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Minimising the Cost of Evaporation Basins: Siting, Design and Construction Factors

Jai Singh and Evan W. Christen

CSIRO Land and Water
Griffith NSW 2680
Technical Report 12/99 March 1999

MURRAY-DARLING BASIN COMMISSION

CSIRO LAND and WATER

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Summary

Evaporation basins are used for the disposal of saline water where there are restrictions on other disposal methods. These basins can be small, 2-10 ha, on-farm basins taking drainage water from individual farms or larger community basins, 20-200 ha, taking drainage water from a group of farms. The basins have many variations in siting with regards to soil suitability, underlying aquifers and surrounding land use. They are also varied in methods of construction and layout. Under these circumstances there is no single cost for an evaporation basin. In the past many authors have quoted the cost of an evaporation basin, but these are all costing particular to a single site and application. This report intends to provide information on the construction and maintenance costs of evaporation basins for a range of sites and designs.

This report also details the costs of evaporation basins and various aspects of evaporation basin design and siting that can be manipulated in order to minimise construction costs. The aggregate cost estimates showed that the earthworks, geotechnical investigations and interception of seepage are the major cost constituents of an evaporation basin. The earthworks are the largest cost varying from 64 to 73%, within this component the compaction of banks and floor accounts for about 50%. The geotechnical investigation cost accounts for 20 -25% of total cost. The cost of intercepting seepage 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 evaporation basin, these are; the geotechnical investigation, leakage control (compaction of floor and banks), basin geometry (shape and number of cells which affect the bank length in evaporation basin) and lateral seepage control.

An intensive geotechnical investigation is generally recommended for siting larger evaporation basins. However, smaller basins can be sited in low as well as high risk environments. Using the method proposed by Christen *et al.* (1998) (Appendix A), the cost of

investigation can be minimised for a low risk basin to about $1059 /ha compared to about $1871 /ha for a high risk basin. The increase in cost 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. The difference in Net Present Cost (NPC) between no compaction and full compaction scenarios ranged from 40% in a 2 ha basin to 50% in 20 and 200 ha basins. This is a significant cost for possibly only achieving 4 to 7 % of additional compaction, as 90 -93% of potential total compaction can be achieved by the scraper in the course of floor and bank formation. Therefore, it is important to find sites that avoid the need for additional compaction, or lining. Larger basins may not require compaction as their siting is based on intensive investigation. The high cost of an intensive geotechnical investigation in small (2-20ha) evaporation basin can be justified if it ensures that the basin does not require additional compaction. Siting of an evaporation basin with full geotechnical investigation can reduce the NPC by about $7000 /ha in a small basin if additional compaction is avoided.

Basin geometry has a significant effect on the total cost. The 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.

Two types of lateral seepage control measures, namely pipe drains and open drains, were compared for controlling lateral seepage. Pipe drains were found to be least expensive in smaller basins (2-20 ha). The use of open or pipe has a similar cost for larger basins.The detailed analysis of costs showed that the cost of any particular evaporation basin will depend upon the site conditions, compaction requirements, geometry and lateral seepage control measures. The costs can vary enormously depending on the selection of any of these items, however, with proper consideration the cost of an evaporation basin can be minimised.

Analysing the NPC variations between best and worst case cost situations a 2 ha basin between $11,000- $22,700 per ha and a 200 ha basin could cost between $4,700-$11,700 per ha. This clearly illustrates the opportunities for cost minimisation in evaporation basin construction.

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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, evaporation basins, pipeline to the sea, and desalinisation. Of these only the use of evaporation basins is currently accepted as a viable, short and long-term disposal option.

There is evidence that evaporation basins can be an effective way of handling drainage water. However, one concern about the use of evaporation basins is the cost involved. 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

1. Determine the cost of siting, design and construction of an evaporation basin, and the relationship between basin size and cost

2. Identify the sensitivity of evaporation basin cost to individual items and the potential for cost minimisation

3. Determine the range of likely evaporation basin costs for different basin sizes, under a variety of siting and design criteria.

3. Methodology

Four different basin sizes (2, 5, 20 and 200 ha) were used to examine the relationship between basin size, siting, design and cost. Detailed estimates of cost were determined by consultation with surveyors, consultants, engineering suppliers and water and electricity supply authorities. The cost estimates of evaporation 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 evaporation 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 an Evaporation Basin

This section gives an account of various steps involved in the construction of an evaporation basin and estimates of the associated costs with each step. There are several steps involved in the construction of an evaporation basin, these are:

4.1.1 Site selection

The selection of a site involves a geotechnical survey of the area proposed for siting an evaporation basin. A discussion paper by Christen *et al.* (1998) (Appendix A) suggests a methodology for determining the geotechnical requirements for evaporation 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

(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 economic and environmental risk involved. 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 categories for an evaporation basin site (Christen *et al.*, 1998) (Appendix A)

Criterion	Low Risk	High Risk
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 an EM 31 survey using 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 and 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 evaporation basins under low and high-risk situations was determined, Table 2. The cost per hectare decreases with increasing basin size under both low and high risk situations. Furthermore, the cost per hectare for a small 2 ha basin is considerably higher than for all other basin sizes. The site assessment cost for leakage constitutes the single largest component (more than 80 percent) in the total geotechnical investigation cost of evaporation basins and this increases with basin size.

