CRC FOR CATCHMENT HYDROLOGY
CSIRO LAND AND WATER
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CHARACTERISATION AND RANKING OF BASINS IN THE MURRAY BASIN OF SOUTH-EASTERN AUSTRALIA

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Foreword

The CRC for Catchment Hydrology S2 project ‘Managing Disposal Basins for Salt Storage within Irrigation Areas’ was based on the premise that disposal basins are 'a fact of life' in the Murray-Darling Basin. Consequently there is a need for guidelines to site, design and manage them to minimise environmental and other problems. However, more than 190 existing basins were built when there were no such guidelines. Some were well designed and sited, some less so. It is important that we not only design better basins in future, but also maintain our existing basins in an appropriate fashion. In some cases, we may need to decommission them. This report describes a methodology for maintaining a portfolio of disposal basins and describes the minimum dataset for doing so. It is then possible to focus attention on those that present the greatest risk and for which more work may be needed. The example uses thirty existing basins. Our selection was most probably biased towards basins we have the most information about. Nonetheless, the attempt to rank them is thwarted by a lack of even minimal information. This is despite some recent work by AGSO in compiling information on existing basins. Because of the lack of information, the list here should be considered preliminary and used as a basis for further discussion on how we manage our existing basins. This is not an output from the MDBC-funded grant on on-farm and community basins in the Riverine Plains, although it complements that work.

Glen Walker,
Leader, Salinity Program.

Executive Summary

The disposal of large volumes of saline water from interception and irrigation drainage schemes is a critical part of all land and water management strategies. Saline disposal basins are a common approach used for disposal of saline water at the land surface. There are currently more than 190 disposal basins in the Murray-Darling Basin of Australia. The ever growing number of disposal basins and potential environmental impacts they may have means that we need to be able to assess and compare a large number of disposal basins across the entire Murray-Darling Basin in a consistent, efficient and timely manner.

This report describes an example methodology that could be used to do this. A set of criteria are used to characterise and then rank a group of about 30 notable disposal basins in South Australia, Victoria and New South Wales. The criteria used within this study are an extension of those developed by Hoxley (1993). In addition, new characterisation criteria are developed to reflect the potential leakage caused by density-driven convection (Simmons and Narayan, 1997) as well as to include time scales for return flows to the river system. Unlike the ranking work carried out by Hoxley (1993), this study also employs a series of separate characterisation and ranking objectives. Five key ranking lists are produced to reflect more accurately key features of disposal basins and their potential impact, namely:

1. Minimum leakage and salt loss from basin
2. Maximum capacity for storage of water
3. Minimum leakage and salt loss and maximum capacity (combining 1 and 2)
4. Minimum impact on River Murray, neighbouring streams and other environmentally sensitive land
5. Minimum loss of water and salt, maximum capacity and minimum impact on River Murray (combining 1, 2 and 4)

Disposal basin ranking lists for each defined ranking objective are produced and a basin's overall performance score can be linked directly to specific attributes of the system. This is seen to be more informative than a single ranked list produced using a "lumped sum" approach.

Problems identified include issues of missing and unavailable data, the accuracy of available data and interdependencies between the characterisation and ranking criteria. The characterisation and ranking approach does, however, provide a relatively simple method for comparing basins, determining which basins need to be examined in more detail to identify possible negative impacts and those for which more information may be required to fill "unknown" data fields.

The results provided for the ranked lists only provide semi-quantitative information about the disposal basins and should be interpreted in this manner. Further work is required to verify the outcomes of the ranking procedure. Therefore, the lists presented within this report should not be used to make direct comparisons between disposal basins at this early stage. Whilst the ranking criteria and objectives presented here are likely to encompass the most important features of a disposal basin's performance, it is by no means complete. It is recommended that further work and discussions between interested parties are required to establish and collectively agree upon a more complete set of criteria and objectives that would form the basis for further disposal basin comparisons. An extended or modified form of the methodology developed in this report could then be readily applied to a larger number of disposal basin sites within the Murray-Darling Basin and updated as more data becomes available for the disposal basins.

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Acknowledgements

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1. Introduction

The Murray-Darling Basin (Figure 1) is one of Australia's most important water and land resources. In its pre-European state, it contained vast amounts of salt stored within soils and groundwater. Intensive irrigation and land clearing have led to rising water tables and the salinisation of land and water resources. Pumping of saline groundwater and the diversion of irrigation drainage returns are used to reduce water table levels and salt accessions to the River Murray. However, this creates the problem of disposing of large volumes of saline water usually at the land surface in what are typically referred to as saline disposal basins.

