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

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

MINIMISING THE COST OF BASINS: SITING, DESIGN AND CONSTRUCTION FACTORS

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Foreword

To limit salinity increases in the River Murray, there are pressures to minimise salt leaving irrigated catchments of the Murray-Darling Basin. Part of this strategy is to store drainage disposal water in the irrigation areas themselves and use disposal basins. Unfortunately, there are no existing guidelines for siting, design and management of such disposal basins. The CRC for Catchment Hydrology and CSIRO Land and Water, with support from the Murray-Darling Basin Commission have embarked on a project with the overall objective of producing such guidelines for the Riverine Plain of the Murray Basin. This report is one of several reports being produced in this project to support the guidelines. It deals with the topic of costs associated with disposal basins. If less water is exported into streams, there are increased costs associated with storing the drainage water in the irrigation water. If these costs are sufficiently high, more consideration needs to be given to the type of irrigation development that occurs and whether it will be financially viable with the inclusion of storage of drainage water.

Glen Walker
Leader, Salinity Program

Summary

Salt disposal basins are used for the disposal of saline water where there are restrictions on other disposal methods. These basins can be small, 2-20ha, on-farm basins taking drainage water from individual farms or larger community basins, 30-200ha, taking drainage water from a group of farms. Basins have many variations in siting with regards to soil suitability, underlying aquifers and surrounding land use and also in methods of construction and layout. Under these circumstances there is no single cost for a salt disposal basin. In the past many authors have quoted the cost of a salt disposal basin, but these are all particular to a single site and application. This report intends to provide information on the construction and maintenance costs of salt disposal basins for a range of sites and designs.

This report also investigates various aspects of salt disposal basin design and siting that can be manipulated in order to minimise costs. The cost estimates show that the earthworks, geotechnical investigations and interception of lateral leakage are the major constituents. Earthworks account for about 70% of the total cost, within this component the compaction of banks and floor accounts for half the cost. Geotechnical investigations for siting account for about 25% of the total cost. The cost of intercepting lateral leakage accounts for about 12% in small basins reducing to 3% in large basins. On the basis of detailed cost investigations four major areas were identified which could be manipulated to minimise the cost of salt disposal basins. These were the geotechnical investigations, leakage control (compaction of floor and banks), basin geometry (shape and number of cells which affect the bank length) and lateral leakage interception.

An intensive geotechnical investigation is generally recommended for siting larger salt disposal basins. However, smaller basins can be sited in low as well as high-risk environments. Using the method proposed by Christen *et al.* (1998) in Appendix A, the cost of investigation can vary from $1059/ha for a low risk basin to $1871/ha for a high-risk basin. The increased expenditure can be justified if it leads to better information to avoid adverse environmental effects. It may also provide sufficient confidence to avoid expensive leakage control measures such as compaction or lining.

The additional compaction of floor and banks for controlling leakage is a major part of total basin cost. Therefore, it is important to find sites that avoid the need for additional compaction, or lining. Larger basins should not require compaction as their geometry results in lower leakage rates and their siting should be based on intensive investigations to avoid areas of high permeability.

Basin geometry has a significant effect on the total cost. Geometry includes

the overall shape of the basin, number and size of internal cells and hence the bank length. A square or rectangular basin is more cost effective than a triangular basin in terms of perimeter and the length of internal banks to create cells.

Increasing the bank height increases the cost of a salt disposal basin considerably. The appropriate bank height should be selected depending upon the frequency and extent of critical periods e.g. high rainfall, when extra storage may be required to prevent farm waterlogging.

Two types of lateral leakage interception drains, namely subsurface horizontal pipe drains and open ditch drains are commonly used for controlling lateral leakage. Subsurface pipe drains were found to be cheaper for smaller basins (2-20ha), whilst open drains and subsurface pipe drains have similar costs for larger basins.

Detailed analysis of costs showed that the cost of any particular salt disposal basin will depend upon the site conditions, compaction requirements, geometry and lateral leakage control measures. The costs can vary enormously depending on any of these items; however, with proper consideration the cost of a salt disposal basin can be minimised. Analyzing the Net Present Cost (NPC) variations between best and worst case cost situations a 2ha basin cost between $19,000-$22,700 per ha and a 200ha basin cost between $4,700-$11,700 per ha. This illustrates the opportunities for cost minimisation in salt disposal basin construction.

Table of Contents

List of Tables

List of Figures

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1. Introduction

The management of saline drainage waters is a complex problem with no readily available low cost solution. To date options considered for the disposal of saline water from irrigated areas of the Southern Murray Darling Basin have been: river disposal, disposal bores, salt disposal basins, pipeline to the sea, and desalination. Of these only the use of salt disposal basins is currently accepted as a viable, short and long-term disposal option. However, there is concern about the cost involved in the use of salt disposal basins.

Although there are numerous salt disposal basins in the Riverine plain, detailed costings are not often available. The reported costs for different basins vary markedly (Table 1).

Table 1.Reported salt disposal basin costs

Basin size (ha)	Cost/ha ($000's)	Basin location	Reference
770	5	Wakool, NSW	Nauton,D *et al.*, 1995
Large	11	unspecified	Gutteridge *et al.*, 1990
30	21	Girgarre, VIC	Sinclair Knight Merz, 1995
20	17	Griffith, NSW	Muirhead *et al.*, 1997
15	9	VIC	Trewhella, 1990
10	3	Kerrang, VIC	Poulton, D., 1998
10	18	Griffith, NSW	Muirhead *et al.*, 1997
2.8	21	Pyramid Hill, VIC	Dept. Food & Agr., undated
2	25	Griffith, NSW	Muirhead *et al.*, 1997

The large variation in costs found in the literature is confusing, thus an investigation into the reasons why basin costs may vary so markedly will be useful to those proposing the use of salt disposal basins.

There is evidence that salt disposal basins can be an effective way of handling drainage water, especially with greater efforts being made to locate basins at sites where hydrogeological effects will be minimal, there are large expenses involved with the detailed investigations required. Also associated with new basins are construction costs (mainly the costs associated with controlling excessive leakage), maintenance and operating costs. When these expenses are added to the costs of the drainage system, the total costs may become prohibitive, RWC (1992), Muirhead *et al.* (1997). Therefore, a detailed investigation is needed to investigate the possible scope of cost minimisation within the existing framework.

2. Objectives

The objectives of this investigation were to:

1. **Determine the cost** of siting, design and construction of salt disposal basins, and the relationship between basin size and cost
2. **Identify the sensitivity** of salt disposal basin cost to individual items and the potential for cost minimisation
3. **Determine the range** of likely salt disposal basin costs for different basin sizes, under a variety of siting and design criteria.

3. Methodology

In conducting these assessments of basin costs it was assumed that the basins were sited, designed and managed according to the guidelines presented by Christen *et al.* (2000). Of particular importance is the relationship between basin size and leakage. Christen *et al.* (2000) show that for basins in the Riverine plain leakage reduces with basin size due to a decreasing perimeter to area ratio. They also state that a desirable leakage rate is 0.5-1mm/day. This leakage rate is generally what is observed for basins greater than 50ha. Basins smaller than this will leak at higher rates which may lead to unacceptable environmental impacts, thus basins smaller than 50ha are assumed to require additional leakage control measures such as soil compaction.

Four different basin sizes (2, 5, 20 and 200ha) were used to examine the relationship between basin size, siting, design and cost. Detailed estimates of cost were determined in consultation with surveyors, consultants, engineering suppliers and water and electricity supply authorities. The cost estimates of salt disposal basins are based on actual costs in 1998 dollars.

To study the effect of individual cost components a sensitivity analysis was carried out using a 30 year Cost Flow Budget at a discount rate of 7 percent. Based on the sensitivity analysis results, best and worst case salt disposal basin cost scenarios were determined. By varying individual item costs the range of likely total basin costs was determined.

The analysis was carried out using an EXCEL spreadsheet, to determine costs and the @RISK tool to generate changes in costs for probability analysis.

4. Results and Discussion

4.1 Cost Components of a Salt Disposal Basin

This section gives an account of the various steps involved in the construction of a salt disposal basin and estimates of the associated costs with each step.

4.1.1 Site selection

The selection of a site involves a geotechnical survey of the area proposed for siting a salt disposal basin. A discussion paper by Christen *et al.* (1998) (Appendix A) suggests a methodology for determining the geotechnical requirements for salt disposal basin siting. They suggest two levels of site assessment

(1) Macro scale; the suitability of the general locality to assess the broad potential risk of basin leakage, considering the environmental sensitivity of the area such as areas of conservation value, flood plains, wetlands and swamps, remnant vegetation and residential areas. Among other factors, the understanding of local hydrogeology including the general extent and character of deep aquifers and likely existence of shallow aquifers, to set performance criteria for leakage and risk assessment are critical. The methodology proposed in Dowling *et al.* (2000) could be useful for this type of macro scale assessment.

