will dominate, and in wet years the rainfall fraction will dominate. In addition to the irrigation and rainfall component, an allowance for interception of local groundwater by lateral flow (from neighbouring farms, supply channels and surface drains), or regional groundwater from up-flow, needs to be made. This depends very much upon local conditions such as the length of farm perimeter, distance to supply channels or rice fields and the elevation of the farm within the local landscape. An assessment of this requirement can be made using local knowledge, and analytical solutions to groundwater flow.

With groundwater pumping systems, the volume to be disposed of from a specific site would be based on the results of site testing to determine both the potential site capacity and that required to serve the area to be protected. This would require a long-term pump test (over at least 3 weeks), with monitoring of both pump output and groundwater level responses across a significant proportion of the area to be protected. The actual volume extraction required or drawdown needs to be determined from local experience and/or modelling analysis. The volume to be discharged to any disposal basin can then be estimated after allowing for any re-use of the drainage water.

Drainage Rates Measured for Clay Soils in the Riverine Plain

As much use as possible should be made of local records of irrigation + rainfall and drainage relationships. Information from existing drainage systems needs to be analysed and local experience thoroughly investigated. Groundwater extraction rates for salinity control for pastures with shallow bores or spear points have been 0.5-1 ML/ha/year for the SIR and 0.5 ML/ha/year for the Wakool drainage scheme. These can be used as indicative values for design under these crop/drainage systems. For horizontal pipe drainage flows, data presented in Table 10.1 indicate a range of values that can be expected.

Table 10.1 Some records of horizontal pipe drainage flows in the Riverine Plain.

Location	**Discharge (ML/ha/year)**	**Reference**
Kerang	2.0 - 4.0	Girdwood (1978)
Kerang	2.8 - 5.8	Poulton (1984)
Pyramid Hill	4.0	Mann (1994)
M.I.A (dry year)	Range 0.05 – 1.8 Average 0.7	McCaffery (1999)

For the MIA, van der Lely (1993) has conducted an analysis of horizontal pipe drainage flows for different irrigation technology on varying soil permeability (shown in Table 10.2). These can be used as indicative values for horizontal pipe drains under perennial horticulture. However, it is important to note that actual drain design and layout must be undertaken to prevent waterlogging effects over shorter critical periods.

Table 10.2 Drainage flow from internal and external sources combined (ML/ha/year), after van der Lely (1993).

Irrigation technology in horticulture	**Soil permeability**		
	Low	**Medium**	**High**
Low efficiency	1.7	2.1	2.6
Medium efficiency	1.3	1.7	2.2
High efficiency	0.8	1.2	1.8

10.3 Assessing Drainage Water Quality

Sampling of soils and shallow groundwater should be carried out to assess the likely quality of the drainage water. The quality will also be dependent on the main drainage flow depths, which will be related to the type of drainage system used. The drainage water quality will determine the type of disposal that is appropriate. As stated in Principle 1 (Chapter 5), before basin disposal is adopted, other possible uses for the drainage water should be considered. The main opportunity will be for full or partial re-use of the drainage water for irrigation. Full re-use is only possible if the drainage water has relatively low salinity and there are adequate volumes of fresh irrigation water available for mixing to an acceptable irrigation salinity level. Partial re-use occurs where there is insufficient fresh irrigation water to mix all of the drainage water to an acceptable level. For greater levels of salt concentration prior to basin disposal, serial biological concentration (SBC) schemes could be considered (Heath *et al.*, 1993). While still in the experimental stage, SBC schemes may become an attractive option in the future.

Drainage water destined for a disposal basin should undergo a full analysis for trace metals, nutrients and pesticides prior to basin installation and then monitored at regular intervals thereafter (see Chapter 15). While measurements carried out to date (Christen *et al.*, 2000b) suggest that concentrations of trace metals and pesticides in basin waters are generally low, evapoconcentration can result in concentrations between 2-20 times higher than in the drainage water. Although this process is simply concentrating toxicants already present in the groundwater, by doing so at the land surface, it exposes humans and animals visiting the basin to some level of risk. These higher concentrations will also occur in the basin leakage water with possible groundwater impacts. Finally, there may be bioaccumulation of trace metals in the organic and sediment layers at the bottom of disposal basins. The potential for accumulation and possible later interaction with the environment needs to be carefully considered in decommissioning plans (Chapter 15). At present there are no suitable guidelines for disposal basins against which the measured values from basin waters and sediments can be assessed. It is recommended that guidelines for each region be developed by consultation between land and water management planning groups, local government and environmental protection authorities.

10.4 Summary

1. The volume of drainage produced will depend on the land use, climate, irrigation practice and the type of drainage system. When determining an appropriate value, existing data and local knowledge should be thoroughly investigated. In areas with no record of drainage works, a crop modelling exercise will probably be necessary.
2. Allowance needs to be made for additional drainage volumes caused by local or regional groundwater flow into the drainage system and by rainfall.
3. An assessment of likely drainage water salinity should be carried out during project planning as this will determine the type of disposal that is appropriate. Full or partial re-use of drainage water for irrigation should be carried out where possible (and economically justified) before disposal to a basin.
4. Drainage water destined for a basin should undergo a full analysis for trace metals, nutrients and pesticides to avoid their possible accumulation to toxic levels in the basin waters and sediment. Land and water management planning groups should work with local government and environmental protection authorities to set minimum investigation requirements for drainage water quality and develop guidelines on acceptable values for different situations in their region.

11. Determining Basin Area

11.1 Introduction

This chapter is concerned with determining the basin area. This area is comprised of the *evaporative area* of a basin, and the area occupied by banks and a buffer zone immediately surrounding the basin, which combine to form the *total area.*

Evaporative area depends on the expected drainage volumes (Chapter 10), basin disposal capacity (Chapter 4), basin depth, and the level of risk of crop damage if the basin is full and drainage has to cease. The drainage volume used is an annual average based either upon an average rainfall year for a low risk crop, or a wetter than average year in the case of a high risk crop. There also needs to be some allowance for particular drainage requirements at critical stages of crop growth as the timing of the drainage volume and the basin disposal capacity through time is critical. For instance, net evaporation will be low in spring and autumn (periods when there may be a critical need to drain). This contrasts with mid-summer when the net evaporation will be high but drainage volumes are generally low.

For the reasons discussed in Chapter 4, it is best to utilise the design disposal capacity of a basin. Leakage may provide additional initial capacity but in the long-term it is expected that a significant portion of leakage will be recycled back to the basin and will not be available as disposal.

11.2 Expressing Evaporative Area

Disposal basins are usually expressed as the open water area (hectares) because their function is to evaporate water. The rate at which this occurs is primarily dependent upon area (unlike storage dams that are expressed as volumes (megalitres), as their function is to store water). *Evaporative area* is often also quoted as a percentage or fraction of the drained area (not farm area) that the basin represents (e.g. a 2 ha basin serving a 20 ha drainage area is termed a 10% *evaporative area*). Expressing evaporative area in this way allows for easy comparison from site to site and across a range of *evaporative areas* (hectares) for a single farm.

11.3 Build it Big?

The fundamental issue of disposal basin design is to determine the minimum required *evaporative area* that will allow adequate protection of the farmed land. A large, *very safe*, basin will provide good drainage control in even the wettest years, despite being much too large in normal or dry years. This will have the disadvantage of the extra cost of constructing a larger than necessary basin, loss of land for crops, and wetting and drying of the basin floor which will lead to increased leakage. This loss of cropped area will affect smaller (or land limited) farms through reduced production, or through the cost of purchasing extra land.

A larger than necessary basin also has a less obvious disadvantage in that it may be dry for significant periods of time. Drying out of basins leads to increased leakage problems as accumulated organic matter on the basin floor oxidises and the soil dries and cracks. Soil cracking is a major issue if a basin has been clay lined and/or has had significant compaction applied. Cracking will open up macropores allowing higher rates of leakage upon refilling. Other disadvantages of the drying out of basin floors includes: mobilisation of salt dust from the basin floor, the environmental qualities of the basin being jeopardised in terms of habitat for aquatic flora and fauna, and the loss of aesthetic appeal of a water body. Having said this, it is useful to allow basins to dry out occasionally for maintenance purposes, but this should be a management decision rather than the result of the basin being over-designed.

11.4
Build it Small?

In selecting an *evaporative area* that is less than *very safe,* there is the risk that in some years the basin will fill as the disposal rate fails to match incoming drainage. In these circumstances, the drainage system pumps should be turned off unless special disposal arrangements have been made. However, discharge of drainage directly to streams or from disposal basins to streams is not recommended, as stated in Principle 5.

If drainage is stopped because the basin is full, then there is the possibility that waterlogging will occur in the cropped area, and yield will be affected. The severity of any impact on yield will depend upon the crop, and the timing, period and frequency of such waterlogging events. In some cases, it may have no effect. Thus, an assessment has to be made whether a larger basin that reduces the risk of occasional waterlogging events is justifiable in terms of the extra crop productivity. The extra productivity gained from avoiding occasional waterlogging events has to be offset against the continued loss of land area and extra capital cost of the larger basin. This is obviously a long-term trade-off and cannot be analysed in the short term or by using average climatic conditions.

11.5
Just Right!

Thus, in general terms, a disposal basin should be in balance with the drainage system and the crop it serves. It should be large enough to provide the desired drainage service in most years and prevent continuous lowered productivity, but not so large that it is an excessive cost burden every year. In assessing an appropriate *evaporative area* it is easier to have a larger basin if the farms physical and financial conditions are good and there are sites available that allow basins to be built at minimum cost (i.e. good soils, good sites and low cost land available). Thus, in some circumstances, it is easier (cheaper) to be safer than it is in others. The cost of the disposal basin should also be taken in context; if a very large investment is being undertaken then increasing the basin area by 10% may have little effect on the overall cost whilst providing a much greater measure of security.

In determining an appropriate *evaporative area* the first approximation is to use average values of evaporation and rainfall. This is likely to be adequate for crops that are not waterlogging sensitive. However, the *evaporative area* chosen should be analysed by way of a salt and water balance model to determine the effects of wetter than average conditions. It is only by investigating the fluctuations over time that variable climatic conditions can be analysed.

The analysis of the chosen *evaporative area* cannot be undertaken from a purely physical standpoint since the costs and benefits over the long-term have to be accounted for. As such the physical analysis has to be linked to a financial analysis that can consider the impacts on total returns, net present value and even annual *cash flows* from varying basin size. This is where the trade-off between increasing *evaporative area* and land lost from production becomes important. This is not easy, requiring modelling of many scenarios. For horizontal pipe drained areas, the **BASINMAN** model (Wu *et al.*, 1999) can provide an analysis of waterlogging risk with different basin areas. **BASINMAN** output must then be linked to *yield/waterlogging productivity functions* that must then be linked to a financial analysis for the enterprise (see Chapter 14).

Where drainage is provided by groundwater pumping, the design should be based on the results of long-term pump testing (as discussed in Chapter 10), coupled with regional knowledge of the drawdown in groundwater levels that are required to protect the target area. The pump test will give the best estimate of the extraction capacity at the site, and will allow an assessment of the area that might be served if the pump is operated at full capacity and for most or all of each year. It is then necessary to determine whether to proceed based on the maximum extraction capacity for the site or some reduced extraction capacity. Extraction capacity can be reduced either by installing a lower capacity pump or pumping for only part of the year. As with horizontal pipe drainage systems, it will be necessary to optimise the system design for a range of possible options. This should consider both the total system cost (i.e.. capital and operating cost of the pump and basin and who pays for them) and the benefits (i.e. the areas protected, who owns them, and the expected economic returns). For example, restricting pumping to only the summer period has the advantage that less freeboard is required to cope with winter and spring rainfalls, but it would protect a much smaller area than could be protected with whole of year pumping. As is the case with basins serving horizontal pipe drains, there is a need to carry out climatic modelling to determine the variability in annual disposal capacity over a representative period of climatic conditions for a specified set of operating rules.

Overall, a safe *evaporative area* can be determined by firstly being conservative regarding the drainage volumes requiring disposal. Then, the *evaporative area* can be designed on average climatic conditions for waterlogging-insensitive crops and using the wettest 10% of years for waterlogging-sensitive, high value crops. The chosen design *evaporative area* must finally be assessed for its performance using a spreadsheet model such as that described in Leaney and Christen (2000a).