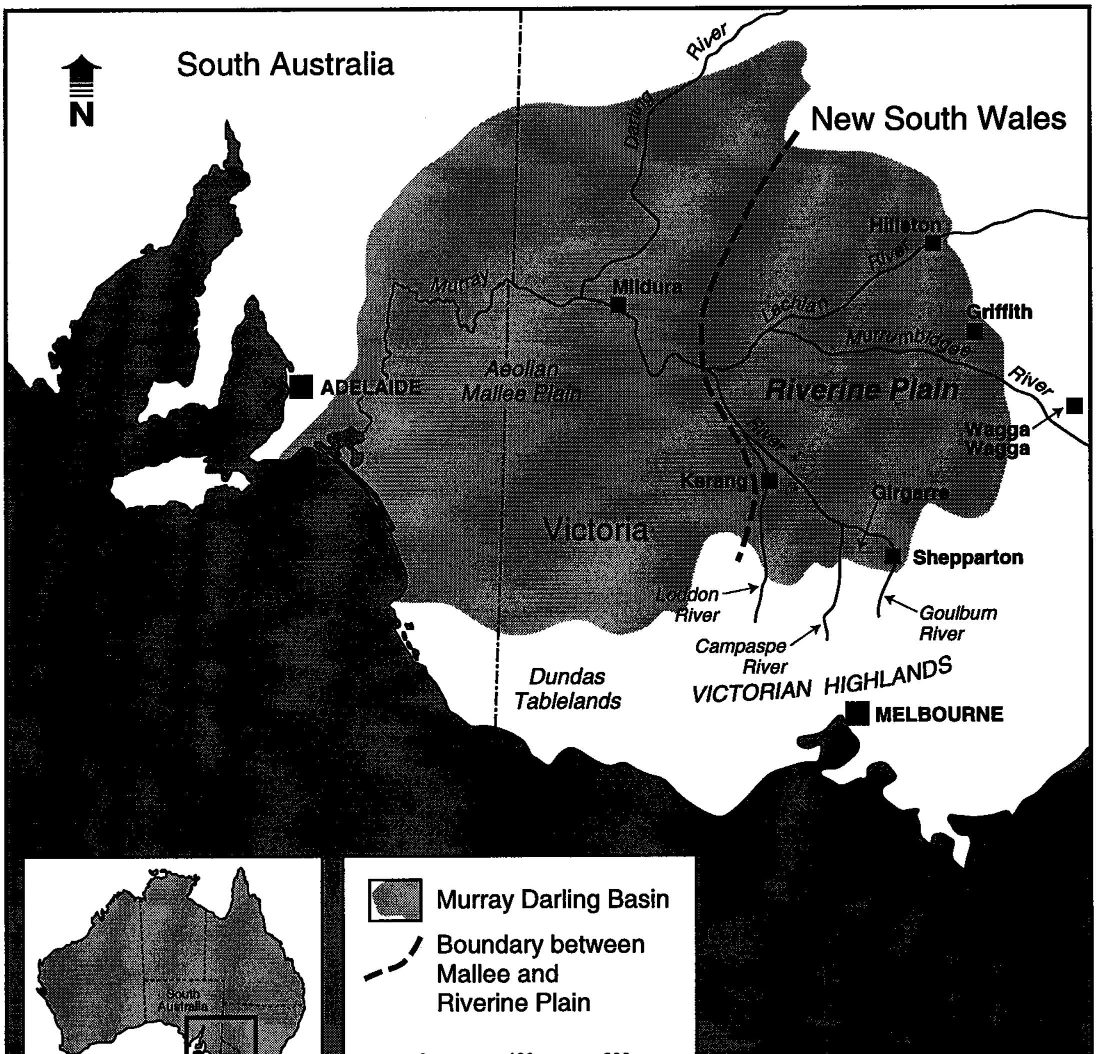

Figure 1.Location of the Murray-Darling Basin,south-eastern Australia

Saline disposal basins have been used since 1917 for disposal of interception and drainage water (Hostetler and Radke, 1995). Figure 2 shows the distribution of the more notable saline water disposal basins along the Murray River, including those that form the basis for this study. Disposal sites are typically topographic depressions in the landscape, salt lakes, freshwater lakes and more recently, small-scale constructed basins. The number of disposal basins in the MDB is currently estimated to be about 190 (Hostetler and Radke, 1995; Evans, 1989). They are now commonplace in all land and water management strategies. However, concerns have been raised about the possible environmental impacts that saline disposal basins may have. Such concerns highlight the need for proper siting, design and management of basins. The ever growing number of disposal basins and potential environmental impacts they may have means that we need to be able to assess and compare a large number of disposal basins across the entire Murray Basin in a consistent, efficient and timely manner. This will allow for effective management decisions to be made within reasonable time frames.