(2) Micro scale; assessment of on-site factors. This is a set of on-site factors that endeavour to estimate potential leakage rates, the possible destination of the leakage and the likelihood of causing environmental degradation. The level of on-site investigation required depends largely upon the scale of the project and the extent of the economic and environmental risk involved. Table 2 shows the factors that should be considered to determine if the proposed basin would fall in a high or low risk category and as such the extent of the geotechnical investigations required.

Table 2. Factors determining the possible risk categories for a salt disposal basin site (Christen et al.,1998) (Appendix A)

Criterion	Low Risk	HighRisk
1. Locality assessment	Detailed	Simple
2. Design	Locally developed guidelines	No local guidelines
3. Potential off site leakage effects	Small	Large
4. Size	Small	Large
5. Hydrogeology	Well documented	Uncertain
6. Management plan	Good	Poor

4.1.2 Geotechnical investigation

The investigations suggested for a high risk situation include: (a) the assessment of the hydrogeology of any local aquifers by determining aquifer characteristics such as depth, extent and transmisivity, piezometric level and water salinity; (b) the on-site assessment of leakage (recommended for both low and high risk situations) to determine the uniformity and suitability of soils on site. For the latter assessment using an EM 31 survey on a 50-metre grid identifies the location and uniformity of heavy soil and possible high leakage zones. Auger holes to 3m are suggested to investigate soil texture, salinity, sodicity and hydraulic conductivity, together with water table depth and salinity. Additional surface infiltrometer and vertical permeability measurements are suggested for high-risk situations.

Using this methodology the geotechnical cost for different sized salt disposal basins under low and high-risk situations was determined, Table 3. The cost per hectare decreases with increasing basin size under both low and high-risk situations. The site assessment cost for leakage constitutes the single largest component (more than 80 percent) in the total geotechnical investigation cost of salt disposal basins and this increases with basin size.

Table 3.Geotechnical investigation costs for low and high-risk basins ($)

Risk scale / Investigations	Low Risk Basin Size (ha) 2	5	20	High Risk Basin Size (ha) 2	5	20	200
A. Hydrogeology: Assessment of local aquifers							
EM34 survey	-	-	-	100	100	142	586
Drilling and construction	-	-	-	740	740	2,960	11,480
Piezometer fittings	-	-	-	203	203	813	3,255
Supervision	-	-	-	130	130	518	792
Logging of piezometers	-	-	-	135	135	538	2,352
sub total	-	-	-	1,308	1,308	1,308	18,465
B. Leakage: Site assessment							
EM31 - 50m grid	2,236	2,236	8,116	2,236	2,236	8,116	79,780
Auger holes	1,260	3,060	12,240	1,260	3,060	12,2401	24,800
Surface infiltrometer measurements	-	-	-	384	1,152	3,600	38,400
Vertical permeability assessment	-	-	-	390	1,050	3,900	37,200
Test pits for infiltration test	-	-	-	1,043	1,043	4,600	55,786
sub total	3,496	5,296	20,356	5,313	8,541	32,456	335,966
Total Cost(A+B)	**3,496**	**5,296**	**20,356**	**6,621**	**9,849**	**37,427**	**354,431**
Cost per ha	**1,748**	**1,059**	**1,018**	**3,310**	**1,970**	**1,871**	**1,772**

4.1.3 Site layout

After selection of a salt disposal basin site, a basin layout is required. The basin area needs to be surveyed before earthworks commence so that the areas of cut and fill can be determined for laser levelling. A survey grid of 40m x 40m can be used for the basin layout at a typical cost of $29.40/ha (Polkinghorne, pers. comm.).

4.1.4 Earthworks

Topsoil, about 100-200mm including vegetation, is stripped from the surface of the area. This operation is done with a scraper or bucket. Once the topsoil is removed the less permeable clay subsoil is exposed. The cost of stripping typically is $0.30/m^3 (Polkinghorne, pers. comm.).

4.1.5 Bank formation

Banks are formed to a typical dam or basin design as shown in Figure 1. This design suggests that

1) Banks should be about 1 metre in height and 2.4 metres wide at the crest to allow the passage of light vehicles;

2) Slope of the inside bank should be 1:5 to minimise erosion, however the outside bank can be formed at a slope of 1:2;

3) Before bank construction, the topsoil should be removed from the area where the bank will be located. This will key the bank into the less permeable subsoil and reduce seepage through the bank. Then the subsoil can be pushed up to form the inside of the bank. The topsoil can then be pushed onto the outside of the bank to encourage revegetation.

Banks formed to these specifications use 5.9 m^3 of soil per m length typically costing $0.70/m^3 of soil to construct. Using a scraper, up to 90-93% of total potential compaction can be achieved by forming the banks at the right soil moisture conditions (Polkinghorne, pers. comm.). The use of bulldozers to construct banks is not recommended, as the banks will not be adequately compacted. The bottom of the basin should be lasered flat as this increases evaporation by allowing a better spread of water, costing $0.70/m^3 of soil moved (Polkinghorne, pers. comm.).

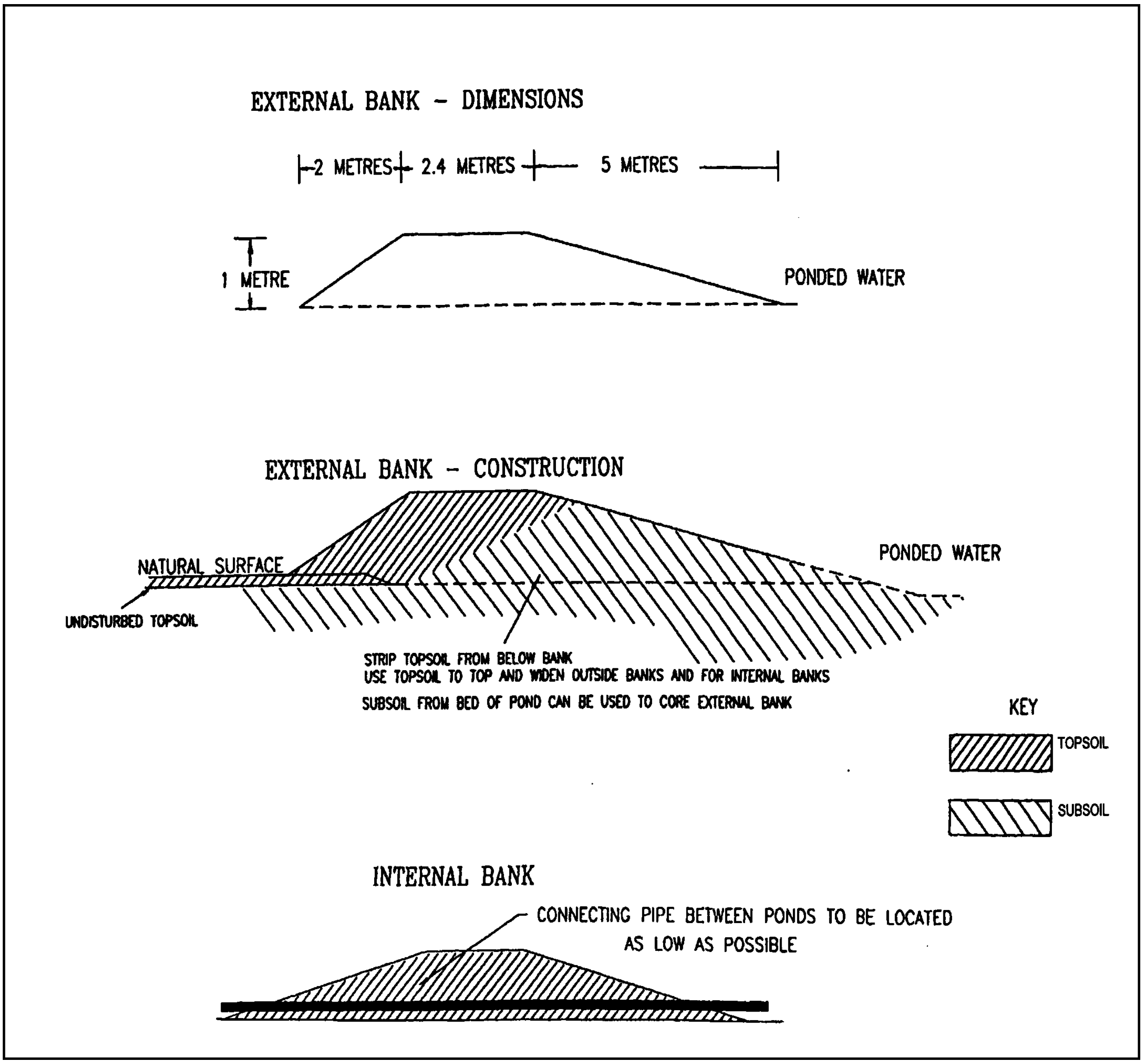

Figure 1.Salt disposal basin bank design,Dept.of Land and Water Conservation (undated)

4.1.6 Compaction

If required, additional compaction of banks and floor can be achieved using a water truck and sheeps foot roller, typically at a cost of $2.00/m³ (Polkinghorne, pers. comm.). The basin siting, soil type and local hydrogeological conditions determine whether the basin requires further compaction. Large basins are less likely to need compaction, whereas small basins (less than 50ha) tend to have high leakage rates and thus require more compaction, (Christen *et. al.,* 2000). These costs are greatly affected by the shape of the basin, the size and number of cells, and the resulting bank length, the various assumptions with regard to these parameters are shown in Table 4.