Given the uncertainty in the estimation process, a suitable compromise may be to set aside an area larger than that determined for the basin. This will allow flexibility in increasing the basin size at a later date should this be required. In the meantime, this area can be used for some short-term productive purpose.

11.6

Determining an Appropriate Evaporative Area

Evaporative area is based on the drainage design volume (as described in Chapter 10). This design volume is an annual average based either upon an average rainfall year for a low risk crop, or a wetter than average year for a high-risk crop. There will also be some regard to particular drainage requirements at critical crop growth stages. However, in making an assessment of *evaporative area* requirement, the timing of the drainage volume and the basin disposal capacity through time is critical. For instance, basin disposal capacity in evaporative terms will be low in spring and autumn (periods when there may be a critical need to drain). This contrasts with mid-summer when the basin evaporative capacity will be high but drainage volume low (Figure 11.1).

As discussed in Chapter 4, it is best to focus on evaporative capacity as being the true long-term *design* disposal capacity of a basin. Leakage may provide additional initial capacity but in the long-term it is expected that a significant portion of leakage will be recycled back to the basin and will not be available as disposal.

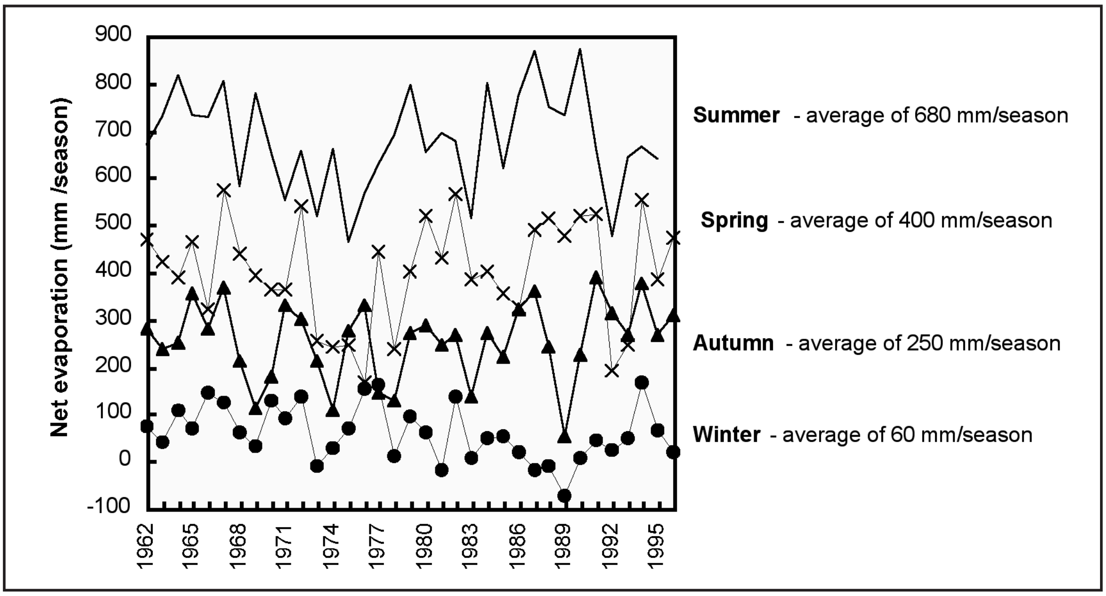

Figure 11.1 Measured monthly net evaporation for the MIA, highlighting the seasonal differences.

First Approximation

The first step in determining the *evaporative area* required for a basin is to calculate the design disposal capacity. Ideally this should be done using the spreadsheet model discussed in Chapter 4, with input from measured data at the basin site and using a lengthy (30-40 years) record of rainfall and pan evaporation data from the nearest meteorological station. Alternatively, a reasonable first approximation is possible for most sites and conditions using the *design* disposal capacities given in Table 4.1.

Following this, one needs a first approximation for the design drainage volume. This will be dependent on the irrigation rate, leaching fraction and a component of rainfall. For example, if citrus irrigation was applying 800 mm/year with a leaching fraction of 10% then the drainage requirement would be 80 mm/year. Add to this 10% of rainfall (40 mm) and the drainage requirement becomes 120 mm/year. If the irrigation area is near Deniliquin and a 1 ha basin is to be used with a leakage rate estimated to be 1 mm/day, then the *design* disposal capacity is 13.2 ML/ha/year (or 1320 mm/year; Table 4.1). This results in the ratio of *evaporative area* to drained area of 8.5% (note: with 20% of the rainfall amount, the ratio would be ~12%). Assuming the drained area is a 20 ha farm, then 1.8 ha of *evaporative area* would be required.

11.7
Assessment of the Appropriate Area

Examining whether the proposed *evaporative area* is suitable is very difficult. The greatest risk is if the basin is too small, possibly resulting in catastrophic crop failure in a sensitive crop. If the basin is too large it will still function and so the consequences are less dire than if the basin is too small. However there will be added cost burden associated with basins that are too large. In these circumstances, it is sensible to err on the side of larger rather than smaller.

What will result if an *evaporative area* is too small? Drainage will be restricted and water tables will be high in the farmed area causing yield losses due to waterlogging. By modelling with **BASINMAN** we can assess the impact of different *evaporative areas* on waterlogging (Figure 11.2). Increasing *evaporative area* decreases the percentage of time that water tables are high. Interestingly, in the MIA, a 15% evaporative area would be required to give the same level of drainage control as is achieved by current installations with unrestricted drainage - a very large *evaporative area.*

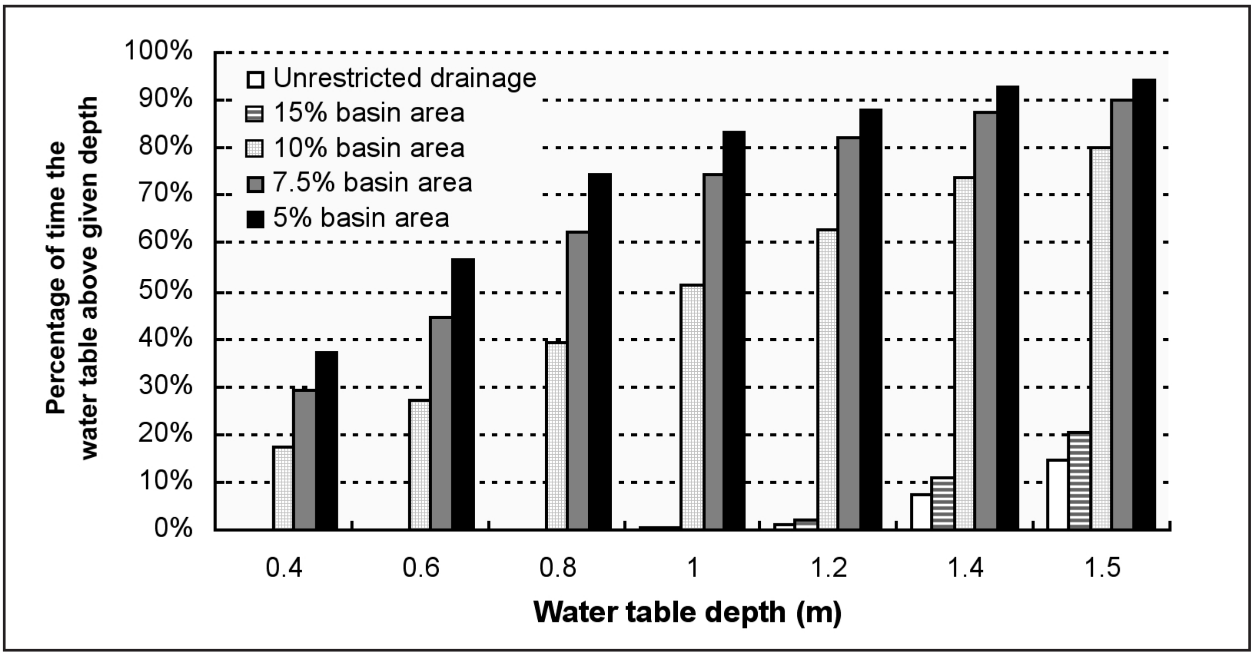

Figure 11.2 Modelled effect of size of evaporative area on water table control.

However, the real question is what is the impact of high water tables upon yield. As long as water tables are below the root zone most of the time, particularly in critical periods, they may not impact greatly upon yield. Figure 11.3 shows the modelled average yield reduction due to waterlogging in the MIA. We can see that the average yield decline for citrus rises dramatically if the *evaporative area* is less than 7.5% and that there is little to be gained from increasing *evaporative area* beyond 10%. Grape vines which are less sensitive to waterlogging than citrus require a smaller *evaporative area*, about 5% would appear to limit yield losses adequately. Controlling water tables to that of unrestricted drainage by having a 15% basin area could not be justified in either crop.

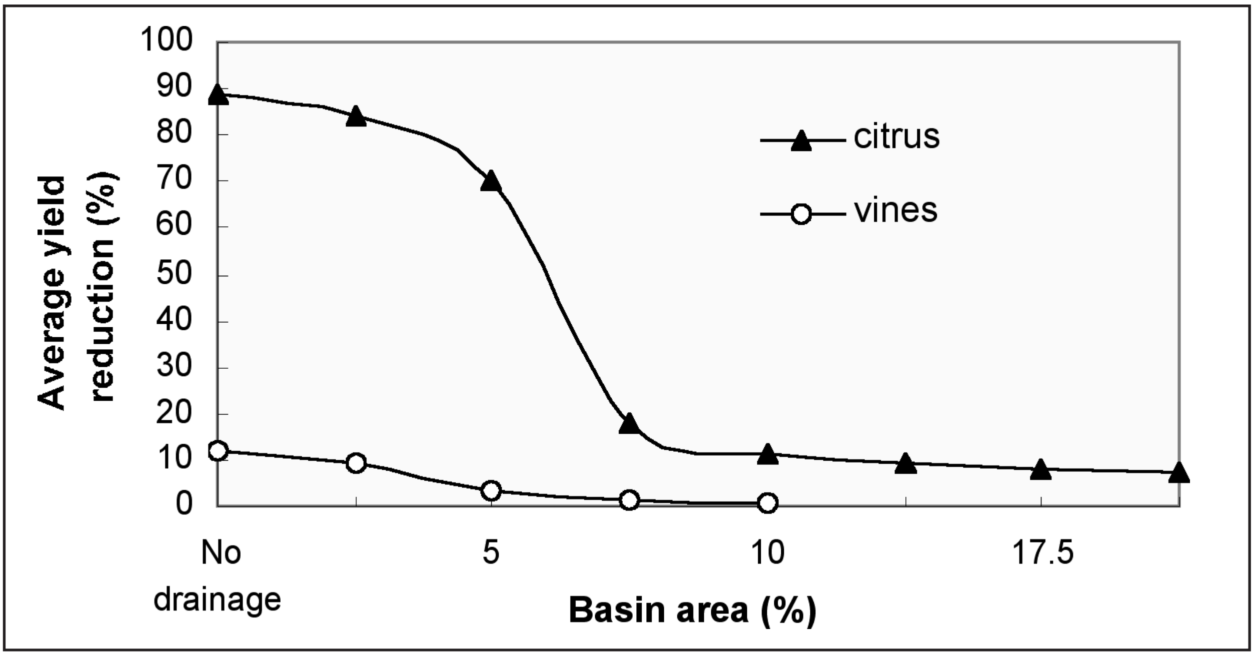

Figure 11.3 Modelled effect of size of evaporative area on crop yield.

These analyses appear to justify the result of the simplistic method used to arrive at an 8.5% *evaporative area.* But these results are based upon averages of all the results of only 36 years of historical weather data. Upon closer analysis we find that in the worst 10% of years the average yield loss is about 20%. This is due to a marked decrease in the net evaporation that reduces the basin disposal capacity. Figure 11.4 shows the frequency distribution of net evaporation in the MIA, it is in the years of lowest net evaporation that the high yield losses occur.