A small number of disposal basins have been studied in detail using hydrochemical and modelling techniques, e.g., Lake Ranfurly (Narayan and Armstrong, 1995), Lake Tutchewop (Simmons and Narayan, 1998), Lake Mourquong (Simmons et al., 1999), Noora Basin (Watkins, 1991), Stockyard Plain (Woodward-Clyde, 1998), Wakool (DWR, 1988) and Girgarre (Sinclair Knight Merz, 1995). These studies have provided insight into the key hydrogeologic processes that affect basin leakage, subsequent impact on underlying aquifers as well as surrounding land and streams. In addition, the factors that affect disposal capacity and storage potential are well understood. The development of generic criteria that make use of knowledge gained from extensive and detailed site-specific investigations provides a framework for rapid characterisation, ranking and inter-basin comparisons. In this way, we can readily identify "safe" and "at-risk" sites within a large group of disposal basins in relation to some particular objective e.g., minimum leakage. This allows us to identify sites for potential further storage, compare performance of basins in a relative sense, and identify disposal sites requiring additional information (in particular, those that require further investigation to establish the extent of negative impacts).

Hoxley (1993) developed and applied criteria for ranking a small number of disposal basins within Victoria. Attempts to fill in missing data fields from that study are also found in Sinclair Knight Merz (1998a, 1998b). Hoxley's criteria were also used to rank several disposal basins in New South Wales by Williams (1993). However, a basin wide comparison of disposal systems has not been undertaken.

In this study, we compare on a standard basis major disposal basins throughout the Murray-Darling Basin in New South Wales, Victoria and South Australia. Many of the more notable basins detailed in Evans (1989)