Table 2. Geotechnical investigation costs for low and high-risk basins ($)

Risk scale	Low Risk			High Risk			
	Basin Size (ha)			Basin Size (ha)			
Investigations	**2**	**5**	**20**	**2**	**5**	**20**	**200**
A. Hydrogeology: Assessment of local aquifers							
EM34 survey	-	-	-	100	100	142	586
Drilling and Construction of Piezometers	-	-	-	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 (20)**	**1,308 (13)**	**4,971 (13)**	**18,465 (5)**
B. Leakage: Site assessment							
EM 31 - 50 meter 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,,240	124,800
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 (80)**	**8,541 (87)**	**32,456 (87)**	**335,966 (95)**
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**

Note: figures in brackets are percentage of total cost

4.1.3 Site layout

After selection of an evaporation 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 40 x 40 meters is used for the basin layout at a cost of $29.40/ha (Polkinghorne, pers.com.).

4.1.4 Earthworks

Topsoil, about 100-200 mm 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 is $ 0.30/ m^3 (Polkinghorne, pers.com.).

4.1.5 Bank formation

The banks are formed to typical dam or basin design, as detailed by the Department of Land and Water Conservation (Anon, undated) which suggests that: (1) the banks should be about 1 metre in height and 2.4 metres wide at the crest to allow the passage of light vehicles; (2) to minimise erosion the slope of the inside bank should be 1:5, however the outside bank can be formed at a slope of 1:2, and (3) before bank construction, the top soil should be pushed out from the area where the bank will be located. This will key the bank into the less permeable subsoil and reduce through bank seepage. Then the subsoil can be pushed up to form the inside of the bank. The topsoil is then pushed on to the outside of the bank to encourage revegetation.

Banks formed to these specifications use 5.9 m^3 of soil for each metre length. 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.com.). The use of bulldozers to construct banks is not recommended, as the banks will not be adequately compacted. Formation of banks following above guidelines costs $ 0.70/m^3. The bottom of the basin is lasered flat as this increases evaporation by allowing a better spread of water. This costs $ 0.70/m^3 (Polkinghorne, pers.com.).

4.1.6 Compaction

If required, additional compaction of banks and floor can be achieved using a water truck and sheeps foot roller, at $ 2.00 /m^3 (Polkinghorne, pers.com.). The soil type, local conditions, and desired seepage rate, determine whether the basin requires further compaction. Bigger basins are less likely to need compaction due to better site selection. 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 3. The earthwork costs of evaporation basins of different sizes are presented in Table 4. 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 cost alone comprises about 70 % of the total earthwork costs.

Table 3. Assumptions for evaporation basin design and construction

Parameters	**2 ha**	**5 ha**	**20 ha**	**200 ha**
Shape	square	square	square	square
Storage capacity (ML)	10	25	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
Vol. of soil per metre of bank (m^3)	5.9	5.9	5.9	5.9
Total vol. soil in banks (m^3)	4,160	6,608	15,824	91,769
Vol. topsoil(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 removed per meter length for an open drain (m^3)	9	9	9	9

Table 4. Earthwork costs for different sized evaporation 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**

Note: figures in brackets are the percentage of total

A significant cost of the earthwork component of construction is the cost of extra compaction with a roller. Some compaction takes place with the scraper during construction and the effect of additional compaction is not known. A study by Grismer *et al*. (1993) concluded that microbial activity is the major factor controlling seepage. This may mean there is scope for comparing compaction cost with other available alternatives for controlling seepage. An alternative to basin compaction is to line it with a plastic membrane. Gardener (1990) suggested that savings in the cost of compaction and the interceptor tile drain installation would offset the cost of laying plastic and covering it with soil to prevent any leakage. There could be an additional saving in that the cost of a geotechnical investigation can be avoided. However, a sealed basin with no leakage will incur additional costs as there will eventually be salt precipitation which will need to be harvested and disposed, and a basin with no leakage will need to be larger than a basin that leaks slightly as evaporation will be reduced. These impacts on the long term costs of lining are not considered. Table 5 provides cost estimates for a range of options that aim to reduce seepage above that achieved by a scraper compaction. Compaction with a water truck and roller is the cheapest option, although effect on leakage may be variable.

Table 5. Costs of compaction and alternative lining materials for different basin sizes ($/ha)

Options	2 ha	5 ha	20 ha	200 ha
Additional Compaction	7,160	5,643	4,628	3,918
Bentonite Blanket	25,715	25,715	25,715	25,715
Chemical Dispersant	7,030	7,030	7,030	7,030
UV Stabilised Plastic	69,375	69,375	69,375	69,375
Builders Plastic	8,000	8,000	8,000	8,000

Costs of lining materials calculated from Gardener (1990)

4.1.7 Interception of Lateral Seepage

There are two modes of basin leakage, lateral and vertical. Lateral seepage is undesirable as it affects the environment immediately surrounding the basin within a short period of time (RWC, 1992). Lateral seepage is generally controlled using subsurface interceptor pipe drains, although open drains are sometimes used for larger basins such as Wakool and Girgarre (Evans, 1989).