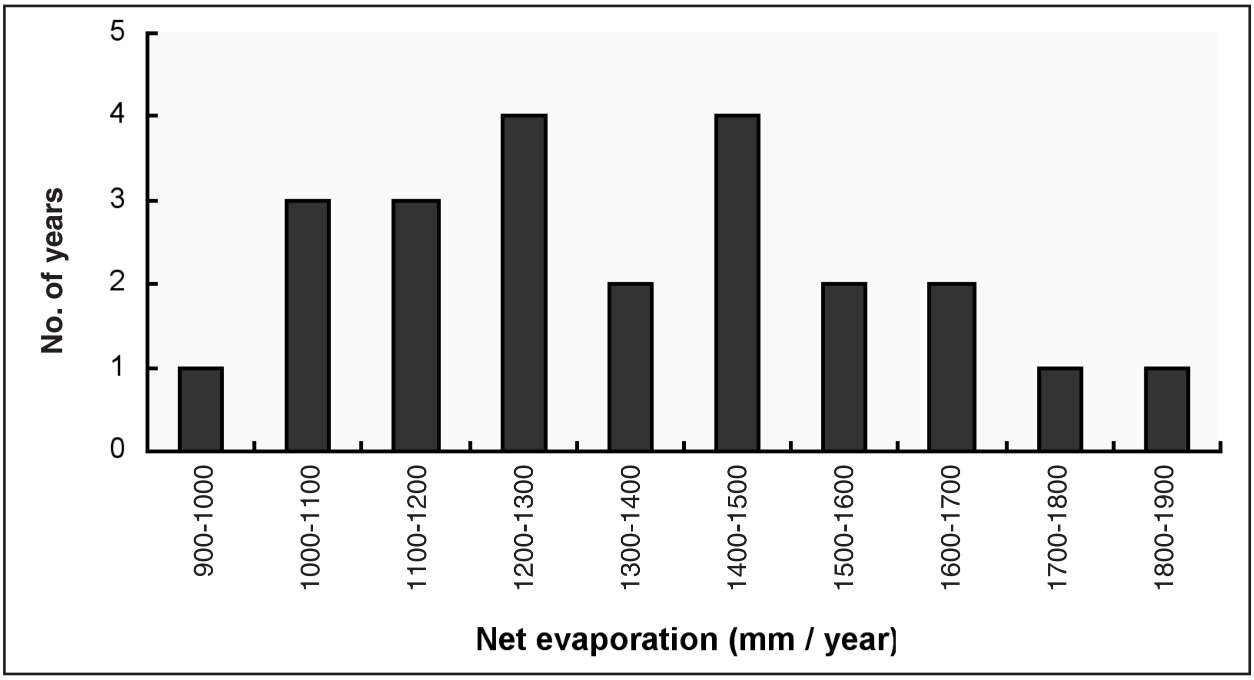

Figure 11.4 Frequency distribution of net evaporation in the Murrumbidgee Irrigation Area (MIA).

Thus, the trade-off in this scenario is whether a 20% yield reduction in the lowest net evaporation years (one year in ten) with an 8.5% area is better or worse than having maximum protection all the time with a 15% area. This can only be resolved by financial analysis that determines the additional cost burden from increasing a 8.5% to 15% basin area against the periodic large losses due to a smaller basin size. Additionally, it depends upon the level of risk that is acceptable to those involved, since income stability is very important to many businesses. Following this example through a full financial analysis, considering the optimal basin area from analysis of marginal returns, found that a 12.5% basin area was optimal for citrus and 7.5% for grape vines. These basin areas also stabilised annual net cash flows (Singh and Christen, 2000b).

Using this financial analysis to guide our original assessment, we see that if we had chosen an average net evaporation from the lowest 10% of years, ~1000 mm, then we would have arrived at a 12% *evaporative area* for citrus, a waterlogging sensitive crop. If we had used 20% of rainfall as the drainage target, which would have resulted in an 11% area, may also have been more appropriate for a waterlogging sensitive crop such as citrus. To arrive at a 7.5% area for grapes with say an average water use of 600 mm/year, 10% leaching fraction and 10% of rainfall requiring a total average 100 mm of drainage then a net evaporation of 1300 mm/year would give a 7.5% area. This shows that using close to the average net evaporation is probably acceptable for a less waterlogging sensitive crop such as grapes.

Losses due to salinity have not been discussed as modelling has shown that if waterlogging is controlled then losses due to salinisation are also minimised.

11.8
Safety

In all types of analysis there is a degree of uncertainty, often a safety factor is used to provide some insurance against this uncertainty. The **safety factor** in the design area will depend upon the degree of uncertainty in the design process and the potential risks to crops if the basins become full and drainage has to be stopped. If a thorough analysis is conducted initially then there is less uncertainty and costs can be minimised. In areas with little data or local knowledge available then a greater safety margin is required. A simple measure is to build a basin that is 10 or 20% bigger than determined as needed, although this may not be very cost effective. A more practical method for incorporating a safety factor into the use of disposal basins may be to build a conservatively large basin but try to only use a proportion of it. If after a number of years the drainage discharge is as predicted and basin water salinity is stable then the unused, excess area of basin could be returned to production. A similar alternative is to set aside more land than is thought to be required which can be left available for future expansion of the basin.

11.9
Determining Total Basin Area

The *total area* of a basin is comprised of the *evaporative area* of a basin, and the area occupied by banks and a buffer zone immediately surrounding it.

It is important to note that as a basin’s *total area* increases, the relative proportion of *evaporative area* also increases. For example, a square basin with a 1 ha *evaporative area* and a 20 m bank/buffer zone has a total area of 1.44 ha (i.e. 1.44 times the *evaporative area*). In contrast, a square basin with a 25 ha *evaporative area* and the same width bank/buffer zone has a total area of 27.04 ha (i.e. 1.08 times the *evaporative area*). This factor needs to be considered when deciding on the size of basin or basins required for a drained area. As discussed in Chapter 9, this may have some impact on the decision to use multiple small basins, or a single large basin.

11.10 Summary

1. It is best to utilise the design disposal capacity of a basin when determining *evaporative area.* Leakage may provide additional capacity initially but in the long-term it is expected that a significant portion of leakage will be recycled back to the basin and thus will not be available as disposal.
2. In general terms, the *evaporative area* of a disposal basin should be in balance with the drainage system and its associated land use. The greatest risk is the possible catastrophic failure of a sensitive crop if the basin is too small. If the basin is too large the consequences are less dire in that the system will function properly, although there is an added cost burden.
3. Obtaining the optimal *evaporative area* is complex and requires analysis over long time frames that incorporate the full range of likely climatic conditions, including seasonal variations. Furthermore, the physical analysis needs to be linked to a financial analysis that considers the impacts on total returns, net present value and annual cash flows for varying basin sizes.
4. The *total area* of a basin is comprised of the *evaporative area* of a basin, and the area occupied by banks and a buffer zone immediately surrounding it.

12. Basin Siting

12.1 Introduction

As discussed in Chapter 6, the risks posed by local-scale basins should be minimised. This can be achieved by careful consideration of basin locations so as to not endanger the general environment, minimise impacts on human and other activities, and meet community standards. Also, as will be shown in Chapter 14, successful implementation requires that costs be constrained as much as possible. For the purposes of this report, it is implicitly assumed that basin siting will be considered within the framework of appropriate existing State and Federal legislation, and Local Government regulations.

As stated in Principle 3 (Chapter 5), basins should preferably be sited within the area of influence of the drainage system. This maximises the opportunity to prevent migration of the saline leakage plume away from the basin. If the basin is to be built outside the drainage area, or in an area where there is the possibility of rapid migration of the leakage plume, then there will need to be additional risk minimisation in the form of leakage control and interception (Chapter 13).

The suitability of a site for a disposal basin depends firstly on the general locality, and secondly on the on-site physical characteristics. The locality assessment is a mixture of biophysical and socio-political considerations. The on-site assessment involves determining potential leakage rates, probable destination of the leakage plume, and the likelihood of other environmental degradation (along with factors such as the costs and impacts on integration with farm enterprises).

12.2 Locality Assessment

The impacts of basins can be partly minimised by the use of buffer zones between the basin and key surface water features, infrastructure and human activities. The first step in locality assessment should be to determine the planning requirements by deciding on buffer distances and threshold values for criteria that define a suitable site in a region.

Suitability criteria include shallow groundwater quality, soil permeability, aquifer hydraulic conductivity and gradient, and depth to water table. The choice of appropriate thresholds and buffer distances is not straight forward, as there will be varying community attitudes and biophysical conditions in different regions. Also, the buffer distances adopted can have significant effects on the potentially available area that is suitable for basins. In the study of Dowling *et al.* (2000), described in Chapter 8, the preliminary buffer distances selected resulted in around 50% of the SIR being not suitable for basins. If similar buffers were applied to property boundaries then it is likely that as much as a further 25% would be classified as not suitable. This example shows that decisions regarding appropriate buffer distances require careful consideration as they may significantly reduce flexibility in basin siting.

Prospective target areas that satisfy the suitability criteria should initially be evaluated to assess the broad potential risk of negative environmental effects. General factors to be considered are availability of sites with potentially suitable soils within or adjacent to drainage areas and their current land use. Also to be considered are the possible consequences of basin leakage on groundwater quality, salinisation of land surrounding the basin and basin leakage (or overflow) reaching rivers, wetlands, remnant vegetation or infrastructure (roads, railways and buildings). The movement of a leakage plume away from a basin site will be dependent on the depth, extent, transmissivity, water levels, and water quality of shallow and deep aquifers. In this context, areas that are hydraulically down-gradient of the basin site will need careful appraisal, as they will be most at risk.

It is likely that, in some areas, appropriate basin sites will not be locally available, especially for on-farm basins. In this case, the target area will have to be broadened and a suitable site for a community basin found and the water transported to it. In extreme cases where there are no feasible sites within a region, an integrated drainage strategy for the region will need to be developed to link drainage to a regional disposal basin.

12.3
On-Site Assessment

As shown in Table 6.1, sites can be categorised as being either low or high risk, depending on a number of factors. However, irrespective of the degree of risk, once a potentially suitable site has been identified it is essential to carry out a geotechnical investigation to obtain a detailed understanding of local hydrogeology, including the general extent and characteristics of deep aquifers and likely existence of shallow aquifers. Furthermore, to assess the risks posed by basin leakage, the geotechnical investigation needs to assess the suitability of the soil for bank construction and compaction requirements. The aim of this is to determine what bank construction and floor treatment is required to reduce long-term leakage to the target range of 0.5-1 mm/day defined in Chapter 4.

For localities defined as high risk, the minimum additional site assessment would be to determine the shallow aquifer characteristics in terms of depth, extent, transmissivity, water salinity and piezometric level. The aquifer characteristics and piezometric levels are essential for determining the probable rate and direction of leakage plume movement below and away from a basin. This should include an assessment of future hydraulic gradients, especially if pumping from the drainage system is discontinued and/or the basin is decommissioned.

For low risk localities, risk assessment techniques can be useful in minimising additional investigation costs whilst still providing adequate information to minimise overall risk. This is important since site investigations to determine aquifer properties and likely rates of leakage are costly. Land and water management planning groups should work with local government and environmental protection authorities to set minimum additional investigations required for these situations.

As shown in Table 6.1 in Chapter 6, sites can be categorised as being either low or high risk, depending on a number of factors. Table 12.1 summarises the geotechnical investigations required for both low and high risk sites. Soil engineers and hydrogeologists should be engaged for the site investigations and assessment of suitability.

Table 12.1 Required geotechnical investigations for low and high risk disposal basin sites.