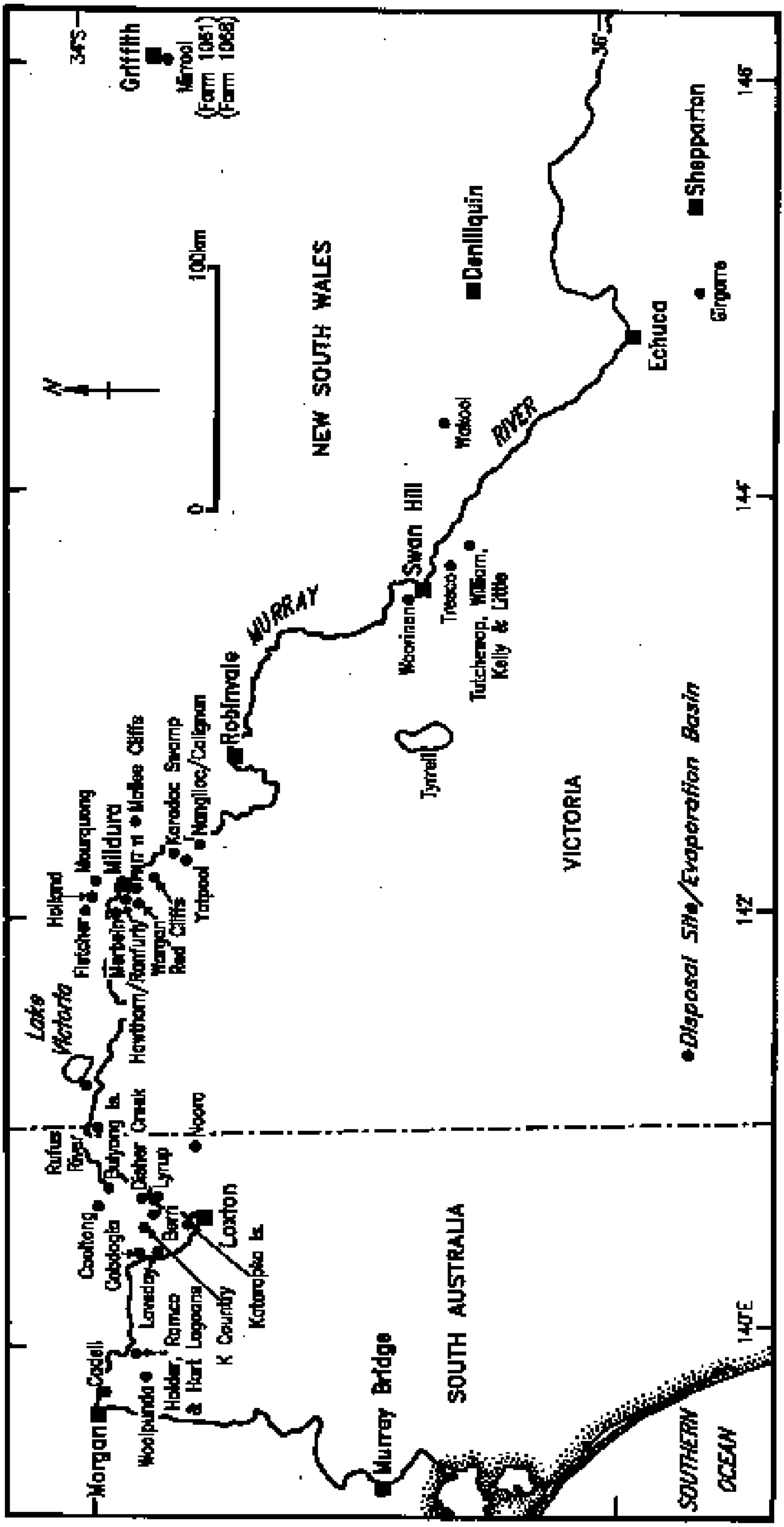

Figure 2.Distribution of major saline water disposal basins along the Murray River, including those used in this study (modified from Evans, 1989)

were especially selected for the study. The criteria used within this study are an extension of those developed by Hoxley (1993). In addition, new characterisation criteria are developed to reflect the potential leakage caused by density-driven convection (Simmons and Narayan, 1997) as well as to include time scales for return flows to the river system. This study also employs a series of separate characterisation and ranking objectives. In this way, several disposal basin ranking lists for each defined ranking objective are produced and a basin's overall performance score can be linked directly to specific attributes of the system. This is more informative than a single ranked list produced using a "lumped sum" approach (Hoxley, 1993) that makes it difficult to assess what aspect of a disposal basin system makes it either a "good" or "bad" site.

The methodology developed in this paper can be applied to all disposal basin sites within the Murray-Darling Basin as it is a framework which can be updated as more data becomes available for the disposal basins.

2. Site Selection and Ranking Methods

The methodology comprises three main steps: (i) the selection of an appropriate number of disposal basins, (ii) "characterising" them in terms of quantitative parameters, and (iii) finally ranking them using a number of different objectives.

2.1 Site Selection

Two criteria were employed for basin selection. The first was that a reasonable number of basins should be selected from each of New South Wales, Victoria and South Australia. Secondly, given the inherent hydrogeological differences between the Mallee and Riverine sections of the Murray Geologic Basin, an attempt was made to balance the number of sites between these two regions. An examination of the inventory of saline disposal basins (Hostetler and Radke, 1995) reveals an obvious bias towards disposal basins in the Mallee region, making it more difficult to choose suitable disposal basin sites in the Riverine Plain region.

28 sites were selected from the three states (SA, VIC, NSW) within the Murray Basin. Several of these sites, as starred below, were previously identified by Evans (1989) as the "notable" basins within each state. Figure 2 shows the distribution of the more notable saline water disposal basins along the Murray River, including those disposal basins that form the basis for this study. The disposal basins chosen for this characterisation and ranking study are:

South Australia:

Noora*, Katarapko Island*, Disher Creek*, Berri*, Bulyong Island*, Loveday*, Woolpunda (Stockyard Plain), K Country.

Victoria:

Tutchewop*, William, Hawthorn*, Ranfurly*, Wargan*, Lamberts Mer-3, Karadoc Swamp, Yatpool, Woorinen (Murrawee), Woorinen (Holloways), Tresco (Golf Club), Tresco (Round), Girgarre.

New South Wales:

Wakool*, Rufus River*, Mourquong*, Holland Lake, Fletchers Lake, Farm 1061, Farm 1068.

* Notable sites identified by Evans (1989).