A pipe drain can be installed around the basin perimeter at a depth of 1.5-2 m. This drain returns lateral seepage water to the basin via a sump and pump. The cost of installing pipe drains for basins of up to 20 ha, was found to be $4.60/m (cost of trenching and installing slotted pipe of 100 mm diameter) and $7/m for large basins of 200 ha (where pipe of 150 mm diameter is required).

A 2 m deep open drain 7. 5 m wide with internal slope of 2:1 can also be used to intercept lateral seepage. Constructing an open drain to these specifications costs $9/m (volume of soil per metre of open drain is 9/m^3 at cost of $1.00/m^3). A part of the lateral pipe drainage system cost would be saved as the open drain would obviate the need for a sump. The pump costs are the same as for the pipe drain. It is assumed that a new pump and sump will be required next to the basin. A sump costs about $600 to install for an evaporation basin size of 2-20 ha and $1000 for a larger basin of 200 ha. An automatic starting electric pump capable of handling 1.3 l/sec, 0.5 kW, costing $ 800 is sufficient to handle the probable lateral seepage from basin sizes of 2 to 20 ha.

A pump capable of handling 6.8 l /sec, 1.5 kW, costing $ 1500 will be required for a 200 ha basin. It is assumed that the farms have already installed electricity to operate the subsurface drainage system pump.

Table 6 presents the cost of intercepting lateral seepage with the different options. Interception of lateral seepage with pipe drains is cheaper than open drains for basin sizes from 2 to 20 ha. However, the cost differential narrows significantly for the 200 ha basin.

Table 6. 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
	Cost per ha	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

Running costs for the pump include electricity at a rate of $0.06/hour for 0.5 kW pumps, and $0.18 /hour for 1.5 kW pumps. Pump repair and maintenance is assumed to be 5 % of the new price of the pump.

Maintenance of the basin banks includes an annual cost of spraying weedicide. Spraying with Glyphosate 450^{R} @ 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.

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 seepage 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 evaporation basin is shared between farms. It is probable that in future all basins will need this cover.

One percent of the capital cost of the basin (taken with investigations for a high risk situation) is used for miscellaneous expenses to meet additional recurring expenses, such as labour to manage and maintain the basin. Table 7 shows the total recurring costs for different sized basins.

Table 7. 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	28	70	280	2,800
Insurance	481	481	620	5,000
Bank repair and maintenance	112	178	427	2,478
Miscellaneous cost	309	559	2,020	15,503
Total annual cost	**1,028**	**1,418**	**3,568**	**26,842**
Cost per ha	**514**	**284**	**178**	**134**

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 100 ML or more storage capacity (Department of Urban Affairs and Planning, 1998). No development consent is required for storage of up to 800 ML if it is outside an environmentally sensitive area. The minimum cost for an Environmental Impact Statement is around $15,000. In this study only the 200 ha basin will require an E.I.S.

4.1.10 Aggregate Cost of Evaporation Basins

All the costs of an evaporation basin are combined in Table 8. The data indicates that earthworks, geotechnical investigation and interception of seepage are the major cost constituents of an evaporation basin. The earthworks are the largest cost varying from 64-71 % in smaller basins (2-5 ha) to 73 % in the larger basin, within this component the compaction of banks and floor accounts for 45-50 % of the total cost. 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 to 22 percent of the total cost per hectare. The cost of intercepting seepage declines from about 12 percent in a 2 ha basin to about 3 percent in a 200 ha basin. The recurring costs vary from 1.5 to 2 per cent of evaporation basin cost, see Figure 1.

Table 8. Total cost of evaporation basin, investigation costs as for a high risk situation ($/ha)

Items	**2 ha**	**5 ha**	**20 ha**	**200 ha**
Geotechnical Investigation	3,310 (20.7)	1,970 (17.2)	1,871 (20.3)	1,772 (22.3)
Site lay out survey	30 (0.2)	30 (0.3)	30 (0.3)	30 (0.3)
Stripping of vegetation	450 (2.8)	450 (3.9)	450 (4.9)	450 (5.7)
Floor and bank formation	2,506 (15.7)	1,975 (17.2)	1,604 (17.5)	1,371 (17.2)
Floor compaction	3,000 (18.8)	3,000 (26.2)	3,000 (32.6)	3,000 (37.7)
Bank compaction	4,160 (26.1)	2,643 (23.1)	1,582 (17.2)	918 (11.5)
Pipe drain installation	1,297 (8.1)	824 (7.2)	411 (4.5)	198 (2.5)
Pump and sump	700 (4.4)	280 (2.4)	70 (0.8)	13 (0.2)
Recurring costs	514 (3.2)	284 (2.5)	178 (1.9)	134 (1.7)
Environmental impact statement	-	-	-	75 (0.9)
Total cost per ha	**15,967 (100)**	**11,456 (100)**	**9,196 (100)**	**7,961 (100)**
Total cost	**31,934**	**57,280**	**183,920**	**1,592,200**