Table 4.Assumptions for salt disposal basin design and construction

Parameters	2 ha	5 ha	20 ha	200 ha
Shape	square	square	square	square
Storage capacity (ML)	10	251	100	1,000
Basin area (m^2)	20,000	50,000	200,000	2,000,000
Side length (m)	141	224	447	1,414
No of cells	2	2	4	20
Size of each cell (ha)	1	2.5	5	10
Total length of banks (m)	705	1,120	2,682	15,554
Bank height (m)	1	1	1	1
Volume of soil per m of bank (m^3)	5.9	5.9	5.9	5.9
Total volume of soil in banks (m^3)	4,160	6,608	15,824	91,769
Volume topsoil removed (m^3) (basin area m^2 x 0.15m)	3,000	7,500	30,000	300,000
Perimeter length (m)	564	896	1,788	5,656
Vol. of soil per m length of open drain (m^3)	9	9	9	9

The earthwork costs of salt disposal basins of different sizes are presented in Table 5. The per unit area earthwork cost decreases with basin size. More than 90% of the total cost of earthworks is the cost of floor and bank formation plus compaction. Of these costs the compaction comprises about 70% of the total earthwork costs.

Table 5.Earthwork costs for different sized salt disposal basins ($)

Costs	2 ha	5 ha	20 ha	200 ha
Stripping of vegetation	900 (4)	2,250 (6)	9,000 (7)	90,000 (8)
Bank and floor formation	5,012 (25)	9,876 (24)	32,080 (24)	274,200 (24)
Bank compaction	8,319 (41)	13,216 (33)	31,640 (24)	183,600 (16)
Floor compaction	6,000 (30)	15,000 (37)	60,000 (45)	600,000 (52)*
Total cost	20,231	40,342	132,720	1,147,800
Per ha cost	10,116	8,068	6,636	5,739

( ) figures are percentages of total cost
* Note that in most cases the 200ha basin would not need compaction.

Since a significant cost of the earthworks component is the cost of extra soil compaction there is scope for comparing this compaction cost with other alternatives to control leakage. An alternative to basin compaction is lining with a plastic membrane. Gardener (1990) suggested that savings in the cost of compaction and interceptor drain installation would offset the cost of laying plastic to prevent leakage. There could be an additional saving in that the cost of geotechnical investigations may be reduced or avoided. However, a sealed basin with no leakage will incur additional costs. These will be due to salt precipitation that will need to be harvested and disposed of. Also a basin with no leakage will need to be larger than a basin that leaks slightly as water evaporation rates will be reduced, (Christen *et. al.,* 2000). These important long-term costs associated with lining are beyond the scope of this study. Table 6 provides cost estimates for a range of options that aim to reduce leakage beyond that achieved by scraper compaction alone. It can be seen that compaction with a water truck and roller is the cheapest option, assuming that all the options are equally effective in reducing leakage to an acceptable level.

Table 6.Costs of compaction and alternative lining materials for a 2ha basin ($/ha)

Leakage reduction option	Cost ($'000's/ha)
Sheepsfoot roller	7
Chemical Dispersant	7
Builders Plastic	8
Bentonite Blanket	26
UV Stabilised Plastic	69

Costs of lining materials calculated from Gardener (1990)

4.1.7 Interception of Lateral Leakage

There are two modes of basin leakage, lateral and vertical. Lateral leakage is undesirable as it affects the environment immediately surrounding the basin within a short period of time (Christen *et al.*, 2000, RWC, 1992). Lateral leakage is generally intercepted using drains around the perimeter of the basin a short distance from the toe of the outer bank. These interceptor drains are generally subsurface pipe drains for smaller basins such as in the MIA or open ditch drains for larger basins such as at Wakool and Girgarre (Evans, 1989).

Subsurface pipe drains are installed about 2m deep, the leakage water is collected at a pump sump and pumped back to the basin. The cost of installing 100mm diameter pipe drains is $4.60/m and $7/m for 150mm diameter pipe (Bill Boersma, pers. comm.) The 100mm pipe is suitable for basins of up to 20ha whereas 150mm pipe would be required for the 200ha basin.

A 2m deep open drain, 7.5m wide with internal slope of 2:1 to intercept lateral leakage would cost $9/m (volume of soil per metre of open drain is $9/m^3$ at cost of $\$1.00/m^3$). The pumping costs would be the same as for the subsurface pipe drain. It is assumed that a new pump and sump will be required next to the basin. A concrete sump costs about $600 to purchase and install for 2-20ha basins and $1000 for a 200ha basin. An automatic starting electric pump capable of handling 1.3l/sec, 0.5kW, costing $800 is sufficient to handle the probable lateral leakage from basin sizes of 2 to 20ha. A pump capable of handling 6.8l/sec, 1.5kW, costing $1500 would be required for a 200ha basin. It is assumed that the farms have already installed electricity to operate the subsurface drainage system pump. If not then electricity supply will be an additional cost, which may be large.

Table 7 presents the cost associated with the different lateral leakage interception options. Interception of lateral leakage with subsurface pipe drains is cheaper than open ditch drains for basin sizes from 2 to 20ha. However, the cost differential narrows significantly for a 200ha basin.

Table 7.Cost of interceptor drain installation for different basin sizes ($)

Drain design	Options	2ha	5ha	20ha	200ha
Pipe Drain	Total cost	3,994	5,520	9,620	42,100
	Costperha	1,997	1,104	481	211
Open Drain	Total cost	5,876	8,864	16,892	52,404
	Cost per ha	2,938	1,773	845	262

4.1.8 Recurring Costs

Maintenance of the basin banks includes an annual cost of spraying weedicide. Spraying with Glyphosate 450R at 1 litre per ha costs $14.00 per hectare of bank. Also, it is assumed that about 10 % of the banks will need to be rebuilt every 10 years.

Power costs for the pump to intercept lateral leakage using electricity cost $0.06/hour for 0.5kW pumps, and $0.18/hour for 1.5kW pumps. Pump repair and maintenance is assumed to be 5% of purchase price.

Farmers in the Murrumbidgee Irrigation Area are required to maintain Public Liability Insurance for an amount of not less than $1 million in the joint names of the landholder and Murrumbidgee Irrigation against surface run-off and leakage into the surface drainage system. The annual insurance premium per farm is $481 and an additional premium at the rate of 20 percent per extra farm is charged where the salt disposal basin is shared between farms. It is probable that in future basins in all areas will need this cover.

One percent of the capital cost of the basin is used for miscellaneous expenses to meet additional recurring expenses, such as labour to manage and maintain the basin. Table 8 shows the total recurring costs for different sized basins.

Table 8.Recurring (annual) costs for different basin sizes ($)

Costs	2 ha	5 ha	20 ha	200 ha
Electricity cost	58	90	181	986
Repair / maintenance	40	40	40	75
Spraying	10	14	35	204
Insurance*	481	577	961	5,281
Bank repair and maintenance	112	178	427	2,478
Miscellaneous cost	309	559	2,020	15,503
Total annual cost	**1,010**	**1,458**	**3,574**	**24,527**
Cost per ha	**505**	**292**	**179**	**123**

*Insurance calculated as 1,2,5 and 50ha farms for the 2,5,20 and 200ha basin respectively

4.1.9 Environmental Impact Statement

Apart from the construction costs discussed above, a development consent/Environmental Impact Statement (E.I.S) is required under the "Environmental Planning and Assessment Act 1979" for carrying out development in an environmentally sensitive area in NSW for a storage structure of 100ML or more storage capacity (Department of Urban Affairs and Planning, 1998). No development consent is required for storage of up to 800ML if it is outside an environmentally sensitive area. This type of assessment is generally required in most States although the exact criteria vary. The minimum cost for an Environmental Impact Statement in NSW is around $15,000. In this study only the 200ha basin is assumed to require an E.I.S.

4.1.10 Aggregate Cost of Salt Disposal Basins

All the individual component costs of a salt disposal basin are combined in Table 9 for the total cost for the four basin sizes.