Investigation	**Low Risk**	**High Risk**
Local aquifer assessment To provide an understanding of local hydrogeology, general extent and depth of regional aquifer and likely existence of shallow aquifers	Already good understanding, no need for extra investigation	Existing knowledge needs to be confirmed/extended by further investigation, e.g.: 1. EM34 transects at 500 m spacing 2. Bore (1 per 5 ha) holes to 20 m for aquifer determination
Leakage assessment To provide an understanding of the likely leakage characteristics	Hydrogeology indicates that leakage plume will be contained and basin sited in low risk environment. Possible investigations: 1. EM31 Survey (50 m grid) 2. Auger holes (1 per 2 ha) for soil texture, water table depth, groundwatersalinity and water table depth	Hydrogeology indicates that leakage plume could spread and/or basin sited in high risk environment. Possible investigations: 1. EM31 Survey (50 m grid) 2. Auger holes (1 per 2 ha) for soil texture, water table depth, groundwater salinity and water table depth 3. Surface infiltrometer measurements (1 per 5 ha) 4. Undisturbed cores for permeability, porosity (1 per 2 ha)

12.4 Site Suitability

Using the locality and site assessments and the above geotechnical investigations, the physical parameters of a site can be determined and then assessed against site suitability criteria. These criteria include:

Shallow Groundwater Quality

While limited leakage is required to provide adequate basin capacity (see Chapter 4), groundwater that has beneficial use should not be polluted by this leakage of saline water, unless the use of an *attenuation zone* for an overall greater benefit has been accepted by environmental protection authorities. In such a case, it is essential to ensure that the saline leakage does not have an impact beyond the agreed *attenuation zone.*

In general, groundwater salinities of less than 3000 mg/L should be regarded as a valuable resource and unsuitable for basin siting. Groundwater with salinity of 3000-7000 mg/L has limited use for irrigation, so basin siting will need to carefully consider the benefits of the disposal basin against the potential degradation of the groundwater resource in that area. Groundwater with salinities above 7000 mg/L has extremely limited use and so can be considered as suitable for basin siting. It should be noted that some jurisdictions do not allow the changing of groundwater quality in any way. In these cases, negotiation with environmental protection authorities to permit the creation of an *attenuation zone* will be required in order to use a disposal basin.

Soil Permeability

This is the critical controlling factor for leakage rate from a basin if it is *infiltration limited*. Any uncertainty in predicting the leakage rate should be thoroughly investigated by carrying out *sensitivity tests* across a range of possible values. It has been found that, in general, a leakage rate of 0.5-1 mm/day will minimise potential environmental contamination, yet still maintain an adequate disposal capacity (see Chapter 4). To achieve this low leakage rate, in the absence of a heavy, poorly structured soil, smaller basins are likely to require compaction of their floors. As such, soil compaction suitability also needs to be assessed.

Aquifer Hydraulic Conductivity and Gradient

Given that in most basins leakage will occur, measurements of aquifer hydraulic conductivity and associated hydraulic gradients are needed to assess the rate and direction of movement. Hydraulic conductivity of shallow aquifers in the Riverine Plain varies between 2-100 m/day (Evans and Kellett, 1989), with typical values at the lower end of this scale. A typical hydraulic gradient in the Riverine Plain is 1:2000 (0.0005). Assuming a hydraulic conductivity of 10 m/day (typical of sand aquifers), and a porosity of 0.3, this gradient will result in a leakage plume moving at about 0.016 m/day. However if the hydraulic gradient is increased to 0.005, flow will be more significant (0.16 m/day). In both cases, the rates greatly exceed the rate at which leakage from the basin is likely to reach the aquifer. The site suitability needs to be assessed to ensure that the leakage plume will not move rapidly to sensitive environments, especially if the basin is decommissioned and the drainage system, including interception strategies, is discontinued. These factors will govern the selection of appropriate buffer distances around basins. Issues and recommendations associated with hydraulic gradients are:

- It is preferable to site basins in low parts of the landscape where hydraulic gradients are small, thus minimising risk of leakage plume movement. However, areas where flooding may occur such as river floodplains should be avoided. Inundation of basins may cause damage to their structure and will result in the escape of salt and any other chemicals into the river.

- Existing discharge areas are often useful sites for disposal basins. However, the impact of loading these areas with water could cause the discharge area to expand or cause new discharge areas to occur elsewhere. Furthermore, some discharge areas may have high environmental value. These considerations must be carefully assessed before using particular discharge areas as basin sites.
- Siting within the farm should be in a position where any potential leakage plume will be contained within the farm boundaries for the maximum time. In areas with negligible regional groundwater gradients, this will be near the centre of the farm (see A, Figure 12.1). Where there are significant regional groundwater gradients then the ideal position will be closer to the side where the regional groundwater enters the farm (see B, Figure 12.1). If the only possible site is close to a farm boundary or at the side of the farm where the regional groundwater leaves the farm, then specific steps such as groundwater interception must be taken to ensure that the leakage plume is prevented from exiting the farm.

In all situations, the downstream environment should be investigated thoroughly, as the movement of a basin's leakage plume constitutes a very long-term risk. Any detrimental effects may prove to be very expensive to control at a later stage.

Groundwater gradients into the drained area can present a further problem, as large inflows collected by the drainage system will necessitate a larger disposal basin. For example, modelling of an on-farm basin system with a 6% basin area showed that if the site experienced an inflow of 50 m^3/day (equivalent to 73 mm/year additional water over the farm) then the basin area would have to be increased to 11% to control waterlogging.

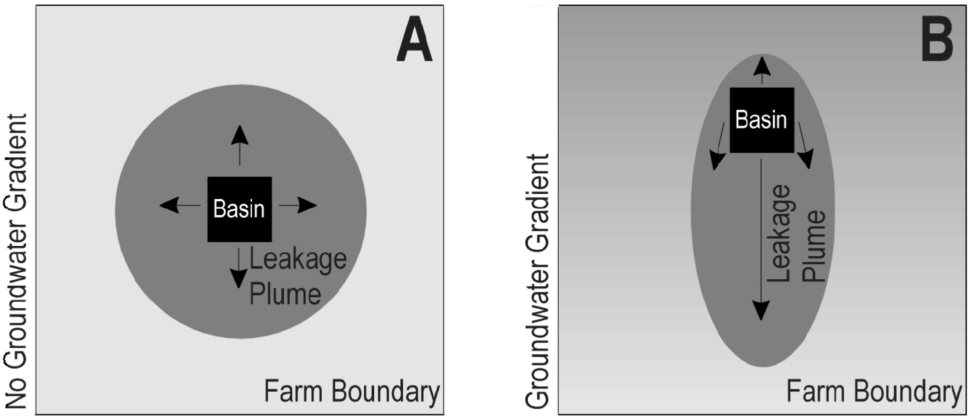

Figure 12.1 Conceptual representation of the effect of regional groundwater gradient on the leakage plume and consequences for on-farm basin siting within a farm.

In situations where there are large groundwater gradients and aquifers with high hydraulic conductivity, the design and siting of a disposal basin and its drainage system will need a thorough groundwater investigation and modelling of likely scenarios for movement of the plume.

Depth to Water Table

It is preferable to site basins in areas with shallow water tables (<2 m) as these will already be at risk from waterlogging and salinity. If leakage from the basin is not infiltration limited, deeper water tables will induce higher rates of leakage than necessary. Over time a groundwater mound will build-up beneath a basin due to leakage (see Chapter 3), and this will impact on the surrounding area. This effect causes a greater hydrological change and impact on the groundwater system in areas with deeper water tables than in those with shallow water tables.

12.5
Summary

1. The suitability of a site for a disposal basin depends both on the general locality, and the on-site physical characteristics. The locality assessment is a mixture of biophysical and socio-political considerations for the surrounding area. The on-site assessment is concerned with potential leakage rates, leakage plumes, and the likelihood of other environmental degradation.
2. Site suitability criteria include shallow groundwater quality, soil permeability, aquifer hydraulic conductivity and gradient, and depth to water table.
3. The detail of the on-site assessment is dependent upon whether the basin location is considered to be of low or high risk. In both cases, minimum geotechnical investigations should include a good understanding of the local hydrogeology and assessment of soil suitability for bank construction and the floor treatment required to reduce long-term leakage to 0.5-1 mm/day.
4. For sites categorised as high risk, additional investigation of the hydrogeology and likely leakage characteristics is required.
5. For low risk sites, minimum additional investigations required should be set by land and water management planning groups, in consultation with local government and environmental protection authorities.

13. Basin Design

13.1 Introduction

This chapter is concerned with the engineering aspects of disposal basin design, namely the selection of the most appropriate basin configuration, and construction approach. For a given location, a poorly designed basin will not be as effective and safe at disposing of the required amount of drainage water as a well designed one. For the purposes of this report, it is assumed that guidelines for construction of above ground storages will be utilised where appropriate (e.g. QWRC, 1984; NSW Agriculture, 1999), and so detailed earthwork construction advice is not provided in these guidelines. It is also assumed that banks will be constructed and compacted under soil moisture conditions that maximise their integrity. Finally, it is assumed that, other than direct rainfall, the only water input to the basin is that of subsurface drainage (i.e.. surface water, either as normal runoff or as flood flows, is excluded).

A *well designed basin* is one that:

1. Does not require an excessive area to dispose of the required drainage by evaporation. This requires that the basin water salinity does not become so high that evaporation rates decline significantly. This is achieved by allowing sufficient leakage to stabilise the basin water salinity at a moderate level, but not having it so high that it causes environmental problems. As discussed in Chapter 4, a leakage rate of 0.5-1 mm/day is a reasonable compromise that satisfies both of these objectives.
2. Concentrates salt up to a maximum of 180 000 mg/L over the economic life of the basin, for storage in the aquifer below the basin by leakage. This requires that leakage is not too high (e.g. in the MIA some basins only double the concentration of the drainage water due to high leakage).
3. Has a well designed interception system that ensures that lateral leakage is recycled back to the basin.
4. Requires minimal maintenance. The main consideration is minimising erosion of the basin banks and any open interception drains around the basin.
5. Has good aesthetics and amenity or environmental value. Larger community basins, or even on-farm basins, can be designed and managed to be a community and ecological resource (e.g. Roberts, 1995).
6. Minimise nuisance effects such as the attraction of large numbers of birds, midges, mosquito breeding, odours and dust.

13.2

Basin Design Factors

The main design criteria can be separated into three main categories: determining suitable **geometry, limiting leakage,** and **interception of leakage.**

Geometry

Shape – A circular basin shape has the smallest bank length per unit area, resulting in the lowest construction cost. However in practice, a square basin (the next most cost effective) is often adopted for ease of construction. While other shaped basins (triangles or long rectangles) are not as cost effective (Singh and Christen, 2000a), they may be preferred in situations where they are more compatible with the farm layout.

The simplest basin design is a single cell basin, which maximises the basin area and minimises its bank length. However, there are good reasons for basins having multiple cells. Multiple cells in basin design allows for the sequential concentration of salt from one cell to the next, ending in a terminal bay. This means that should salt precipitation occur it will be concentrated in a small section of the basin, and the terminal bay (with the most saline water) can be located in the centre of the basin. Having the most saline water concentrated at the centre of the basin reduces the risks posed by leakage of this very saline water. This is because it is located in the part of the basin where leakage is likely to be the least, it increases the distance of travel for leakage to reach the basin perimeter, and forces this leakage downwards rather than laterally due to the water ponded in the surrounding cells.

The best geometric design for a basin is that of a square with a series of internal cells such that the water flows in a spiral to the terminal cell in the centre (Figure 13.1). Leakage from the inner (more saline) cells is likely to be less due to the greater mounding of the underlying groundwater levels. Use of multiple cells also assists with maintenance, as a cell can be allowed to dry out for a period of time. While multiple cell basins are the desired geometric design, for small basins the additional construction costs for multiple cells represent a larger proportion of the overall basin costs and may be prohibitive in some circumstances. Multiple cell basins also require a *greater total area*, because of the space required by the internal banks.

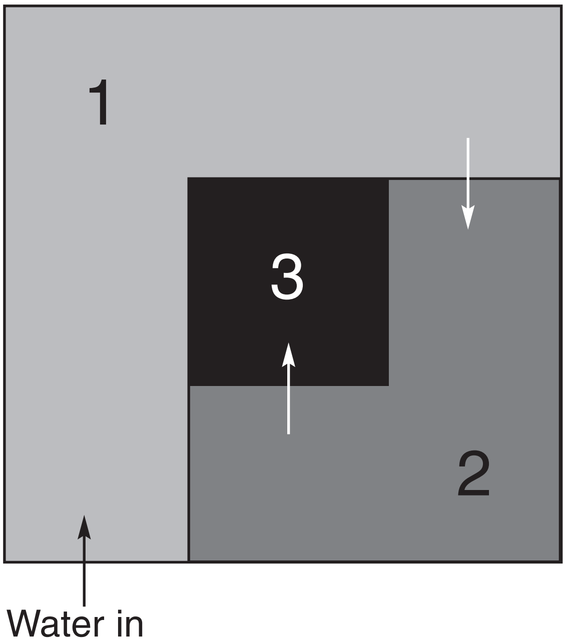

Figure 13.1 Example of a multiple cell basin configuration.