2.2
Ranking Objectives

Given a set of disposal basins, a multitude of rankings may be possible depending upon what is being assessed and the criteria the ranking is based upon. For example, a basin might rate highly as a potential site for further storage but rate low on its performance in terms of leakage to underlying aquifer systems. It was therefore necessary to define clear "ranking objectives" in order to produce ranking lists which reflect information about specific features of a disposal basin's performance. Five ranking lists were produced based upon the following ranking objectives:

1. Minimum leakage and salt loss from basin
2. Maximum capacity for storage of water
3. Minimum leakage and salt loss and maximum storage capacity (combining 1 and 2)
4. Minimum impact on River Murray, neighbouring streams and other environmentally sensitive land
5. Minimum loss of water and salt, maximum storage capacity, and minimum impact on River Murray (combining 1, 2 and 4)

It is clear that leakage and salt loss are prime issues that must be addressed in the impacts of any disposal basin. For many sites, leakage inadvertently becomes a major part of the disposal mechanism. However, where possible, leakage should be minimised especially to protect groundwater quality in regions where underlying groundwater is not overly saline already and also to minimise leakage to local freshwater streams. Another critical issue that needed to be addressed was determining sites that could be used for potential further storage. If a certain volume of water needed to be disposed, which disposal basins would have sufficient capacity to handle that volume of water and which wouldn't? Identifying sites for further storage is an interesting ranking objective and one that has important management ramifications. Potential impacts on neighbouring streams, environmentally sensitive land and the River Murray system were also considered. Furthermore, hybrid combinations of the above ranking objectives were examined e.g., a ranking which considered minimum leakage of salt as well as maximum capacity to store water.

2.3
Characterisation Parameters and Variables

Several key variables were identified in order to develop a quantitative method of characterising the selected disposal basin sites. In order to satisfy the ranking objectives detailed in Section 2.2, the following parameters were selected for the ranking exercise. Many of these were considered by Evans (1989) in the typical factors used in evaporation basin design as shown in Figure 3 and were also considered appropriate in this study.