Table 9. Total cost of a salt disposal basin,investigation costs as for a high-risk situation ($/ha)

Items	2 ha	5 ha	20 ha	200 ha
Geotechnical investigation	3,310	1,970	1,871	1,772
Site lay out survey	30	30	30	30
Stripping of vegetation	450	450	450	450
Floor and bank formation	2,506	1,975	1,604	1,371
Floor compaction	3,000	3,000	3,000	*3,000
Bank compaction	4,160	2,643	1,582	918
Pipe drain installation	1,297	824	411	198
Pump and sump	700	280	70	13
Recurring costs	505	292	179	123
Environmental impact statement	-	-	-	75
Cost per ha	**15,967**	**11,456**	**9,196**	**7,961**
Total cost	**31,934**	**57,2801**	**83,920**	**1,592,200**

* Note that floor compaction is unlikely to be required for a 200ha basin

The data indicates that earthworks, geotechnical investigation and interception of leakage are the major cost constituents of a salt disposal basin. The earthworks are the largest cost varying from 64 -71% in smaller basins (2 - 5ha) to 73% in the 200ha basin, within this component the compaction of banks and floor accounts for 45 - 50% of the total cost, Figure 2.

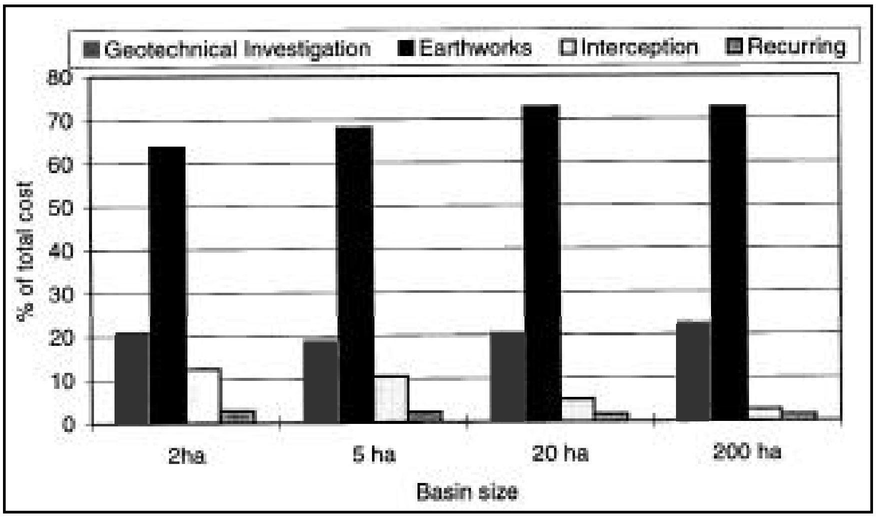

Figure 2.Evaporation basin size and cost relationship

The cost per hectare of floor compaction increases while the cost of bank compaction decreases with increasing basin size. The geotechnical investigation cost (high-risk situation) accounts for about 20% of the total cost per hectare. The cost of intercepting leakage declines from 12% in a 2ha basin to 3% in a 200ha basin. The recurring costs account for about 2% of the total cost.

Since compaction to control leakage is a major cost, it is useful to investigate cost variations when different levels of compaction are applied, Table 10.

Table 10.Effect of compaction on basin total cost ($/ha)

Level of compaction	Min. investigation*			Full investigation*			
	2 ha	5 ha	20 ha	2 ha	5 ha	20 ha	200 ha
No compaction[1]	7,245	4,902	3,761	8,807	5,813	4,614	4,043
Bank compaction only	11,405	7,045	5,343	12,967	8,456	6,196	4,961
Full compaction (floor and bank)	14,405	10,545	8,343	15,967	11,456	9,196	7,961[2]

* Denotes level of geotechnical investigation for siting

[1] Note that bank compaction is recommended for all basins to prevent bank seepage

[2] Floor compaction is unlikely to be necessary for a properly sited 200ha basin

It can be seen that uncompacted basins are the cheapest, this assumes the basin design is such that the basin does not leak excessively.

It is generally assumed that larger basins do not require compaction as their large size generally results in leakage at acceptable levels, Christen *et al* (2000). Also siting of large basins is often based on a more intensive geotechnical investigation than undertaken for small basin. Choosing a site that avoids the need for leakage control can approximately halve the cost of a large salt disposal basin. Thus expenditure on a full geotechnical investigation may be justified if it provides confidence that leakage control measures are not necessary. Smaller basins due to their geometry will nearly always need full compaction regardless of the level of geotechnical investigation.

4.2 Net Present Cost (NPC)

The total cost of salt disposal basins, based upon the previous sections, was estimated for basins from 2 to 200ha, over a 30 year period at a 7% discount rate to give the Net Present Cost (NPC). It is assumed that the 2,5 to 20ha basins require compaction to control leakage to acceptable levels, whilst the 200ha basin is large enough not to require compaction, Christen *et al.* (2000).

Table 11 shows that the initial construction cost (earthworks) increased from $19,000 to $1,078,000 as the size of salt disposal basin increased from 2 to 200ha, however the NPC per ha declined from $20,000 to $9,000, Figure 3.

Table 11.Effect of salt disposal basin size on the Net Present Cost ($)

Item	2 ha	5 ha	20 ha	200 ha
Geotechnical investigation[1]	6,200	9,200	35,000	331,200
Earthworks[2]	19,000	37,800	124,600	517,600
Interceptor drain + pump[3]	3,700	5,200	9,000	39,400
Recurring	12,400	16,900	40,100	324,800
Total NPC	**41,300**	**69,100**	**208,700**	**1,213,000**
NPC/ha	**20,600**	**13,800**	**10,400**	**6,065**

[1] High risk situation - full investigation

[2] Floor compaction not included for 200 ha basin

[3] Subsurface pipe drains for 2,5,20 ha and open drains for 200 ha

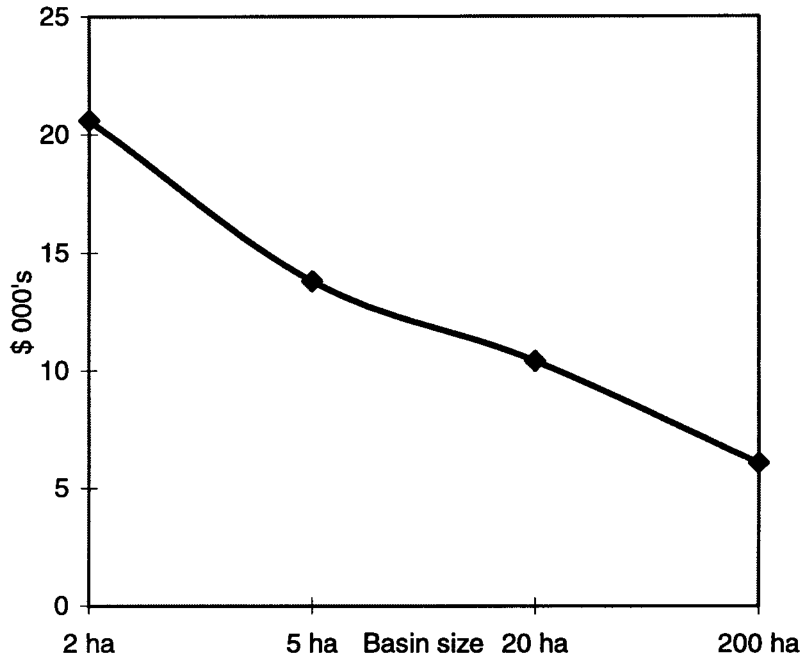

Figure 3.Net present cost of different size evaporation basins

4.3 Sensitivity Analysis for Cost Minimisation

The sensitivity analysis of salt disposal basin cost on the basis of Net Present Cost (NPC) was performed by varying the scale and cost of the following parameters:

a) geotechnical investigation;

b) leakage control;

c) basin geometry;

d) bank height;

e) lateral leakage control.

4.3.1 Geotechnical Investigation

Intensive geotechnical investigation is generally recommended for siting larger salt disposal basins. However, smaller basins can be sited in low or high-risk environments depending upon the level of understanding of the biophysical system of the area. The increase in NPC of different sizes of salt disposal basins ranged from about 8 to 10% when siting is done with full geotechnical assessment compared to a minimal investigation, Table 12.

Table 12.Effect of geotechnical investigation on NPC per ha of salt disposal basin($)

Level of investigation	Basin size			
	2 ha	5 ha	20 ha	200 ha
Minimum	19,000	12,800	9,500	-
Full	20,600	13,800	10,400	8,900
% increase	**8.4**	**7.8**	**9.5**	**-**

This small increase can be justified if it leads to better information to avoid adverse environmental effects. It may also provide enough confidence to obviate expensive leakage control measures such as compaction or lining. This difference in NPC is mainly due to the cost of hydrogeological, surface infiltrometer and vertical permeability assessments, as on-site assessment of leakage is needed for both low and high risk situations.