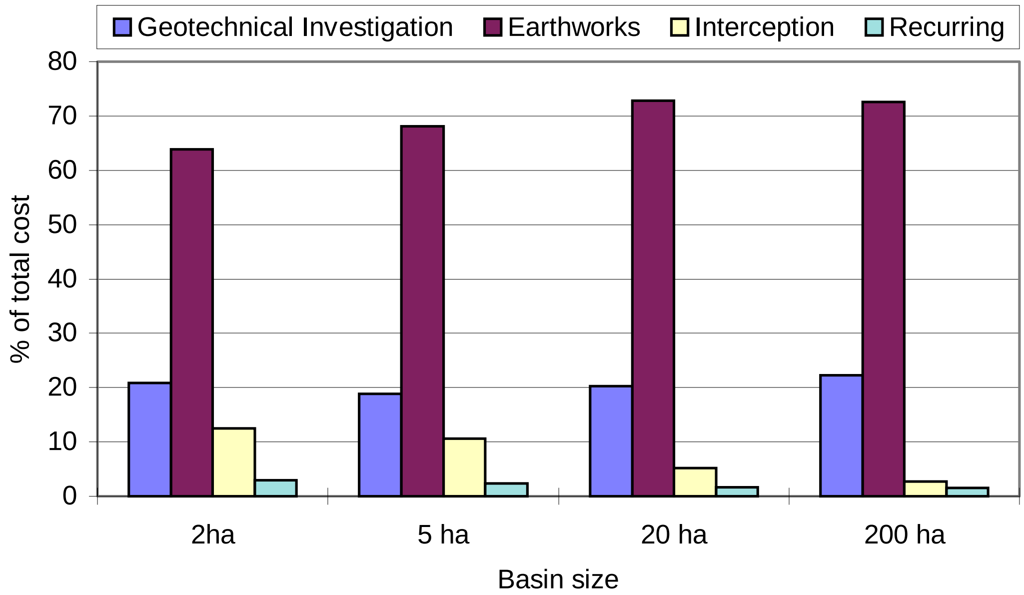

Figure 1. Evaporation basin size and cost relationship

Further analysis of the total cost per hectare with different leakage control methods indicates that the cost of leakage control is a major cost (about 45 to 50 percent of total cost) in the construction of an evaporation basin, Table 9. When fully and partially compacted basins are compared to the uncompacted (scraper compacted) basin, it can be seen that the uncompacted option is the cheapest. This basin design would be the least cost as long as the basin did not leak excessively. It is generally assumed that larger basins do not require compaction as siting of these is based on a more intensive geotechnical investigation. Choosing a site that avoids the need for leakage control can approximately halve the cost of an evaporation basin. Thus expenditure on a full geotechnical investigation may be justified if it provides confidence that leakage control measures are not necessary.

Table 9. Effect of seepage controls (compaction) on basin's total cost ($/ha)

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

* Denotes level of geotechnical investigation for siting

4.2 Net Present Cost (NPC)

The total cost of construction of an evaporation basin using the Department of Land and Water Guidelines (Anon, undated) was estimated for basins varying in size from 2 to 200 ha (Table 10). This total cost is expressed as Net Present Cost (NPC), which is the discounted outlay of cost over a 30 year period at 7% rate of discount. The initial construction cost (earthworks) increased from $19,000 to $1,078,000 as the size of evaporation basin increased from 2 to 200 ha. The NPC per ha declined from $20,000 to $9,000 as the basin size increased from 2 to 200 ha, see Figure 2.

Table 10. Effect of evaporation basin size on the Net Present Cost ($)

Item	2 ha	5 ha	20 ha	200 ha
Geotechnical investigation	6,200	9,200	35,000	331,200
Earthworks	19,000	37,800	124,600	1,078,200
Interceptor drain + pump	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**	**1,773,600**
NPC/ha	**20,600**	**13,800**	**10,400**	**8,900**