Depth – Theoretically, the depth of water in a basin will affect the rate of evaporation (due to its impact on water temperature), and also leakage rates (due to the driving head of water). Deeper basins cost more to construct as banks need to be larger and as such excessive depth will add unnecessary expense. Disposal basins function on an area basis (for evaporation) rather than a storage basis (volume), so the basin area is the primary key to basin performance. However, increasing depth will provide additional storage that may be useful in short-term critical periods. Apart from the design maximum water level, an adequate level of freeboard should be added that will store rainfall on the basin and prevent overtopping by wind/wave action.

Deeper basins are more expensive to construct as banks need to be larger, and as such, excessive depth will add unnecessary expense. However increasing depth will provide additional storage that may be useful in short-term critical periods. Modelling using **BASINMAN** has shown that increasing basin depth from 0.5 m to 1 m did improve the performance of the basin in controlling waterlogging in the farmed area in the long-term. However, further increasing the basin depth to 1.5 m resulted in only a very minor improvement in performance. Thus it would appear that a maximum design **water depth of about 1 m** is most useful (note that increasing basin depth should not be regarded as justification for decreasing basin area below design recommendation).

Apart from the design maximum water level an adequate level of freeboard should be added to store rainfall on the basin and prevent overtopping by wind/wave action. Suitable values for **freeboard** for basins in the Riverine Plain range between **0.6 m** and **0.8 m** (Leaney and Christen, 2000a).

Orientation – Basins should oriented so as to maximise the speed at which the humidity above the basin (caused by the evaporation) is removed. This is achieved by having the longest side of the basin perpendicular to the prevailing wind. This is also minimises the fetch and in doing so minimises wave heights that can erode banks. Whether or not this factor can be justified in basin design will depend on the farm layout and other factors.

Bank Design – Bank design should be such that the banks are sufficiently robust to prevent bank leakage and risk of failure. Design and construction should follow good earthwork construction practice, especially in regard to suitability of material, compaction requirements, internal and external batter slopes, water and wind erosion control, and sealing to prevent cracking. It is important that banks are constructed and compacted under soil moisture conditions that maximise their integrity. Provision for vehicular access and maintenance should be made, particularly for large basins. A key problem with disposal basins is wind/wave action causing bank erosion. Experience at the Girgarre Basin has shown that a minimum internal batter slope of 5:1 is required, with 7:1 being optimal. In the MIA a 7:1 batter has also been recommended. External batters are generally 2:1. Note that a batter of 8:1 provides good nesting and shallow water habitat for birds (Melville *et al.* 1993). The crest of the bank is usually at least 2 m wide to allow vehicular access. Topsoil is usually removed to form the outside of the bank (to promote establishment of plant cover) and subsoil used on the inside to reduce bank leakage. Figure 13.2 shows a cross-section through one side of a basin illustrating the desired bank design, maximum water depth, interception drain and buffer zone.

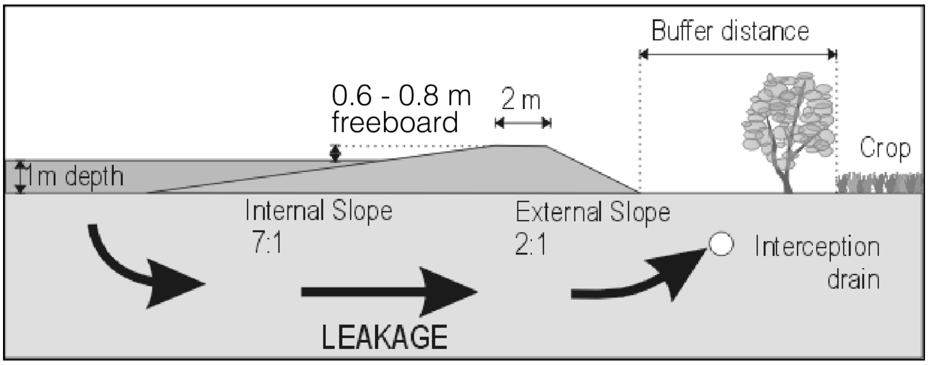

Figure 13.2 Cross-section through one side of a basin.

Designing for Limited Leakage

It is very difficult to prevent leakage from occurring from the floor of a basin. Fortunately, some leakage is beneficial as it can significantly extend a basin's life. However, leakage needs to be limited to low values to prevent excessive pollution of groundwater and other sensitive environmental features.

Without leakage, the basin water salinity increases more rapidly and evaporation is reduced, as discussed in Chapter 4. Also without leakage, precipitation of salt will gradually fill the basin. However, this has not occurred in any of the constructed disposal basins in the Riverine Plain to date.

A wide range of factors can affect the leakage rate of basins. 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. The throttle to leakage may also be at some depth below the basin but still at an elevation above the water table. The rate of leakage will also be determined by the rate at which the leakage is able to dissipate after the groundwater mound has stabilised. It is likely that, for any basin, different factors may control leakage at different stages of the basin life.

The following factors have been identified in laboratory and field studies as important in determining leakage from disposal basins:

1. The area of the basin is an important factor in determining leakage from disposal basins in the Riverine Plain. The leakage rate from large basins is generally very constrained by the capacity of the leakage to dissipate and is likely to be much less than the leakage rate from small basins in similar conditions.
2. Soil type and soil compaction (heavier soils or compacted soils will, in general, have lower rates of leakage).
3. Hydraulic head of water (deeper basins and/or lower regional water tables may enhance leakage).
4. Soil and water sodicity (chemical interaction of water and soil may lead to dispersion or flocculation of the soil and changed infiltration rates). While this has been observed in laboratory and small field studies, it has not been confirmed for disposal basins.
5. Algal and organic matter clogging (polysaccharide production as a result of microbiological activity or addition of organic matter may reduce leakage from the basins).
6. Preferential flow paths (leakage may be enhanced if it occurs via preferential rather than piston-flow).

If leakage reduction is considered to be necessary. For example, for a basin with low input water salinity then key elements to consider are:

1. Select an alternate site (soil type) or basin size that will reduce leakage.
2. Determine an appropriate physical measure for leakage reduction:
    - this may be the choice of construction equipment; the use of a scraper at suitable soil water contents can achieve a much high degree of compaction, than using a bulldozer or excavator;
    - compaction using a sheeps-foot roller - this costs about $3 000/ha and can reduce leakage significantly;
    - use of a liner - this is extremely expensive at $11 000-35 000/ha for bentonite and plastic liners respectively. Gardner (1990) reports lining of a dam with cheap builders plastic costing about $4 000/ha. However, the longevity of this plastic is unknown and practical attempts to use this type of plastic on the Riverine Plain have not been successful. Note that no type of lining will provide a perfect seal.
3. New methods for leakage reduction. Reducing leakage from dams, channels and other structures is an area that is undergoing constant research and as such the latest techniques should always be reviewed. A new technique currently proving successful for reducing leakage from rice bays and irrigation channels is impact compaction. Trials have found this technique can reduce water leakage from rice bays to less than 0.1 mm/day with three passes. Compaction to this level with this technique costs about $1 200/ha.
4. Management for reduced leakage. Filling the basin with fresh water to promote dispersion of the soil before filling with saline water can reduce leakage rates. (There are commercially available dispersants that can be applied to soils. These are relatively costly and how well they work is unknown.) Microbiological clogging is considered to be an important long-term process that reduces leakage. This relies on sealing with polysaccharides. Addition of cyanobacteria to water may facilitate this process. Algal mats also reduce leakage and are used in the salt industry. This type of organic clogging of pores takes time to become effective and as such needs to be protected. Drying of basins relying on this sealing should be avoided as this will oxidise the organic matter and destroy the sealing effect. Drying should also be avoided in compacted or clay lined basins as soil drying can create cracks that will allow preferential flow past the seal.

For the reasons described in earlier chapters, a leakage rate that is limited to 0.5-1 mm/day should be the aim when designing a basin. This requires the selection of sites with soils that have low conductivity throughout their profile. In many instances, particularly for small basins, compaction will be necessary to reduce leakage rates. Experienced soil engineers should always be consulted for the selection of suitable soils and advice on any compaction requirements.

Interception of Leakage

Lateral Flow and the Saline Leakage Plume – All disposal basins will be subject to leakage. There will be leakage from the basin that builds up a saline groundwater mound below the basin that in the long-term will develop into a saline plume. There will also be shallow lateral flow at the basin perimeter. The relative volumes of these leakages will depend upon the size, siting and configuration of the basin. Basins where leakage is *expansion limited* will be dominated by lateral flow as discussed in Chapter 4.

Shallow lateral flow will affect the land immediately adjacent to the basin and if left unchecked can cause waterlogging and salinisation problems in adjacent land over a relatively short period of time, a few years. Lateral flow will disappear relatively quickly after a basin is emptied, but the saline areas created may persist for much longer until salt is leached out of the soils.

The saline leakage plume will develop over a longer period of time, as it generally requires considerable time to change the groundwater salinity. The leakage plume is not so much a problem of water levels or water volume as with lateral flow but a problem of a changed groundwater quality under the basin. The direction and velocity of the saline leakage plume if left unchecked will be that of the regional groundwater flow. Thus the saline leakage plume is a longer-term threat to the environment as it will not disappear when a basin is emptied. The saline leakage plume will move with the regional groundwater and as such careful assessment of regional groundwater trends need to be made and assessment of the impact on the surrounding environment of the movement of such a plume.

Leakage Control Strategies – These need to consider the prevention of land salinisation around the basin due to lateral flow and the control of the saline leakage plume within the drained area.

Lateral flow is a function of the head difference between the ponded water level in the basin and the water table in the adjacent land and the permeability of the soil. Therefore, to minimise this, the banks of the basin should be adequately compacted, as should the basin floor, as required for leakage control discussed above. There may be merit in compacting the outermost 50 m or so of all basin perimeters to minimise this lateral flow. This compaction would effectively lengthen the flow path for lateral flow and hence reduce its effect. This logic can be extended further for larger multi-cell basins that have flow spiralling in toward the centre. In these basins, the outer cells should be compacted to reduce leakage rates to as little as possible. This will have the effect of minimising lateral flow. Also the concentrating effect of the bays will be very high, the saline water can then move on to the inner bays which are not compacted. This also has the advantage of concentrating the saline leakage plume at the centre of the basin thus reducing the risk of that saline plume moving out beyond the basin.

The other driving factor that can be manipulated to minimise lateral flow is the head difference between the basin and the adjacent water table. This can be manipulated by reducing the depth of water ponding in the basin. However, this is limited by the need for an adequate storage volume to act as a short-term buffer. This dual goal of adequate storage volume and minimising head difference can be achieved by a basin design that is partially or totally below ground level. Many basins are in fact partially below ground level as this is the soil taken to construct the banks. The depth below ground depends upon the size of the basin. Small basins, where the perimeter to area ratio is high, can probably be up to ~0.3 m below ground, whereas large basins will be largely at surface level as only a proportionally small volume of soil is required for the bank (e.g. a turkey nest dam).

Basins that are entirely below ground level will minimise these head differences. Hydraulically, such a basin still develops a groundwater mound in the surrounding area but the slope of this mound is shallower and hence is less likely to cause salinisation in the surrounding land. This type of below ground basin is more costly to construct as the soil from the basin is not utilised in bank construction and hence more soil is moved per unit volume of water storage than a normal surface basin. This makes this method impractical for large basins but may be useful for small basins. Two such basins, ~2 ha in area, are in existence in the MIA, both constructed at no cost to the farmer as the soil was excavated for use in channel construction by the local irrigation company. Despite these suggested design measures, there will still be some lateral flow. This is because the hydraulic gradients at the edge of the basin will be greatest (assuming that the basin is *expansion limited*, not *infiltration limited*).

In order to prevent problems from lateral flow occurring, an interception scheme should be implemented around the perimeter of the basin. This applies for basins within the drainage scheme as well as outside. These interception works can take the form of a deep open drain, a horizontal pipe drain, or a series of spear points or ground water pumps. Groundwater pumping will obviously serve the dual purpose of also containing the saline leakage plume from below the basin as well as the lateral flow at the perimeter. A case by case analysis needs to be undertaken as to the appropriate interception measure. Existing basins in the Riverine Plain where measurements have been taken have shown that lateral flow interception systems can recycle back to the basin 25-50% of the estimated annual leakage. Some measurements for on farm basins have found that this figure could be higher, up to 80%, especially over short periods when poorly constructed basins are very full.