4.3.2 Leakage Control

Additional compaction of the floors and banks for controlling leakage is a major part of the total cost. The effect of different leakage control measures on the NPC of a salt disposal basin was analysed, Table 13.

Table 13.NPC per ha of salt disposal basin with various leakage control measures($)

Leakage control measure	Basin size			
	2 ha	5 ha	20 ha	200 ha
No compaction, minimum geotechnical investigation (low risk)	NA	NA	4,700	NA
No compaction, full geotechnical investigation (high risk)	NA	NA	5,600	4,700
Floor and bank compaction (minimum geotechnical investigation)	19,000	12,800	9,500	8,900*
Plastic liner (minimum geotechnical investigation)	18,900	15,400	13,100	13,200*

* For 200ha basin the full geotechnical investigation cost is used as this size basin is assumed to be high risk

NA denotes not applicable, as these small basins will require compaction to control leakage

The difference in NPC between no compaction and full compaction scenarios was about 50% in the 20 and 200ha basins. This is a significant cost for possibly only achieving 4 -7% additional compaction, as 90 - 93% of potential compaction occurs due to the scraper in the course of floor and bank formation (Polkinghorne, pers. comm.).

The use of a plastic liner as a leakage control measure is more expensive than compaction, except for the 2ha basin where the cost is the same. Although lining the basin may save costs in terms of the geotechnical investigation and lateral leakage control measures, there will be an ongoing cost of salt harvesting and disposal. Since it is desirable to have some leakage to prolong the basin life, the use of liners would only be recommended in the concentration bays leaving the terminal bays free to leak the concentrated saline solution.

4.3.3 Basin Geometry

Basin geometry has a significant effect on the ultimate cost of a salt disposal basin. The geometry includes the shape of the basin and the number and size of internal cells. This affects the total length of bank required, Table 14.

Table 14. Total length of bank (m)

Basin Size (ha)	Shape	Cell size (ha)				
		1	2	5	10	20
2	Square	705	564	-	-	-
	Rectangular	700	600	-	-	-
	Triangular	825	683	-	-	-
5	Square	1,789	1,118	894	-	-
	Rectangular	1,568	1,000	944	-	-
	Triangular	1,974	1,211	1,080	-	-
20	Square	6,258	5,811	2,682	2,235	1,788
	Rectangular	5,056	3,792	2,844	2,212	1,896
	Triangular	8,113	4,951	3,053	2,421	2,159
200	Square	45,248	31,108	21,210	15,554	12,626
	Rectangular	43,010	33,015	21,006	16,006	12,003
	Triangular	89,632	66,122	45,867	18,064	14,920

Table 15 shows that basin shape has significant impact on the NPC. A square or rectangular basin is more cost effective than a triangular basin in terms of perimeter and length of internal banks to create cells. The cost difference between basin shapes increases with basin size.

Table 15.Effect of basin shape on NPC per ha of salt disposal basins ($)

Basin Shape	2 ha basin, 1 ha cell	5 ha basin, 2.5 ha cell	20 ha basin, 5 ha cell	200 ha basin, 20 ha cell
Square	19,000	12,800	9,500	8,900
Rectangular[1]	18,900	14,500	11,700	11,400
Triangular[2]	20,100	16,000	14,500	15,600

[1] Sides are twice the end lengths

[2] Equal length sides

The cost of compacting the floor and banks ($2/m^3) to reduce leakage was the largest cost in the construction of a salt disposal basin. This cost is largely determined by the total bank length, thus the cell size and thus the total length of internal banks has a significant effect on the total cost, Table 16.

Table 16. Effect of cell size on NPC per ha of a square salt disposal basin ($)

Cell size (ha)	Basin size (ha)			
	2	5	20	200
1	19,000	15,300	12,800	11,600
2	17,700	12,900	12,400	10,300
5	-	12,000	9,500	9,400
10	-	-	9,100	8,900
20	-	-	8,700	8,600

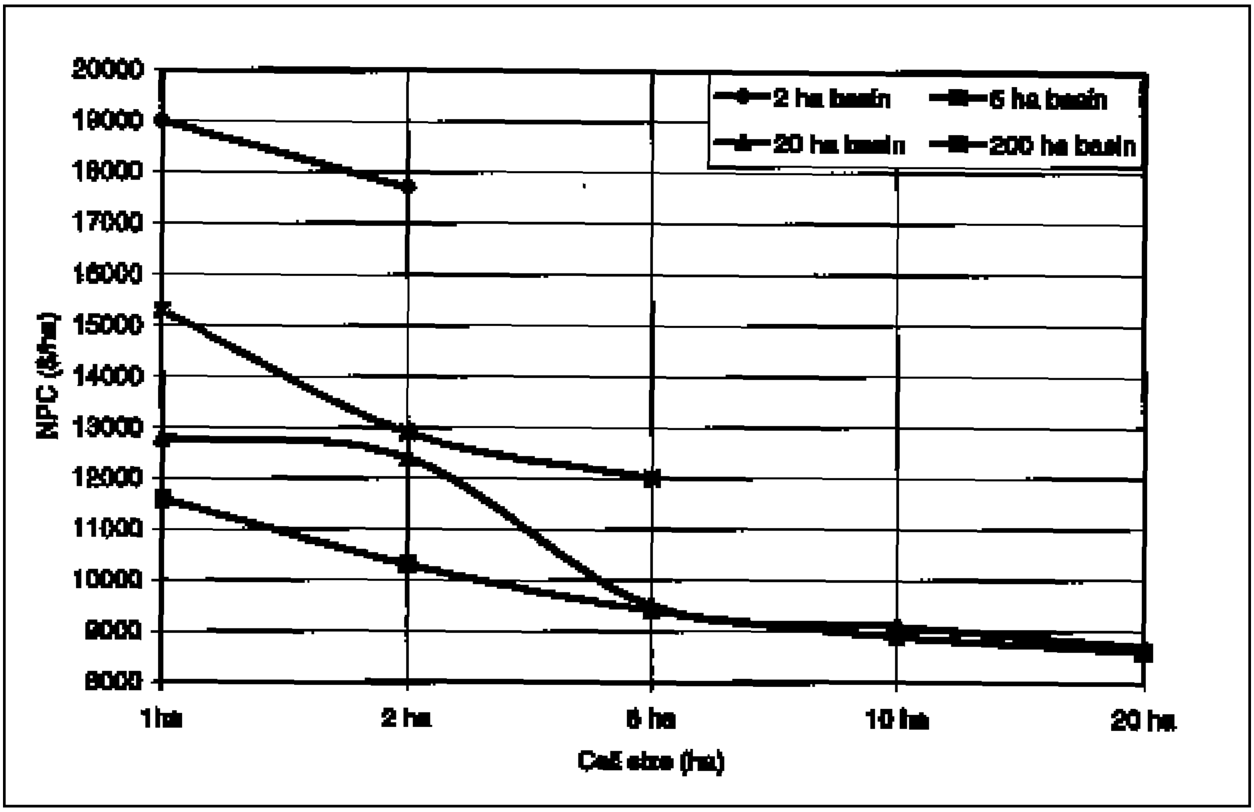

Figure 4.Cell size vs Net Present Cost

Figure 4 shows that the cost of a salt disposal basin is reduced considerably by increasing cell size. However, there are a minimum number of cells required in any salt disposal basin in order to provide management flexibility. This may be in order to allow cells to dry out periodically or to provide a sequence of ponds of increasing salinity. Internal cells are also required inside the outer banks to help prevent wave formation and resulting erosion. Muirhead *et al.* (1997) observed that the simple design currently used for salt disposal basins in the Murrumbidgee Irrigation Area does not effectively concentrate salt for storage in deeper aquifers. During winter, the increase in the concentration of the drainage water can be as little as 2dS/m. They suggested that a superior design would contain the following three elements, possibly each of about equal size:

1) a primary storage area for drain effluent, water from the drained area would be initially held in an impermeable basin, able to hold 1 metre (or greater) depth of water

2) water from the first area would be circulated through a series of shallow ponds (about 200mm deep), to maximise the concentration of salt, leakage from these ponds would also be minimised

3) the final cell, preferably located in the centre of the basin, could be deep (2m) and mostly below ground. This cell would be designed to leak at an acceptable rate so that brine is returned to the aquifers. The detailed costing of such a design has not been undertaken in this analysis as the areas for the various stages have yet to be adequately defined.

4.3.4 Bank Height

Disposal basins function by evaporation that is constrained by the area of open water surface, not by the storage volume for the drainage water. However, basins do require certain storage so that drainage pumping can continue during periods of low evaporation. Thus added storage volume by increasing the bank height may be useful in critical periods e.g. high rainfall. However, excessive storage is costly and unnecessary as the primary mode of water disposal is by evaporation. Cost sensitivity to bank height was carried out for heights ranging from 0.7 to 1.5m, Figure 5.