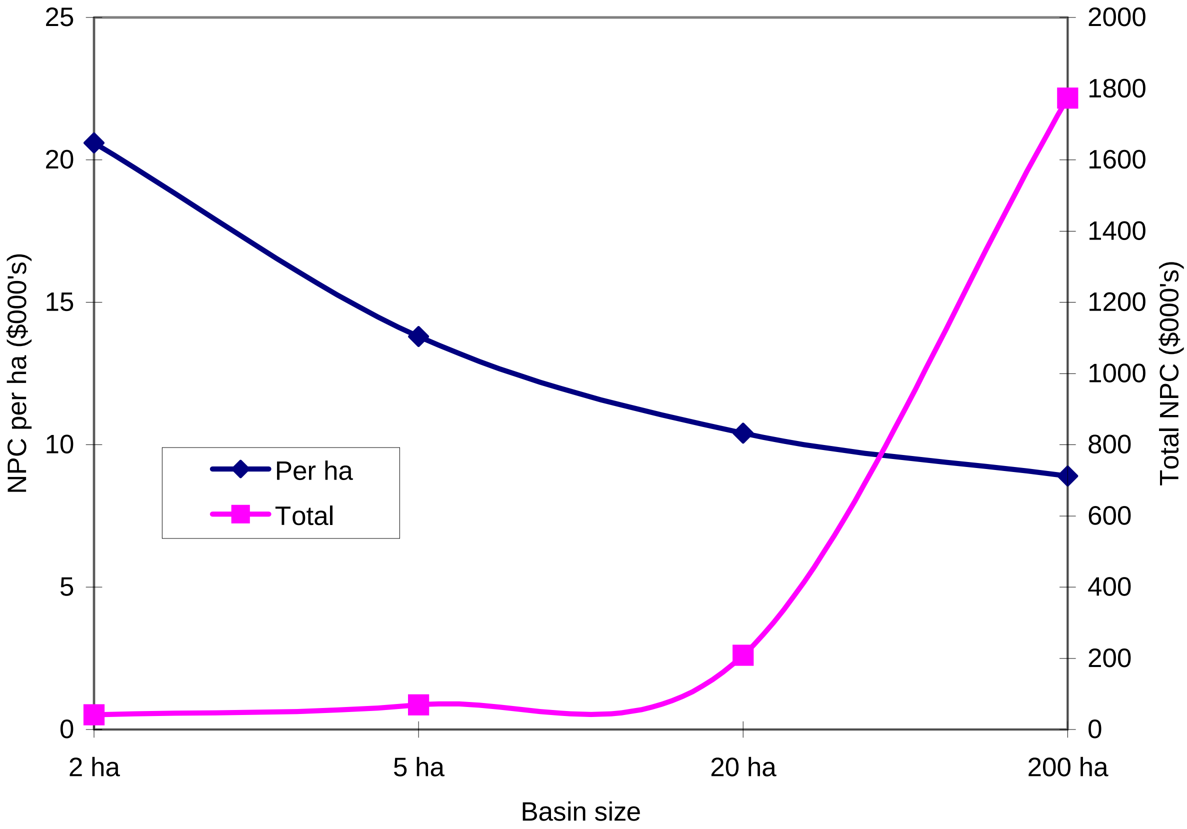

Figure 2. Net present cost of evaporation basins

4.3 Sensitivity Analysis for Cost Minimisation

The sensitivity analysis of evaporation basin cost on the basis 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) lateral seepage control

*4.3.1 Geotechnical I**nvestigation***

Intensive geotechnical investigation is generally recommended for siting larger evaporation 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 evaporation basins ranged from about 8 to 10% when siting was done with full geotechnical assessment compared to a minimal investigation, Table 12. 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 both for low and high risk situations.

Table 11. Effect of geotechnical investigation on NPC per ha of evaporation 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**	**-**

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 an evaporation basin was analysed, Table 12. The difference in NPC between no compaction and full compaction scenarios ranges from 40 percent in a 2 ha basin to 50 percent in 20 and 200 ha basins. This is a significant cost for possibly only achieving 4 -7 % of additional compaction, as 90 - 93% of potential compaction is already achieved by the scraper in the course of floor and bank formation (Polkinghorne, pers. com.).

Table 12. NPC per ha of evaporation basins with varying seepage control measures ($)

Leakage control measure[1]	**Basin size**			
	2 ha	**5 ha**	**20 ha**	**200 ha**
No compaction, low risk (minimum geotechnical investigation)	11,400	6,900	4,700	4,700*
No compaction, high risk (full geotechnical investigation)	13,000	7,900	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 200 ha basin the full geotechnical investigation is required
[1] All basins have a minimum compaction due to use of scraper

The use of a plastic liner as a seepage control measure is more expensive than compaction, except for the 2 ha basin where the cost is the same. Although lining the basin may save costs in terms of the geotechnical investigation and lateral seepage 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 leakage bays free to leak the concentrated saline solution.

4.3.3 Basin Geometry

Basin geometry has a significant effect on the ultimate cost of an evaporation 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 13.

Table 13. Total length of bank (metres)

Basin Size (ha)	Shape	Cell size (ha)				
		1	**2**	**5**	**10**	**20**
2	Square	705	564	-	-	-
	Rectangular	700	600	-	-	-
	Triangular	825	683	-	-	-
5	Square	1789	1118	894	-	-
	Rectangular	1568	1000	944	-	-
	Triangular	1974	1211	1080	-	-
20	Square	6258	5811	2682	2235	1788
	Rectangular	5056	3792	2844	2212	1896
	Triangular	8113	4951	3053	2421	2159
200	Square	45248	31108	21210	15554	12626
	Rectangular	43010	33015	21006	16006	12003
	Triangular	89632	66122	45867	18064	14920

Table 14 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 14. Effect of basin shape on NPC per ha of evaporation basin ($)

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	19000	12800	9500	8900
	(705)	(1118)	(2682)	(12626)
Rectangular[1]	18900	14500	11700	11400
	(700)	(1000)	(2844)	(12003)
Triangular[2]	20100	16000	14500	15600
	(825)	(1211)	(3053)	(14920)

[1] Sides are twice the end lengths and [2] Equal length sides
Figures in parentheses are the total length of bank in meters

The cost of compacting the floor and banks ($2 / m^3) to reduce seepage was the largest cost in the construction of an evaporation basin and this cost is largely determined by the total bank length. The cell size and thus the total length of internal banks have a significant effect on the cost of an evaporation basin. Table 15 and Figure 3 show the effect of increasing cell size on the NPC of evaporation basins of different sizes. It can be seen that the cost of an evaporation basin is reduced considerably with increasing cell size. There is a minimum number of cells required in any evaporation basin in order to provide management flexibility, e.g. allowing 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.