As stated in Principle 3, siting of basins within the influence of the drainage system is preferred, as this will help contain the movement of the saline leakage plume. If the basin is sited outside the drainage system then specific measures to contain the plume will need to be implemented. In either case, it will be necessary to define an *attenuation zone* around the basin where pollution of the groundwater is permissible (as discussed in Chapter 5). As an example of long-term interception, modelling of the Girgarre Basin has shown that the leakage plume is in the capture zones of the groundwater pumps (T101, T102 and T103) and as such in the distant future the saline leakage will be recycled to the basin (Figure 13.2). This is because the groundwater pumps have altered the regional groundwater flow paths.

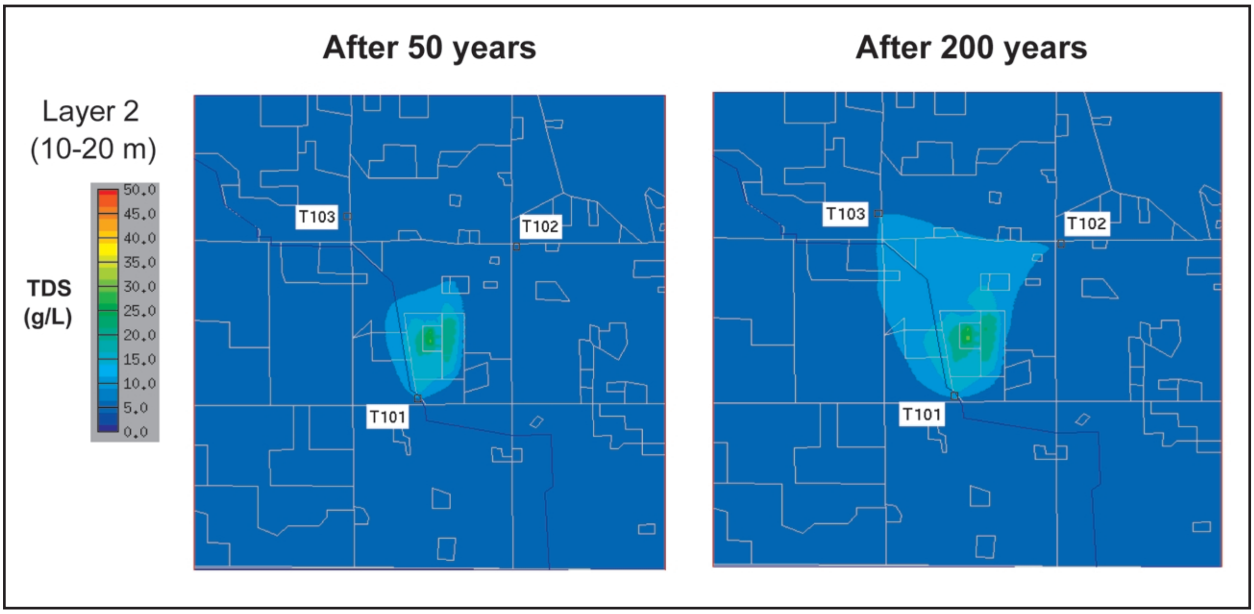

Figure 13.3 Simulation of the fate of leakage under the Girgarre Basin.

For both horizontal pipe drainage or groundwater pumping schemes, analysis should be undertaken of the rate and direction of movement of the saline leakage plume should the subsurface drainage system fail or be decommissioned. In such circumstances, the plume will be uncontrolled. In most irrigated areas of the Riverine Plain, the hydraulic gradients are small and as such the movement of such a plume would be slow. However, in the long-term the plume will still pose a risk to groundwater in surrounding areas if it is of beneficial use. Land and water management planning groups will need to develop policies in conjunction with local environment protection authorities, for the management of plumes from abandoned or decommissioned basins in their areas. These policies should take account of the fact that, in many cases, the shallow groundwater resources adjacent to the basin may be a result of irrigation on adjacent areas and would have low resource value compared to groundwater resources usually used for irrigation or other purposes.

When considering the long-term control of saline leakage plumes, the use of groundwater pumping is a technically feasible but expensive option. The plume could be trapped by strategic ongoing pumping or even in the long-term recycled back to the disposal basin. This will be an ongoing operation, but only if the plume is a hazard. In the very long-term alternative uses or disposal options for these saline leakage plumes in the groundwater may be found.

The appropriate leakage interception strategy required will be specific for each individual situation. It will primarily depend on the type of drainage system being used and the hydrogeology of the site and the surrounding region. Experienced hydrogeologists and drainage engineers should always be consulted to determine the optimal interception strategy for a particular situation.

13.3

Other Design Considerations

Other important aspects which need to be considered in basin design include:

- Minimising dust problems by maintaining water in the basin at all times, and keeping vegetation on banks and access tracks.
- Improving their aesthetic appeal through use of bushes and trees as screens around the basin.
- Minimising the impacts of mosquitoes and midges by siting basins away from residential areas, minimising areas of very shallow water, controlling vegetation and floating plants, stocking of the basin with fish, ensuring vegetation screens are in place around the basin, and use of decoy ultra-violet and blue-green lighting.
- Minimising odours by ensuring the basin does not dry out unnecessarily and removing excessive algal growth.
- Ensuring adequate fencing and signed warnings for safety reasons.
- Providing facilities for bird habitat, if desired.

13.4 Summary

It is important:

1. To use best practice investigation, design and construction techniques, by using experienced soil and drainage engineers and hydrogeologists to minimise the risks to surrounding land and underlying aquifers.
2. To ensure that only subsurface drainage water is allowed into the basin. Surface water, either as normal runoff or as flood flows, should be excluded.
3. To maximise evaporation by allowing a small amount of leakage to reduce salt concentrations in the basin water.
4. To limit leakage to an acceptable level by selection of appropriate sites that have soils with low hydraulic conductivity throughout their profile.
5. To contain the leakage within the drained area surrounding the basin to avoid problems with contaminating downstream neighbouring areas and downstream water users.
6. That land and water management planning groups develop policies in conjunction with local environment protection authorities and local government for the approval of basin designs and for the monitoring of basin performance, and for the management of plumes from abandoned or decommissioned basins in their areas.

14. Financial Viability of Disposal Basins

14.1 Introduction

All proposals for a new basin should include:

- ***a property development plan that includes a high standard of irrigation infrastructure; and***
- ***a comprehensive financial analysis of the impacts of the basin on the farm enterprise.***

This Chapter deals with the issues to be considered as part of the financial analysis. The overall goal of this analysis is to assess the impact of basins on farm viability.

14.2 Scenerios

Adoption of disposal basins can occur under two basic conditions, each of which requires separate analysis:

1. New development, where the farmer is undertaking a new enterprise with subsurface drainage and a disposal basin.
2. Existing development, where the existing crop has subsurface drainage already in place and the farmer is required to change from off-site disposal to a disposal basin.

In the former case, apart from considering the costs and benefits associated with a subsurface drainage system with a disposal basin, the profitability of an enterprise without drainage and other options such as more efficient irrigation systems should be considered. For adoption to take place, the profitability of an enterprise with a subsurface drainage system coupled with a disposal basin should be higher than other options. With groundwater pumping, benefits are likely to spread over more than one farm and thus analysis of profitability needs to consider all beneficiaries (see Singh *et al.*, 2000d).

In the case of an existing enterprise, the farm viability needs to be considered with the additional cost burden of a disposal basin. In this case, there is no extra benefit accruing from using a basin.

14.3 Analysis Outline

It is assumed that a regional assessment (see Chapter 8) has taken place where a decision has been made as to whether an on-farm or community basin will be constructed. The following outline can be used to analyse the financial viability of a subsurface drainage system with a disposal basin:

1. Determine basin construction costs for the selected site.
2. Determine if the enterprise is viable with a disposal basin by including the cost of the subsurface drainage and the basin with all other enterprise costs, assessing the returns from the enterprise, and then developing a *cash flow budget.* This may include a cost-sharing mechanism for groundwater pumping.
3. Undertake sensitivity analysis of key parameters affecting farm viability such as crop price and yield, farm size and basin area.
4. Assess whether the basin area, as determined by physical analysis, is economically optimal.

14.4 Determining Disposal Basin Cost

An estimate of the appropriate *safe* basin area is determined from the physical site assessment. The cost of this disposal basin should include:

1. Selecting a suitable site on the basis of geotechnical investigations.
2. Site survey and layout of design - including buffer areas and space occupied by banks.
3. Earthworks – stripping vegetation and removing topsoil, bank formation using a scraper, and additional protection and compaction of banks and floor, if necessary.
4. Lateral flow interception works – open drain or horizontal pipe drain to a sump and pump, spear points or groundwater pumps.
5. Recurrent costs – pump operation, pump repair and maintenance, repair and maintenance of basin banks, monitoring costs and public liability insurance.
6. A decommissioning cost should be estimated for each basin, and assumed to occur at the end of the design life.

These costs should then be used to develop a *cash flow budget* with an appropriate discount rate (e.g. 8%) to determine the annual *Net Present Cost* (NPC) over the life of the basin. The expected life of this type of engineering structure should be a minimum of about 30 years.

The cost of a disposal basin will vary markedly depending upon the site and design. Therefore, cost minimisation should be examined by carefully considering the appropriate level of geotechnical investigation, basin shape and cell size, bank shape and size, compaction requirements and leakage interception works (Singh and Christen, 2000a).

14.5 Enterprise Viability with a Disposal Basin

The viability of an enterprise with a disposal basin is determined by developing a *cash flow budget* that includes all **costs** and **returns**. Assessing the **costs** for a farm enterprise with a subsurface drainage scheme and a basin is relatively straightforward because the design and hence cost is known. However, assessing the **returns** is more difficult as assumptions about the level of yield associated with the system are required. The key factor in this is the sustainable yield with the chosen basin area, as this is affected by climate, waterlogging and soil salinity. This assessment is complex and difficult due mainly to the lack of information on plant responses to waterlogging and salinity in the Riverine Plain. The loss functions adopted need to be consistent with the best information available for the various land and water management plans, or for pasture those in the **Drainage Evaluation Spreadsheet Model** (MDBC, 1994) may be adopted (Figure 14.1). A further complication with groundwater pumping is that the area of influence is not known at installation and may be spread over more than one farm.

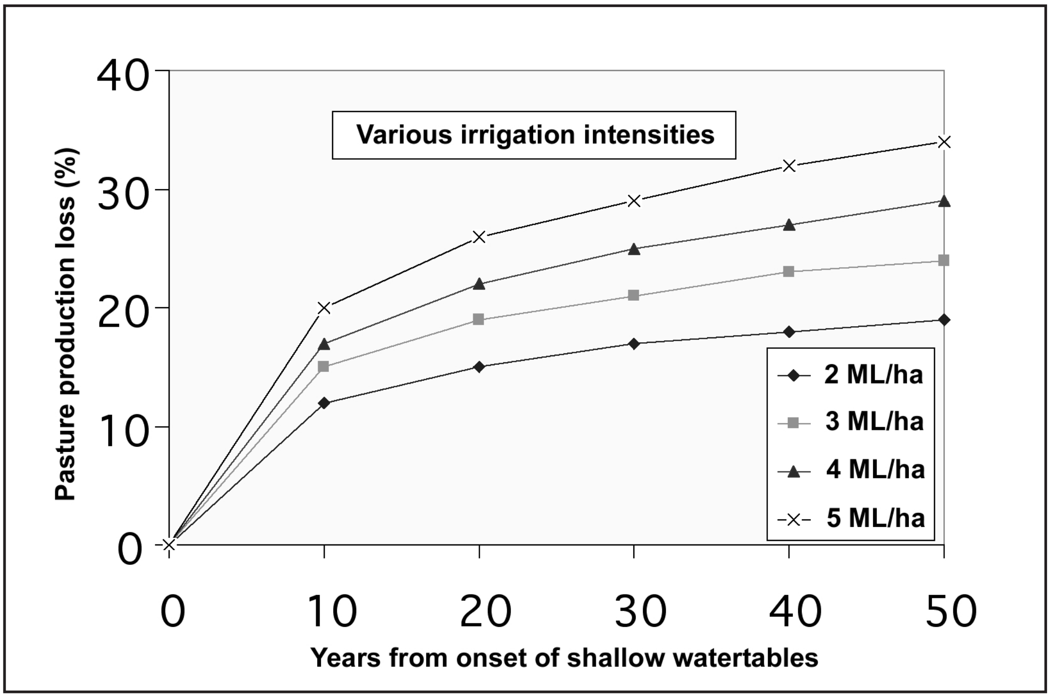

Figure 14.1 Salinity loss function for pasture.