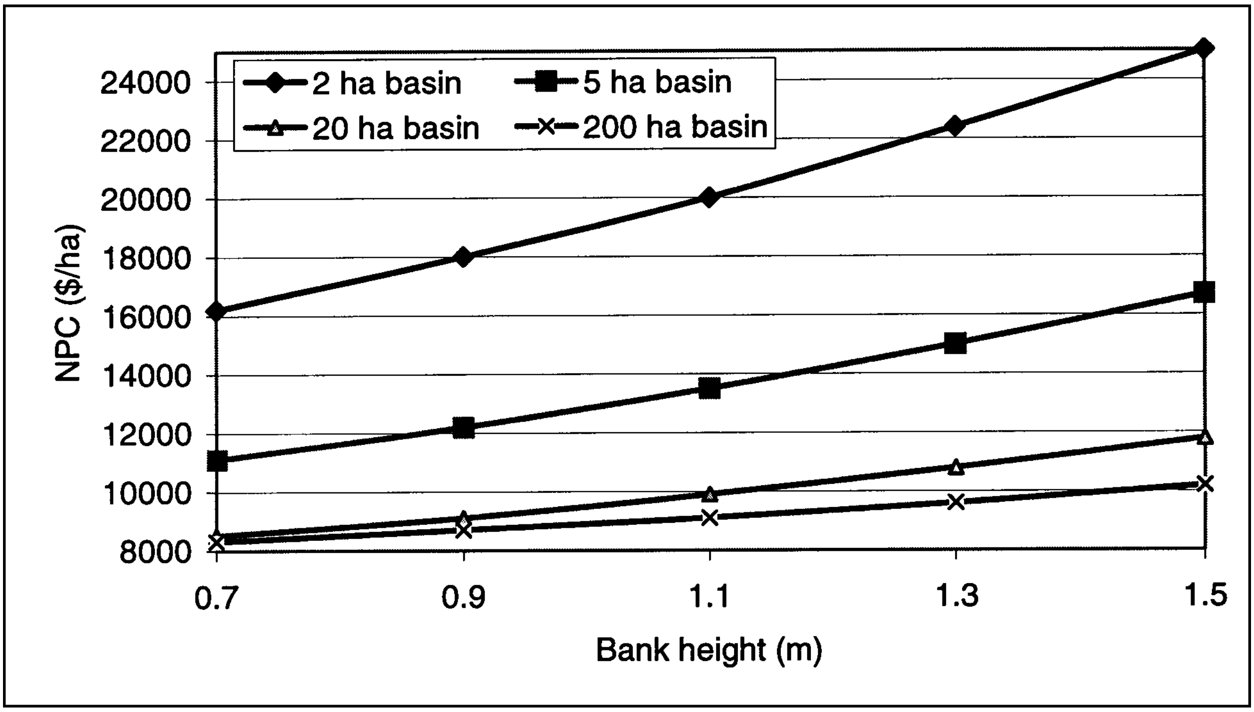

Figure 5.Bank height vs Net Present Cost

The results show that bank height has considerable impact on basin cost. With increasing basin size the per ha cost decreases due to a decreasing total bank length per unit area. The NPC of a 2ha basin increased from $16,000/ha with a 0.7m high bank to $25, 000/ha for a 1.5m high bank. However, this increased the storage volume from 14 to 30 ML and the cost per ML reduced from $2.285 to $1,667. Bank height had less impact on the NPC for the 200ha basin, as the bank length per unit area is lower. The 200ha basin had a storage volume of 1400ML at a NPC of $1,214/ML for a 0.7m high bank compared with 3000ML at a NPC of $667/ML for a bank 1.5m high. Thus there are considerable savings per ML storage by increasing bank height, however in the long term it is the evaporation area that is important. The extra storage merely reduces the risk of short term waterlogging in the drained area.

4.3.5 Lateral Leakage Control

Two types of lateral leakage control measures, namely subsurface pipe drains and open ditch drains, are often used in controlling lateral leakage from salt disposal basins. The NPC of using these two alternatives on different basin sizes are shown in Table 17.

Table 17.Effect of lateral leakage control measures on NPC per ha of salt disposal basin ($)

Basin size (ha)	Pipe drain	Open drain
2	19,000	19,900
5	12,800	13,500
20	9,500	9,900
200	8,900	8,900

Subsurface pipe drains were found to be least expensive in smaller basins (2-20ha) whereas the cost of pipe and open drains were similar for the 200ha basin. The use of an open drain could be more economical for larger basins due to the larger capacity of open drains compared to pipe drains. However, the use of open drains requires more land and achieving adequate depth to effectively intercept leakage may be more costly.

4.4 Variability in Salt Disposal Basin Cost

From the previous analysis it is clear that the cost of any particular salt disposal basin will depend upon the site conditions, compaction requirements, geometry and lateral leakage control measures. The cost can vary enormously depending upon selection of any of these items. To show the variability of costs, best and worst case scenarios were compared by selecting the factors applying to a bad design and poor site and a good design and suitable site, Table 18.

Table 18.Best and worst case scenarios for salt disposal basin siting and construction

Cost Items	Scenarios	Basin Area (ha)			
		2	5	20	200
Geotechnical investigation	Best Worst	minimum full	minimum full	minimum full	full full
Basin shape	Best Worst	square triangular	square triangular	square triangular	square triangular
Size of cell (ha)	Best Worst	2 1	5 2	10 5	20 5
Floor compaction	Best Worst	yes yes	yes yes	no yes	no yes
Lateral leakage interceptor drain	Best Worst	pipe open	pipe open	pipe open	open pipe

Apart from variations in costs due to siting and design, there will be variations in the construction costs between contractors and also regional cost factors. Variations in these factors were investigated by applying a lowest, highest, and most likely cost to each individual item, Table 19.

Table 19.Summary of variables used to generate probability distribution function of basin cost

Variables	Cost range	Basin size (ha)			
		2	5	20	200
Geotechnical investigation ($/ha)	Lowest	1573	953	916	1595
	Most Likely	1748	1059	1018	1772
	Highest	1923	1165	1120	1949
Stripping vegetation ($/m^2)	Lowest	0.2	0.2	0.2	0.2
	Most Likely	0.3	0.3	0.3	0.3
	Highest	0.5	0.5	0.5	0.5
Floor and bank formation ($/m^3)	Lowest	0.5	0.5	0.5	0.5
	Most Likely	0.7	0.7	0.7	0.7
	Highest	0.9	0.9	0.9	0.9
Floor and bank compaction ($/m^3)	Lowest	1.5	1.5	1.5	1.5
	Most Likely	2.0	2.0	2.0	2.0
	Highest	2.5	2.5	2.5	2.5
Interception pipe drain ($/ha)	Lowest	1795	994	433	1795
	Most Likely	1997	1104	481	1997
	Highest	2197	1214	529	2197

Table 20 shows that the siting and design of a salt disposal basin, together with variations can cause the cost to vary enormously. Therefore, site selection and appropriate design are critical to cost minimisation. By combining all of the possible price variations for each scenario a cost probability function was determined for 5 and 200ha basins, Figures 6 and 7.

Table 20. Variability in the Net Present Cost of salt disposal basins ($/ha)

Scenarios	Cost range	Basin Area			
		2 ha	5 ha	20 ha	200 ha
Best Case	Lowest	17,200	10,700	4,100	4,300
	Most likely	19,000	12,100	4,600	4,700
	Highest	21,300	14,000	5,200	5,300
Worst Case	Lowest	20,200	13,300	9,700	10,000
	Most Likely	22,700	14,900	11,200	11,700
	Highest	24,600	16,800	12,700	13,300