Table 15. Effect of cell size on NPC per ha of a square evaporation basin ($)

Size of cell (ha)	**Basin size**			
	2 ha	**5 ha**	**20 ha**	**200 ha**
1	19,000	15,300	12,800	11600
	(705)	(1789)	(6258)	(45248)
2	17,700	12,900	12,400	10300
	(564)	(1118)	(5811)	(31108)
5	-	12,000	9,500	9400
		(894)	(2682)	(21210)
10	-	-	9,100	8900
			(2235)	(15554)
20	-	-	8,700	8600
			(1788)	(12626)

Figures in parentheses are the total bank length in metres

Muirhead *et al* (1997) observed that the simple design currently used for evaporation basins in the Murrumbidgee Irrigation Area do not effectively concentrate salt for storage in deeper aquifers. During winter, the increase in the concentration of the drainage water can be as low as 2 dS/m. They suggested that a superior design would contain the following three elements, possibly each of about equal size: a) a primary storage area for tile 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, b) water from the first pond would be circulated through a series of shallow ponds (about 200mm deep), to maximise the concentration of salt, seepage from these ponds should also be minimised c) the final basin preferably located in the centre of the evaporation basin could be deep (2 m) and mostly below ground. This basin should 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.

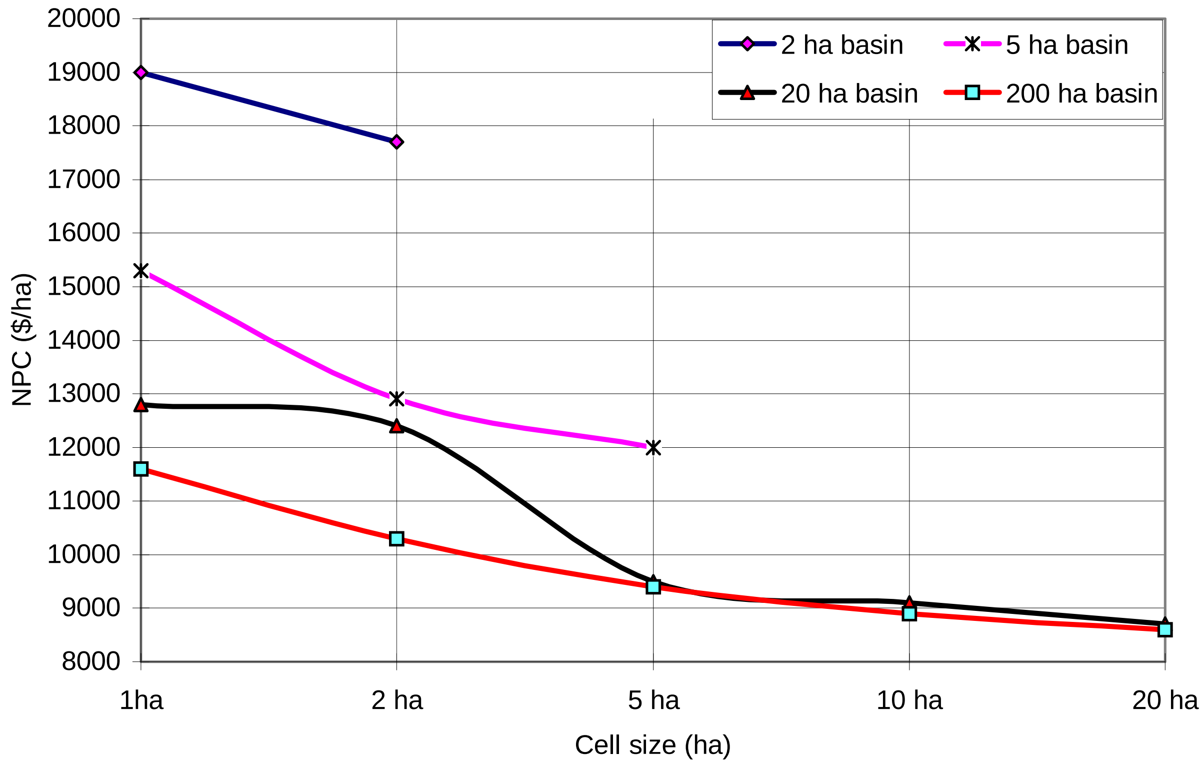

Figure 3. Cell size vs Net Present Cost

4.3.4 Lateral Seepage Control

Two types of lateral seepage control measures, namely pipe drains and open drains, are often used in controlling lateral seepage from evaporation basins. The effect of these measures on the NPC of different basin sizes was assessed, Table 16. Pipe drains were found to be least expensive in smaller basins (2-20 ha) whereas the cost of pipe and open drains were the same for a 200 ha basin. The use of an open drain could be more economical assuming for larger basins due to the large capacity of open drains, which may require large pipe sizes which would be costly. However, the use of open drains require more land and adequate depth to intercept all seepage may not be achieved. Therefore, the use of an open drain in large basins would be recommended. However, in smaller basin sizes (2 and 5 ha) the use of an open drain was expensive even with a large reduction (25 %) in the per metre cost of construction.