An example of using **BASINMAN** modelling to estimate these loss functions associated with waterlogging for horizontal pipe drainage systems is given. (Figure 14.2). This figure shows that if basins are too small, both vines and citrus have high yield losses due to waterlogging; on the other hand, if the basin is too large, there is loss of production due to the additional land sacrificed for the basin.

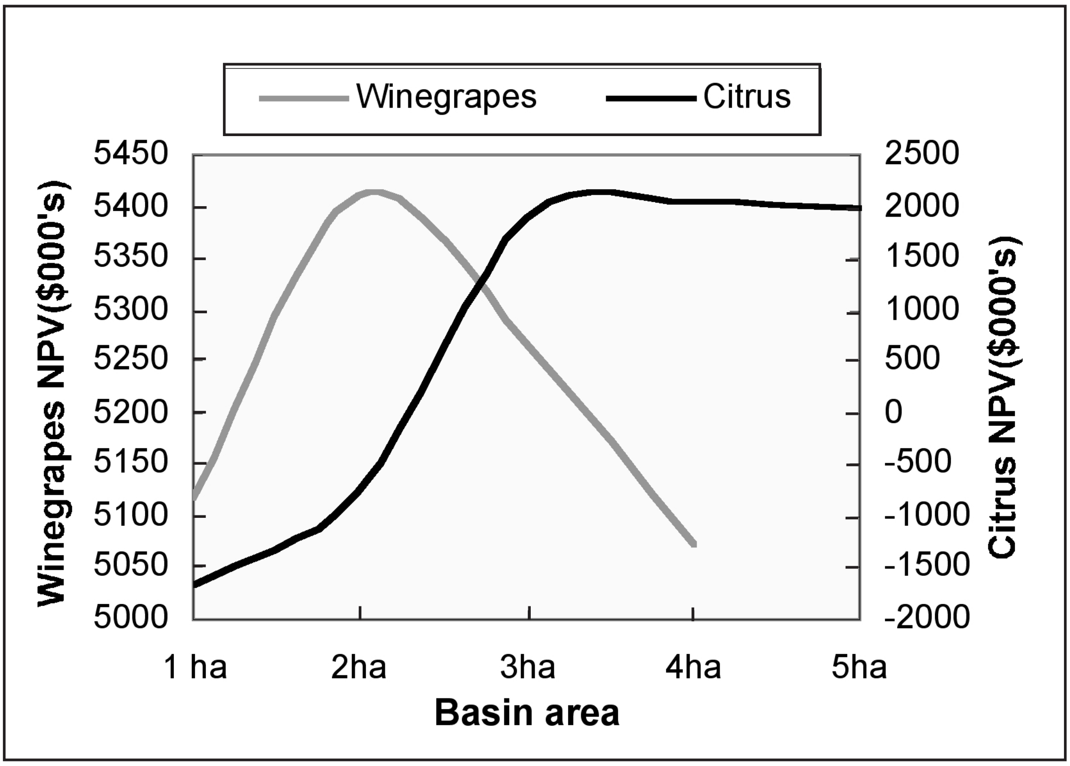

Figure 14.2 Figure showing that the NPV varies with basin area, small basin = high yield losses due to waterlogging, large basin = high yield loss due to area.

Analyses Required

Using the *cash flow budget,* the enterprise viability should be tested against the main financial criteria, such as *Net Present Value* (NPV) and/or a *Benefit Cost Ratio* (BCR). Variations in the annual *Net Cash Flow* (NCF) should also be examined for periods of low returns affecting enterprise ability to pay for costs. Assessments for basins need to be made in parallel with assessment of irrigation infrastructure and the potential to minimise drainage. For existing enterprises (those currently disposing of drainage to surface waters), the main assessments required are whether the enterprise is still viable and the change compared to the previous status quo of subsurface drainage without a basin. For new basins, where it may be difficult to accurately estimate drainage volumes, there is a need to factor in contingencies in regard to the need for drainage and disposal if and when needed. In the case of groundwater pumping additional key issues that need to be analysed include total area served by a pump, and how much of that area is within the farm paying for the pump and disposal basin. Moreover, if the analysis is carried out from a salinity plan perspective (as opposed to a individual landholder perspective), total costs and benefits over the whole area should be considered. In all of these analyses, sensitivity analysis is required of the key factors (crop price and yield, farm size, basin area and land value).

14.6 Optimising Basin Area

The financially *optimal basin area* is the one that gives the best return over the analysis period (i.e. highest BCR or NPV). In financial terms, the *optimal basin area* may be smaller than the *safe basin area* as determined by physical analysis. This is a trade-off between the financial losses due to occasional waterlogging events and the continual losses incurred by a larger basin (Figure 14.3). However, a financial analysis of grape and citrus enterprises in the MIA has found that the *optimal basin area* in the long-term results in a highly variable *cash flow* reflecting varying climatic conditions (Singh and Christen, 2000b). This is not desirable for a business enterprise, and most of the fluctuation can be eliminated by adopting the safe basin area.

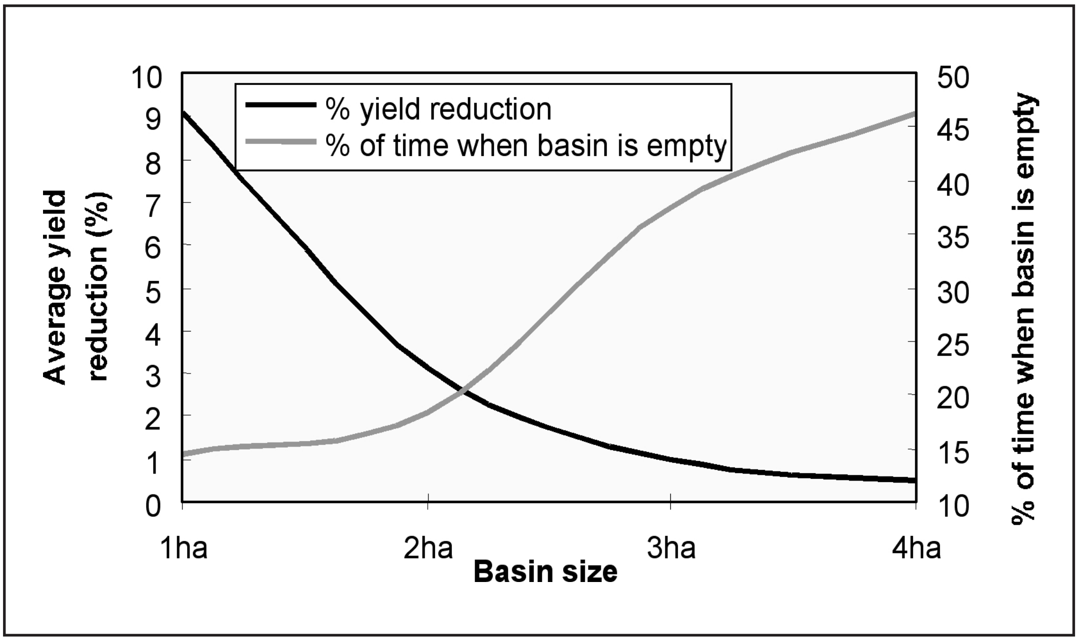

Figure 14.3 An example of the trade-off between more basin = less yield loss but also = less utilisation.

The required **optimal** basin area is sensitive to the amount of drainage and hence irrigation efficiency. If irrigation efficiency can be improved then there is less waterlogging and yield reduction allowing a reduction in the required basin area. In this context, it is useful to compare investment in improved irrigation techniques against the reduction in basin area required. Moll and Christen (1996) found that it was financially attractive to invest in a drip irrigation system for wine grapes as the basin size could be reduced from 10% under flood irrigation to less than 6.5% with drip irrigation.

14.7 Summary

1. All new development proposals should be accompanied by a full financial analysis that should include decommissioning costs should the development be abandoned.
2. The use of local-scale disposal basins is generally difficult to financially justify for low value crops as they significantly add to the cost of drainage.
3. They are most financially attractive for crops that have high yields and prices and are sensitive to waterlogging and salinity.
4. Financial viability is greater for existing plantings than for new developments. There is a need to plan for the installation of a basin, if and when needed.
5. For groundwater pumping, mechanisms for equitable distribution of costs need to be consideration, because benefits tend to be spread over more than one farm.
6. Irrigation management is a key factor in the financial attractiveness of a drainage system. Efficient irrigation results in less drainage, leading to a smaller basin.

15. Management and Monitoring

15.1 Management and Monitoring Objectives

The monitoring and management of a disposal basin has two key objectives:

1. To ensure that environmental impacts of the basin are maintained within the agreed limits set at the design stage; and
2. To ensure that the basin is functioning adequately to dispose of the drainage water at the design rate.

The most important factor in achieving the above objectives is that leakage from the basin is close to the predicted rate defined in the design and that the leakage plume remains in a defined area. We recommend, therefore, that disposal basin monitoring should focus on four main aspects:

1. Input water quantity and quality (used in estimating leakage rate);
2. Basin water quantity and quality (used in estimating leakage rate);

3 Groundwater quality (used in defining the spread of the leakage plume); and

4 Water table depth (used in assessing the speed and direction of spread of the leakage plume).

As a general guide, aspects 1 and 2 should be measured at least monthly, and Aspect 3 and 4 should be measured at least every 6-12 months. Monitoring can be very costly, and so the level of effort for a given basin should be commensurate with the risk that is poses (see Chapter 6).

All basins should have management and monitoring plans that clearly state how the basin will be managed over its life and the monitoring that will be carried out to ensure that basin operation conforms to its management objectives. Both documents should approved and regularly reviewed by a regulatory agency on a regular basis to ensure compliance and amended, when necessary, to take advantage of any new technologies.

Monitoring the Operation of the Basin (Leakage Rate)

Determining basin leakage rates is not easy. However, simple methods based on combined water and salt (or preferably chloride) balances provide the most accurate estimates (see Chapter 4). The leakage thus determined for the basin should be compared to the design leakage (usually ~0.5-1 mm/day; see Chapter 4).

If the measured leakage is much higher than the design leakage, then the monitoring of groundwater quality should determine where the leakage is occurring and if it will have a significant impact on the environment. Depending on where the leakage is occurring, several forms of remedial action are possible (e.g. reduce the water level in the basin, fix the basin walls, compact the floor of the basin or improve the lateral flow interception measures). In any case, the saline leakage plume needs to be monitored carefully.

If the determined leakage is confirmed as significantly lower than the designed leakage, this is likely to result in elevated salinity levels within a few years of operation of the basin. If these levels are above 180 000 mg/L, then there may be a reduction in the rates of evaporation and reduced drainage disposal capacity. In this case, the disposal capacity should be recalculated using the measured leakage rate and assess if the disposal capacity is adequate. If not, then the basin will need to be enlarged or drainage reduced.

15.2 Management Strategies

Basins should not be allowed to dry out to prevent nuisance from dust, cracking of compacted layers, loss of organic mats acting as seals (see Chapter 13). The main water management concern is that the *system* should be adequately buffered to be able to dispose of the normal drainage requirement as well as cope with periods of higher drainage volume coinciding with periods of lower net evaporation. The *system* should be considered as the disposal basin plus the unsaturated zone in the farmland protected by the subsurface drainage. This is because the unsaturated zone below the root zone in the farmland also has a useful storage volume for excess water in periods when the disposal capacity (net evaporation) of the system is low. The management of basin water level should reflect the time of year and probable net evaporation conditions (e.g. basins should be managed so that they have a low water level when entering the low evaporation winter period). These may also be critical periods when good root zone drainage needs to be assured (e.g. first flush spring growth, autumn harvest time).

The best method of achieving a well-buffered system is to ensure that disposal basins always have water in them (25% of capacity is a realistic minimum) to ensure ongoing evaporation. The rest of the basin capacity should be used to prevent root zone waterlogging after irrigation or rainfall. This ensures maximum water evaporation from the system, and maximum available storage below the root zone in the farmland. Good farm irrigation management is also critical in managing basin water levels since it can reduce the drainage requirement.