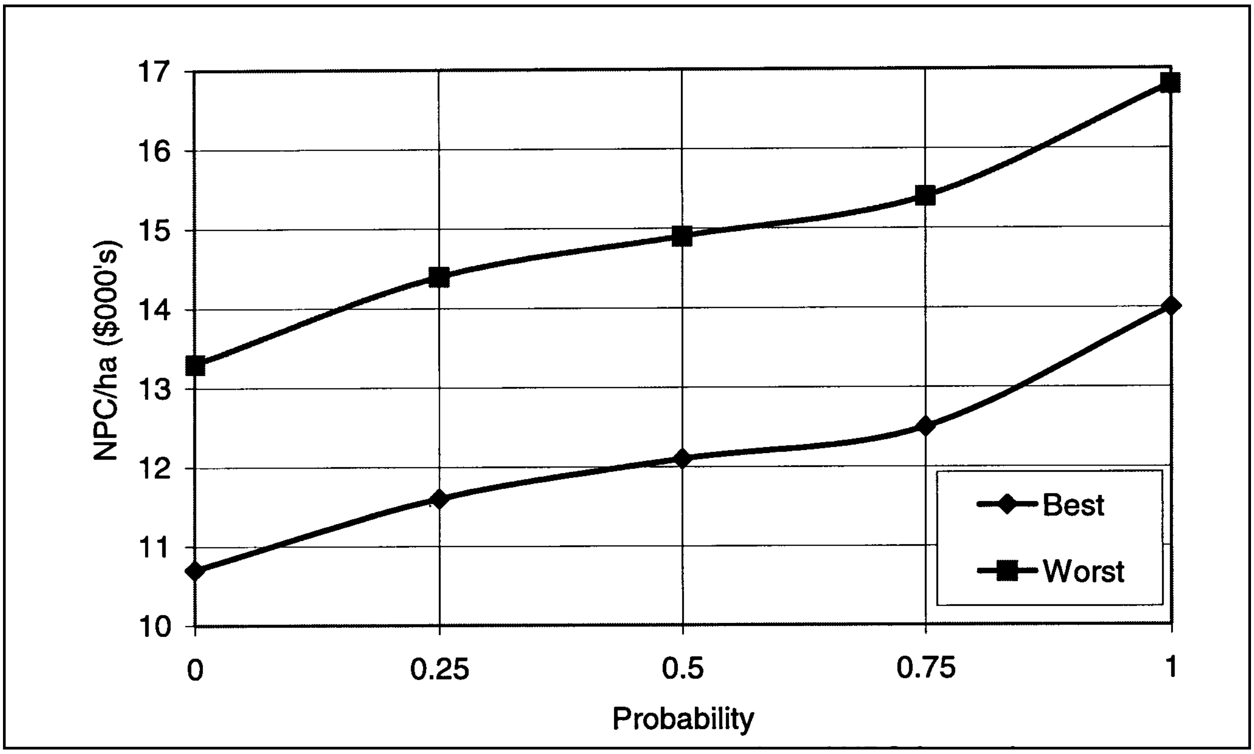

Figure 6.Cumulative probability distribution of NPC for a 5ha basin

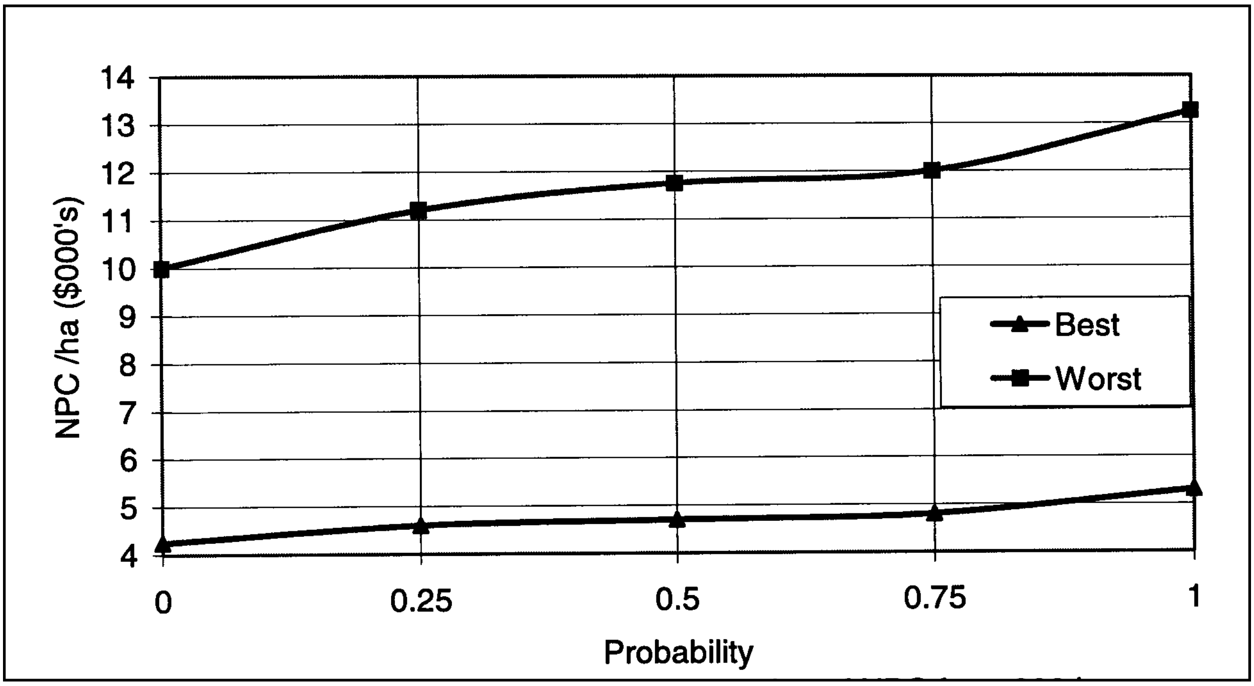

Figure 7.Cumulative probability distribution of NPC for a 200ha basin

5. Conclusions

- Large basins cost less to construct on a per unit area basis, a well designed and sited 2ha salt disposal basin will cost about $16,000/ha whereas a 200ha basin under the same conditions would cost about $5,000/ha. This is due to economies of scale in construction, especially with regard to bank length and also due to small basins requiring compaction to control leakage. There may be significant advantage in using a smaller number of large basins compared with many smaller basins. This however will depend upon drainage water transportation costs. The reduction in cost with larger basins also indicates that the overall design of the drainage network and basin will be critical in reducing costs.
- Leakage control is an important factor in cost minimisation. A basin design that requires no additional leakage control measures is the cheapest. Therefore, it is important to find sites that avoid the need for additional compaction, or lining. Larger basins are less likely to require compaction due to the size limiting leakage rates and their siting being based on intensive investigation, whereas smaller basins will nearly always require compaction to control leakage.
- Site selection and appropriate design are critical in cost minimisation of salt disposal basins, the Net Present Cost of a 2ha basin can increase from $17,000 to $25,000/ha if the design and siting is not carefully considered, a 200ha basin can increase from $5,000 to $13,000/ha. These factors make it important that basins are designed and sited with full understanding of the impacts of design decisions on costs.
- Basin geometry, which includes the shape of the basin and the number and size of internal cells, has a significant impact on the ultimate cost. Square or rectangular basins are more cost effective than triangular basins. The cost of a salt disposal basin is highly sensitive to the bank length and hence number of internal cells. Therefore, selecting the best basin shape and appropriate size of internal cells will reduce costs. This may impact on basin siting as in some cases basins have been constructed on small irregular shaped areas of farms which must increase costs.

- Bank height will affect the cost of a salt disposal basin considerably, however the storage cost per ML of water is reduced with increasing bank height. The appropriate bank height should be selected depending upon the frequency and extent of periods when evaporation is low and thus storage is required in order to maintain pumping from the drainage system. If pumping is stopped this is likely to result in waterlogging in the drained area that may affect crop yield. Thus the optimal bank height will depend upon the crop sensitivity to waterlogging and other crop and yield factors. For practical reasons a minimum bank height should be 1m as this will provide a reasonable amount of storage and reduce the risk of overtopping, remembering that a freeboard should always be maintained to store rainfall and contain wave action.
- Intercepting lateral leakage by pipe drains in smaller basins was less costly than open drains, while for larger basins the costs are similar.
- The geotechnical investigation cost for siting a salt disposal basin increases with basin size.

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7. Appendix A. Geotechnical Investigation Paper

Managing disposal basins for salt storage in irrigation areas
A project funded by MDBC, CSIRO Land and Water and the CRC for Catchment Hydrology

DISCUSSION PAPER

Geotechnical Investigations for Siting Salt disposal Basins in the Riverine Plain

28/8/98

by

E.W. Christen, J. Singh and D. Skehan

Abstract

The geotechnical investigations required for siting a salt disposal basin are a key consideration to ensure that adverse environmental effects are avoided; they have been undertaken in a rather ad-hoc fashion in the past. In this paper a methodology is developed for determining the investigations requirement for salt disposal basin siting on the basis of risk. This methodology minimises costs for low risk situations. The costs for a low and high risk basin are given.

1. Introduction

Salt disposal basins are seen as the most viable option for storing saline drainage water in southeastern Australia (Evans, 1989). However, the Murray Darling Ministerial Council (1986) state that lateral leakage may have local adverse salinity and waterlogging effects with possible adverse environmental impacts. In addition they state that the cost of geotechnical investigations for siting may be high.

Investigations for existing basins have been undertaken on an ad-hoc basis without a framework for consistent standards across regions and between controlling authorities. Investigations have ranged from detailed survey and drilling for large public basins constructed by government authorities to cursory site inspections for basins constructed by farmers on their own land.