Table 16. Effect of lateral seepage control measures on NPC per ha of evaporation basin ($)

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

4.4 Variability in Evaporation Basin Cost

From the previous analysis it is clear that the cost of any particular evaporation basin will depend upon the site conditions, compaction requirements, geometry and lateral seepage 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 17.

Table 17. Best and worst case scenarios for evaporation basin siting and construction

Cost Items	**Scenarios**	**Basin Area**			
		2 ha	**5 ha**	**20 ha**	**200 ha**
Geotechnical investigation	Best	*minimum*	*minimum*	*minimum*	*full*
	Worst	*full*	*full*	*full*	*full*
Basin shape	Best	*square*	*square*	*square*	*square*
	Worst	*triangular*	*triangular*	*triangular*	*triangular*
Size of cell (ha)	Best	*2*	*5*	*10*	*20*
	Worst	*1*	*2*	*5*	*5*
Compaction	Best	*no*	*no*	*no*	*no*
	Worst	*yes*	*yes*	*yes*	*yes*
Lateral seepage Control	Best	*pipe*	*pipe*	*pipe*	*pipe*
	Worst	*open*	*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 in regional cost factors. Variations in these factors were investigated by applying a lowest, highest, and most likely cost to each individual item, Table 18.

Table 18.Summary of variables used to generate probability distribution function of basin cost

		Geotechnical investigation						
Variables	**Cost range**	**Minimum**			**Full**			
		2 ha	**5 ha**	**20 ha**	**2 ha**	**5 ha**	**20 ha**	**200 ha**
Geotechnical investigation ($/ha)	Lowest	1573	953	916	2979	1773	1684	1595
	Most Likely	1748	1059	1018	3310	1970	1871	1772
	Highest	1923	1165	1120	3641	2167	2058	1949
Stripping of vegetation ($/m^2)	Lowest	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Most Likely	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Highest	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Floor and Bank formation ($/m^3)	Lowest	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Most Likely	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Highest	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Floor and Bank compaction ($/m^3)	Lowest	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Most Likely	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Highest	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Interception Pipe drain ($/ha)	Lowest	1795	994	433	1795	994	433	190
	Most Likely	1997	1104	481	1997	1104	481	211
	Highest	2197	1214	529	2197	1214	529	232

These comparisons show that depending on the siting and design of an evaporation basin and price variations the cost can vary enormously, Table 19. Therefore, selection of site and appropriate design are critical in cost minimisation. By combining all of the possible price variations for each scenario a cost probability function was determined for 5 and 200 ha basins, Figures 4 and 5.

Table 19. Variability in the Net Present Cost of evaporation basins ($/ha)

Scenarios	**Cost range**	**Basin Area**			
		2 ha	**5 ha**	**20 ha**	**200 ha**
Best Case	Lowest	10,200	6,100	4,100	4,300
	Most likely	11,000	6,700	4,600	4,700
	Highest	11,900	7,400	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