For groundwater pumping systems, we suggest a minimum depth of water in the basin of approximately 0.2 m (as was found suitable for the Girgarre Basin). The maximum water level is determined primarily by the most cost-effective way of operating the pumps (after allowance for high rainfall/low evaporation periods), but should not exceed 1 m for prolonged periods (see Chapter 13).

All basins should have a contingency plan that describes actions in response to excessive leakage and plum movement, and basin overtopping. It should be approved and regularly reviewed by a regulatory agency. The plan needs to include containment of surface water in the local area and notification of adjacent landowners and regulatory authorities should such circumstances arise.

15.3 Maintenance

Maintaining the integrity of the basin, which includes the repair of banks and access tracks, and maintenance of the lateral flow interception system (cleaning out open drains and replacing pumps) is of primary importance. Banks may become damaged and leaky through wave erosion or biological macropores. Experience from the Wakool Basin, which has been operating for approximately 25 years, is that this is an extremely important on-going management issue, particularly once the basin had been operating for some time.

Another important aspect of maintenance and management is to minimise nuisance from disposal basins (by minimising dust, odours and insects). Dust problems can be minimised by maintaining water in the basin at all times, and keeping vegetation on banks and access tracks. Undesirable odours often result from excessive algal growth in the basin and so periodic removal may be necessary. A real hazard in terms of nuisance and human health are mosquitoes since they can transmit disease (WHO, 1989). Siting basins away from residential areas is important in this regard. Management and maintenance to reduce mosquito problems includes minimising areas of very shallow water, controlling vegetation and floating plants, and stocking of the basin with fish. Experience from the Girgarre Basin suggests that swarming of midges may also occur in the early stages of basin operation. The problem abated after a year or so once the trees around the basin provided a sufficient shield against the migration of midges from the basin (they are very dependent on wind for migration). Stocking of the basin with fish and decoy ultra-violet and blue-green lighting can also reduce midge problems.

15.4 Monitoring for Environmental Assurance

Monitoring for toxicants is important to:

- ***avoid risk of harm to wildlife living in, or visiting, the basin; and***
- ***avoid risk of consumption of contaminated fish or other aquaculture that may be carried out formally or informally in the basin.***

Results of sampling of basin waters and sediments in this project (Christen *et al.*, 2000b) have found elevated levels of some trace metals and pesticides. At present, the fate of these toxicants is unknown. They may leak from the basin with the leakage plume or possibly accumulate in the sediment in the basin.

In addition to the routine monitoring suggested earlier in this chapter, the basin water also needs to be monitored after the first year of operation for toxicants such as pesticides and trace metals. Providing there are no concerns with elevated levels of some toxicants, subsequent monitoring should take place every two years thereafter. The particular toxicants that need to be monitored depend upon the local environment, and advice should be sought from the environmental protection and other regulatory authorities.

15.5

Monitoring Leakage Rates

The spreadsheet model described in Chapter 4 (and documented in Leaney and Christen, 2000a) can also be used to calculate the leakage rate of a basin that has been in operation for one or more years. The model uses the same input data as described earlier, in this case, using leakage as a variable and matching the predicted development of basin salinity to that observed during the monitoring period. It is possible to vary the leakage rate temporally or, in the case of multiple cell basins, to assign different leakage rates to individual bays. The salinity of water in the basin is reasonably sensitive to changes in leakage rates, particularly in the range 0-3 mm/day. This method provides water managers with a far more confident estimate for leakage rate than that determined by water balance calculations. The spreadsheet model is not designed for basins that are allowed to empty or for basins with hyper-saline water (near saturation levels for precipitation of sodium chloride). An example of this use of the spreadsheet model is shown in Figure 15.1.

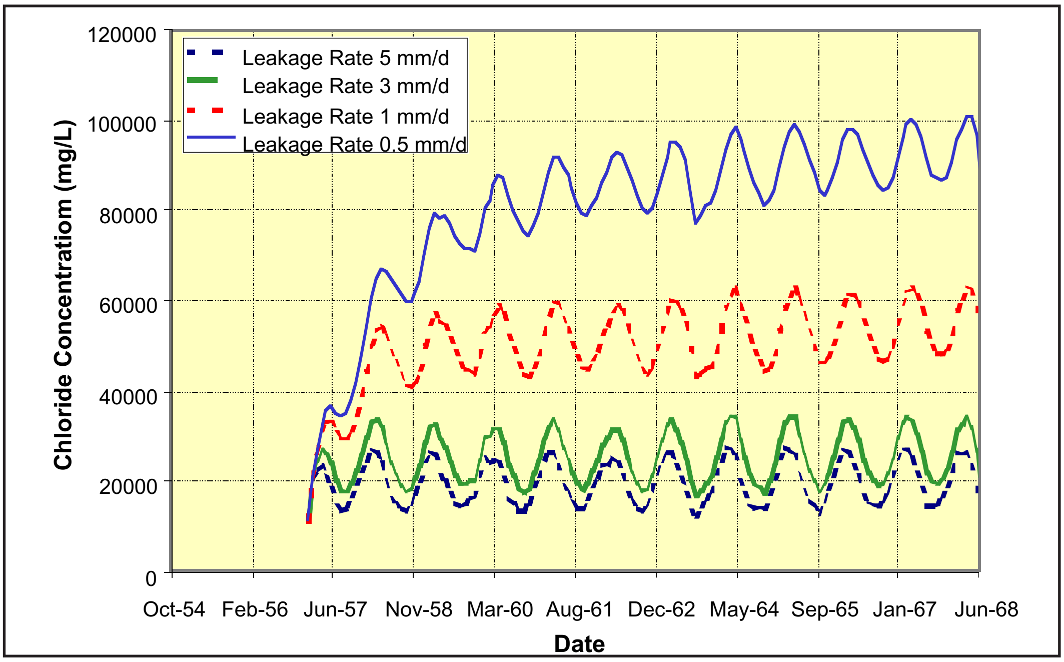

Figure 15.1 Predicted basin salinities (as chloride concentration) versus time for a 10 ha basin located at Hillston, for a range of leakage rates.

15.6 Monitoring for Movement of the Leakage Plume

To monitor movement of the leakage plume, piezometers need to be installed in and around the basin. In addition to identifying the presence of the plume (from the water quality), piezometric levels indicate the hydraulic gradients being set up by the basin and hence the likely long-term direction and speed of movement of the leakage plume. Inside the basin, nested piezometers should be installed at the time of construction with screens at depths of 1, 2, 5 and 10 m (1-3 sets of nested piezometers for each bay depending on size). Nested piezometers, with screens at 1 m and 5 m beneath the water table should be installed at 100-300 m intervals around each side of the basin (at least one nest per side). Special emphasis should be given along the downstream side of the regional groundwater gradient, and on sides in the direction of sensitive environments. It should also be recognised that preferential/bypass flow is possible and as such some part of the leakage may move deeper or further than would estimated by piston flow processes. This requires placement of a small number of piezometers at greater depths and distances from the basin. Suitable locations should be determined by investigating site groundwater conditions.

Another useful tool in tracking the development of saline leakage is the use of Electro-Magnetic survey equipment (EM31, EM34). These allow the area around the basin to be surveyed at a level of detail not possible by soil sampling. A baseline survey before the basin is filled is required and then surveys carried out at regular intervals such as annually or biannually.

The piezometers should be sampled before the basin is filled and analysed for salinity, chloride, trace metals, and pesticides to provide base level data at each monitoring point. The sampling, undertaken as part of the site investigations pre-basin construction, will also be useful in establishing this base level. Measurement of piezometer levels and water sampling should be undertaken on a regular basis (at least annually) following the commissioning of the basin. If the leakage is higher than the design leakage, monitoring of the piezometers should be take place more frequently.

Monitoring of the lateral flow interception system in terms of quantity and salinity should also be conducted regularly. If there are surface water features such as drains, streams, lakes near the basin then these can also be monitored for any changes in water quality.

15.7 Decommissioning

A well sited, designed, constructed and managed local-scale basin can have an effective lifetime of the order of decades to hundreds of years. However, it is possible that within that timeframe a decision will be made that it is no longer required and hence will need decommissioning. To date no local-scale disposal basin has been actively decommissioned, although a number have been abandoned. Due to the lack of experience in basin decommissioning it is clear that further work needs to take place to determine how this should be best carried out. Hence, the following discussion is somewhat speculative in relation to the issues concerned and how they should be addressed.

Decommissioning of a disposal basin involves two key processes:

- ***management of any saline leakage plume that has developed; and***
- ***clean up of salt and other toxicants stored in the basin sediments.***

All basins should have a decommissioning plan that describes how these issues will be dealt with in the event that the basin is no longer required, and it should be approved and regularly reviewed by a regulatory agency.

Basin decommissioning should be considered at the design stage in terms of long-term control of the saline leakage plume and local impacts. However, it is only when the basin is in operation that the actual drainage salt load to the basin and the actual hydraulic changes in the local groundwater system due to the basin will be known. Also, the date of decommissioning is unknown and hence the amount of salt and toxicants stored in the pond and the depth and extent of the saline leakage plume cannot be accurately predicted.

In these circumstances multiple options need to be developed, both before construction and during the life of the basin. The key factor is that if the basin is no longer used then the saline leakage plume still needs to be managed. This may necessitate ongoing pumping to the basin from interception wells, even if drainage input water to the basin is stopped. In the very long-term it would be possible, but expensive, to put in bores that could capture and extract the saline leakage plume from the groundwater for alternate disposal. In many cases the effect of pumping and disposal will have been to redistribute salts already in the area, resulting in reduced groundwater salinities in the drained areas and increased salinities under and adjacent to the basin. If pumping and disposal is terminated migration of any plume may result in a further redistribution of the salts, but the final outcome may be no worse that that which existed prior to the implementation of the drainage scheme

If a basin is decommissioned with no water input, then assessment of the basin site for toxicants needs to be undertaken. This also needs to be undertaken for the groundwater affected by the saline leakage plume. As described above, toxicants such as trace metals and pesticides have been detected at elevated levels in the sediments of some disposal basins in the Riverine Plain.

Due to the concentration of toxicants in the basin sediment, these sites need to be treated with caution. Even when they are returned to agriculture there may still be unacceptable levels of trace metals. The magnitude of this problem will not become clear until the basin has been in operation for some time. However, the existing evidence suggests that there should be discussions with environmental protection authorities and other regulators as a basin may eventually come under the category of a contaminated site. In which case there are regulations that apply for the registration and management of that site which may mean covering the site or removing contaminated soil (NSW EPA, 1999).

15.8 Summary

1. The primary purposes of a management and monitoring program are to ensure that environmental impacts of the basin are maintained within the agreed limits set at the design stage, and to ensure that the basin is functioning adequately to dispose of the drainage water at the design rate. All basins should have management and monitoring plans that detail this process. These should be approved and regularly reviewed by a regulatory agency to ensure compliance, and amended, when necessary, to take advantage of any new technologies. They should also have an approved contingency plan for basin failure that is regularly reviewed by a regulatory agency.
2. Disposal basin monitoring should focus on four main aspects: input water quantity and quality, basin water quantity and quality, defining the leakage plume, and assessing its speed and direction of movement.
3. All basins should have a decommissioning plan that describes the management and clean up of basin sediments and any leakage plume, should the basin be no longer required. The plan should be approved and regularly reviewed by a regulatory agency. While decommissioning options should be developed prior to construction, they may need to be changed during the life of the basin, as the potential impacts of basin operation whilst it is active become apparent.

Concluding Remarks

Use of the **guidelines** presented here, and the **principles** that underpin them, should assist in resolving most of the biophysical and financial issues associated with the **effective** and **safe** use of local-scale basins. However, it should be noted that they do not encompass the social and political issues associated with these basins, as these are generally specific to individual situations and are more appropriately handled by the communities concerned and their local authorities. In particular, determination of thresholds for the factors which define site suitability (groundwater salinity, water table depth, soil texture, buffer distances), planning control and approval processes, risk assessment and contingency procedures, monitoring and decommissioning requirements, and cost-sharing arrangements are all key issues which need to resolved for each region. Local land and water management planning groups need to take the initiative in these issues to ensure appropriate controls, agreements and arrangements are put in place, prior to widespread implementation of local-scale basins in their area.

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