A general guideline that detailed geotechnical and hydrogeological investigations are required for all basins does not consider the scale of risk associated with different size basins or the general locality and as such is not cost effective. A methodology is required for determining the level of geotechnical investigation required according to the risk associated with any particular site.

2. General site assessment:

When siting a salt disposal basin there are two levels of site assessment: the macro scale of the suitability of the general locality, and the micro scale of on-site physical factors. The first level assessment is a locality assessment, which considers a mixture of socioeconomic and biophysical factors. The second level assessment is a set of on-site factors that endeavour to estimate potential leakage rates, the possible destination of the leakage and the likelihood of causing environmental degradation.

2.1 Locality assessment

The general overview of the potential target areas should initially be evaluated to assess the broad potential risk of basin leakage and/or other potential negative environmental effects. General factors to be considered are;

1. Environmentally sensitive areas:

- areas of conservation value
- flood plains
- wetlands, swamps
- remnant vegetation

- residential areas

2. Hydrogeology:
   - depth, extent, transmissivity ,water quality of shallow aquifers
   - regional aquifer systems with respect to river systems
3. Land characteristics
   - general soil types
   - land value
   - farm layout
   - extent of potentially suitable areas

Critical in this is the understanding of local hydrogeology, including the general extent and character of deep aquifers and likely existence of shallow aquifers, to set performance criteria for leakage and risk assessment.

2.2 On-site assessment

The level of on-site investigation required depend largely upon the scale of the project and the extent of economic and environmental risk involved. There is a need to establish the biophysical and conceptual context within which the investigation is to proceed as the investigation requirements will be very different depending up the level of risk associated with the development. The level of risk associated with a basin development can be categorised as high or low.

High Risk:

- larger community basins with relatively high associated infrastructure costs and potentially high economic and environmental cost of failure, or
- smaller basins sited in areas with high levels of uncertainty of the biophysical system.

Low Risk:

Small basins with:

- relatively low associated infrastructure costs and potentially low economic and environmental cost of failure
- sited in situations where there is a good understanding of the biophysical system
- designed to minimum specification with a detailed management plan

Table 1 shows the factors that should be considered to determine if the proposed basin would fall in a high or low risk category and as such the extent of geotechnical investigations required.

Table 1: Factors determining the possible risk scale for a salt disposal basin site

Criteria	Low Risk	High Risk
1. Locality assessment	Detailed	Simple
2. Design	Locally developed guidelines	No local guidelines
3. Potential off site leakage effect	Small	Large
4. Size	Small	Large
5. Hydrogeology	Well documented	Uncertain
6. Management plan	Good	Poor

3. Hydrogeology: Assessment of local aquifers

In high-risk localities the minimum geotechnical analysis that would be required for a locality assessment would be to determine the shallow aquifer characteristics:

- depth, extent, transmissivity
- piezometric level
- water salinity

The methodology for this could be EM34 transects at 500m intervals and one bore hole to 20 meters for 5 ha basin, 4 bore holes for 20ha and 16 bore holes to 20 meters for 200ha basin, for aquifer determination and piezometer installation (ground water level and salinity, basis for future monitoring).

4. Leakage: On-site assessment

The on-site assessment of leakage is necessary for both low and high-risk situations. Minimum specifications are required for soils used in basin floor and bank construction for leakage control. The methodology for this could be:

1. EM31 grid survey at 50m interval to identify the location and uniformity of the heaviest soils and possible high leakage zones in the surveyed area
2. Auger holes to 3m guided by EM survey, generally one per ha within final site area, for analysis of;
   - soil texture
   - soil salinity and sodicity (1:5 extracts at 0.5 meters intervals)
   - water table depth/ground water salinity
   - hydraulic conductivity

1. Surface infiltrometer measurements (1 per 2ha)
2. Vertical permeability assessments (1 per 2ha)
   - undisturbed cores to 3 meters, with visual/ microscopic estimates of secondary porosity
     - Infiltrometer tests in pits at 0.5, 1.5, and 2.5 meters below surface (1 per 5ha)

The geotechnical investigations that are required under high and low risk situations are summarised in Table 2.

Table 2. Geotechnical investigations required for low and high-risk salt disposal basin sites

INVESTIGATION	LOW RISK	HIGH RISK
Hydrogeology: Assessment of local aquifers		
Understanding of local hydrogeology, general extent and depth of regional aquifer and likely existence of shallow aquifers	*Good, no need for extra investigation*	*Existing knowledge needs to be confirmed/ extended by further investigation*
1. EM34 survey at 500m spacing	*Not required*	*Required*
2. Bore holes to 20m for aquifer determination at 1 for 5ha, 4 for 20ha and 16 for 200ha.	*Not required*	*Required*
Leakage: Site assessment		
1. EM31 Surveys at 50m grid	*Required*	*Required*
2. Auger holes 1 per ha to 3m	*Required*	*Required*
* Soil texture, salinity and sodicity at 0.5m interval		
* Water table depth		
* Ground water salinity		
* Hydraulic conductivity		
3. Surface infiltrometer measurements 1 per 2ha (3 rings method)	*Not required*	*Required*
4. Undisturbed cores to 3m, 1 per 2ha	*Not required*	*Required*
* vertical permeability		
* estimate of secondary porosity		
5. Test pits1 per 5 ha for infiltration tests at 0.5, 1.5, 2.5m depth.	*Not required*	*Required*

Costing

This methodology of risk analysis minimises investigation costs for low risk basins whilst providing adequate information to minimise overall risk. Using this methodology the costs for a 5ha low risk basin and a 20ha high-risk basin have been analysed, the investigation cost for the low risk basin is about $1059/ha compared to about $1871/ha for the high-risk basin, Table 3. The individual costs of items are detailed in Table 4.

Table 3. Investigation costs for a low risk 5 ha basin and a high risk 20 ha basin.

Investigation	**Low Risk 5ha Basin ($)**	**High Risk 20 ha Basin ($)**
Hydrogeology: Assessment of local aquifers		
EM34 survey	-	142
Drilling and Construction of Piezometers	-	2,960
Piezometer Fittings	-	813
Supervision	-	518
Logging of Piezometers	-	538
Leakage: Site assessment		
EM 31 survey	2,236	8,116
Auger holes	3,060	12,240
Surface infiltrometer measurements	-	3,600
Vertical permeability assessment	-	3,900
Test pits for infiltration test	-	4,600
Total Cost	**5,296**	**37,427**
Cost per ha	**1,059**	**1871**

Table 4. Detailed costing of geotechnical investigations (based on a 20 ha area)

Investigation	Description and cost
Hydrogeology: Assessment of local aquifers	
1. EM 34 Transects	500 m long, 500 m apart @ $ 92.00 per km
	Hire of equipment @ $ 50.00 per day
2. Drilling and construction of Piezometers	20 m deep @ $ 37.00 per m
Piezometer Fittings	
• 40 mm UPVC class 9 pressure pipes	@ $ 2.10 per m
• 40 mm UPVC screen	3 m per piezometer @ $ 8.70 per m
• 40 mm end cap	@ $ 1.65 each
• well head fittings	@ $ 60.00 each
• Installation of well head fittings	@ $ 50.00 each
• Supply of marker posts	@ $ 10.00 each
• Installation of marker post	@ $ 20.00 each
• Site supervision	one day @ $ 60.00 per hour
3. Travel	200 km @ $ 0.69 per km
4. Logging of Piezometers	hire of equipment @ $ 50.00 per day
	operators expenses for one day @ $ 50.00 per hour & travel to site 200 km @ $ 0.69 per km

Table 4.Continued

Leakage: Site assessment	
1. EM31 - 50 meters grid	Four days hire of equipment @ $ 1000 per day
	8 days of work @ $ 60.00 per hour
	Travel 400 km @ $ 0.69 per km
2. Auger holes	
• soil salinity and sodicity (0.5m interval)	1 per ha up to 3m, three hours work @ $ 60.00 per hour
• Water table depth/ground water salinity/hydraulic conductivity	6 samples per ha @ $ 40.00 per sample two men for four days @ $ 60.00 per hour
3. Surface infiltrometer measurements (one measurement per two ha by 3 ring method)	ten measurements, 8 days @ $ 60.00 per hour
4. Vertical permeability assessment	
• Undisturbed core to 3m (one per 2ha)	10 cores to 3m @ $ 50.00 per meter
• estimates of secondary porosity (visual estimate)	two hours per ha @ $ 60.00 per ha
5. Test pits for infiltration tests (one per 5ha)	excavator hire for 8hrs per test pit @ $ 75.00 per hour
• Infiltration Test in pits	one man for 4 days @ $ 60.00 per hour
• Site supervision	one man for 4 days @ $ 60.00 per hour
6. Travel	400 km @ $ 0.69 per km

5. Acknowledgments

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6. References

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