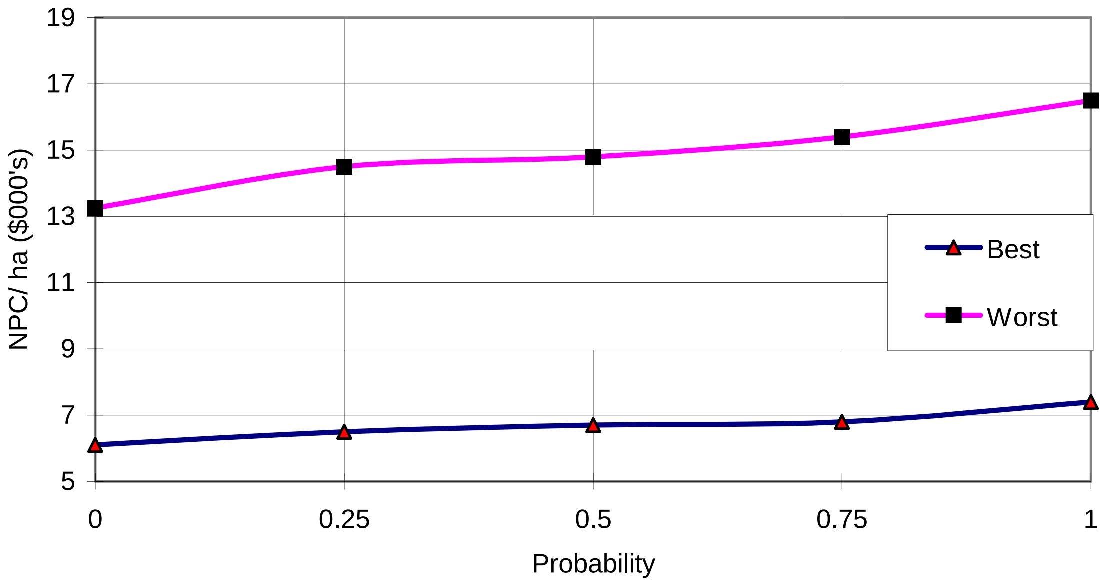

Figure 4. Cummulative probability distribution of NPC for a 5 ha basin

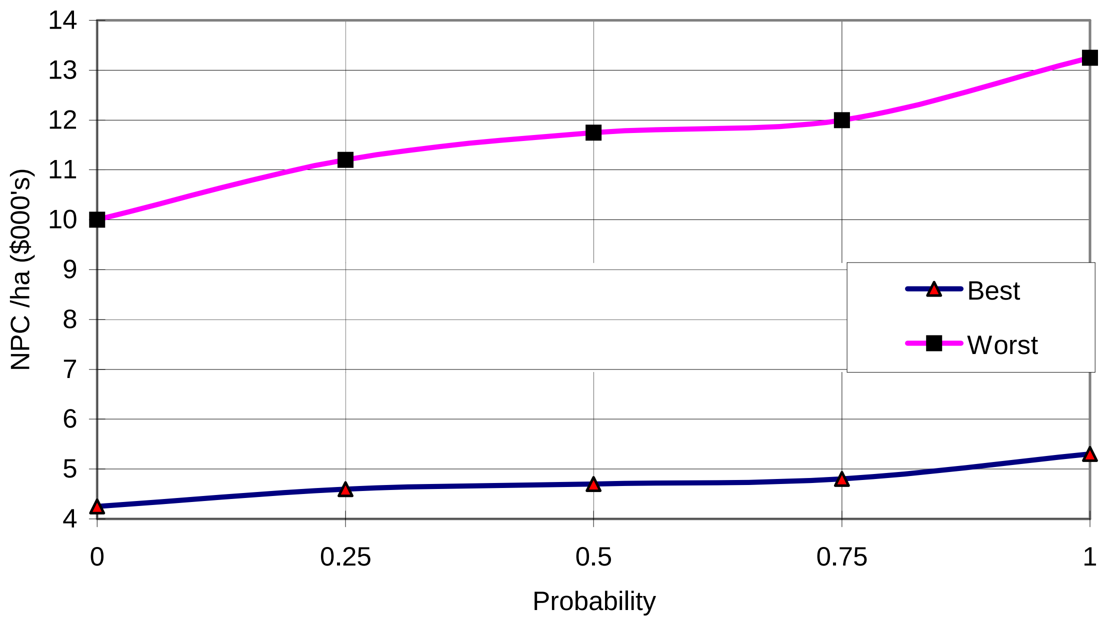

Figure 5. Cummulative probability distribution of NPC for a 200 ha basin

5. Conclusions

- Large basins cost less to construct on a per unit area basis, a well designed and sited 2 ha evaporation basin will cost about $11,000/ ha whereas a 200 ha basin under the same conditions would cost about $4,700/ ha.

- Site selection and appropriate design are critical in cost minimisation of evaporation basins, the cost of a 2 ha basin can increase from $ 11,000 to $ 22,700 /ha if the design and siting is not carefully considered, a 200 ha basin can increase from $ 4,700 to $ 11,700.

- Earthworks are the largest construction cost, ranging from 64 to 73 percent for different basin sizes, and within this component the additional compaction by sheeps foot roller constitutes about 50 %.

- 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 may not require compaction as their siting is based on intensive investigation, whereas smaller basins may require compaction. The high cost of an intensive geotechnical investigation in small (2-20 ha) evaporation basins can be justified if it finds that the basin does not require additional compaction. Siting of an evaporation basin with full geotechnical investigation can reduce the cost of construction by about $7000/ ha in a smaller basin if additional compaction is avoided.

- 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 an evaporation 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.

- 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 an evaporation 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 Evaporation Basins in the Riverine Plain

28/8/98

by

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

Abstract

The geotechnical investigations required for siting an evaporation 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 evaporation 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

Evaporation 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 seepage 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 an evaporation 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 depends 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 will 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 an evaporation 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 20 ha and 16 bore holes to 20 meters for 200 ha 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 seepage control. The methodology for this could be:

1. EM31 grid survey at 50 m interval to identify the location and uniformity of the heaviest soils and possible high leakage zones in the surveyed area

2. Auger holes to 3 m 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 evaporation 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 20 m for aquifer determination at 1 for 5 ha, 4 for 20ha and 16 for 200ha.	*Not required*	*Required*
Leakage: Site assessment		
1. EM31 Surveys at 50 m grid	*Required*	*Required*
2. Auger holes 1 per ha to 3 m	*Required*	*Required*
• Soil texture, salinity and sodicity at 0.5 m interval • Water table depth • Ground water salinity • Hydraulic conductivity		
3. Surface infiltrometer measurements 1 per 2 ha (3 rings method)	*Not required*	*Required*
4. Undisturbed cores to 3 m, 1 per 2 ha	*Not required*	*Required*
• vertical permeability • estimate of secondary porosity		
5. Test pits1 per 5 ha for infiltration tests at 0.5, 1.5, 2.5 m 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 5 ha low risk basin and a 20 ha 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 5 ha 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 (0.5 m interval)	1 per ha up to 3 m, 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
5. Vertical permeability assessment	
• Undisturbed core to 3 m (one per 2 ha)	10 cores to 3 m @ $ 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 5 ha)	excavator hire for 8 hrs 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

We are grateful to Mr W. Trewhella, Senior Natural Resources Project Officer, Goulburn Murray Water and Sinclair Knight Mertz, Tatura. Mr B. Polkinghorne of Polkinghorne, Budd & Longhurst, Griffith.

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