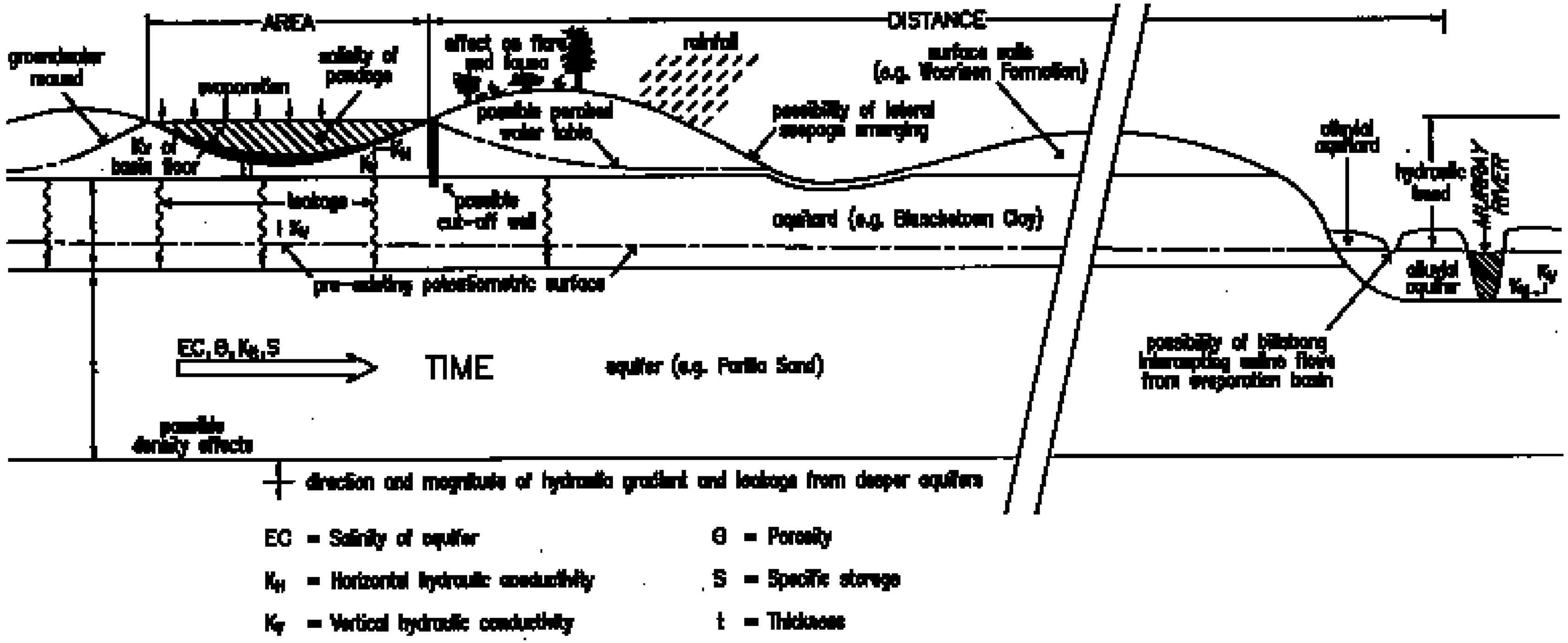

Figure 3. Typical factors considered in evaporation basin design (after Evans, 1989)

- Potential leakage (head difference between basin and groundwater) *(m)*
- Vertical hydraulic conductivity *(m/day)*
- Salinity (TDS) difference between basin and groundwater *(g/L)*
- Ratio of inflow volume to evaporation volume
- Capacity of basin *(ML)*
- Distance between basin and streams/rivers or environmentally sensitive land in the River Murray trench *(m)*
- Horizontal hydraulic conductivity *(m/day)*
- Viability (time taken for hydraulic pulse transmission to River) *(years)*
- Size of basin *(ha)*

All data used in this project was collected from the inventory of saline disposal basins (Hostetler and Radke, 1995). This inventory documents all known disposal basins in the Murray Basin. It is drawn from individual state inventories and databases and reports on individual basins where they exist. Included are all parameters identified by Evans (1989) as essential for disposal basin design, and are therefore applicable for an assessment of sustainability. It details location and coordinates of the disposal basin, operational history, spatial attributes, salinities and water volumes, engineering/administrative information, hydrogeological information, hydrodynamic summaries as well as lithostratigraphic cross-sections, sketch maps and air photo imagery.

Where information was not available in the inventory, an attempt was made to locate that information from individual reports on the disposal basin under consideration. However, in several cases, the information could not be found. This then created the problem of an incomplete data set and how to most appropriately deal with such cases.

2.4

Data Used in Characterisation Methods

For each disposal basin, its area *(ha),* horizontal and vertical hydraulic conductivity *(m/day)* of the underlying aquifer, hydraulic head in the basin, hydraulic head of the groundwater system, distance to River Murray *(m)* (or neighbouring streams and environmentally sensitive land), groundwater salinity *(mg/L),* basin capacity *(ML),* inflow volumes *(ML/yr)* and evaporative capacity (mm/yr) were extracted from the inventory. Table 1 provides the complete data listing as extracted from the inventory for each of the chosen 28 disposal sites. Information that could not be determined from the inventory or reports is inserted as “unknown”.

An Excel spreadsheet was developed to convert collected data in Table 1 into

Table 1.Information sheet: All data collected that is used in the characterisation process.

Information Sheet

ID Number	Name of the basins	Loca-tion	Area (ha)	Kh m/day	Kv m/day	head ba (m)	head gw(m)	Deff.hd b&r(m)	distan. (m)	salin.b mg/L	salin. gw mg/L	capacity ML	inflow ML/year	evapor mm/year
1	**Woolpunda**	SA	675	50.0	0.001	31	6.0	27.5	10,500	64,000	22,000	unknown	7,500	2,200
2	**Loveday**	SA	300	20.0	0.2	9.95	9.5	0	100	7,620	unknown	2,200	2,600	1,650
3	**Katarapko**	SA	812	20.0	0.013	13.3	12.0	1.5	500	4,704	28,300	7,600	4,000	1,716
4	**Berri**	SA	400	20.0	0.013	14.7	13.2	0	500	24,500	10,000	unknown	2,500	1,650
5	**Disher Creek**	SA	500	20.0	8.64	15.8	13.4	0	20	7,540	42,000	unknown	4,400	1,650
6	**Bulyong Island**	SA	330	20.0	0.013	17.6	18.0	0.6	35	15,200	unknown	1,210	550	1,650
7	**Noora**	SA	1,700	10.0	0.03	18.7	17.5	7	19,000	12,000	28,800	unknown	4,945	1,700
8	**Rufus River**	NSW	300	5.0	0.03	54.5	22.7	34.5	2,200	34,680	54,000	unknown	4,500	1,400
9	**Fletchers Lake**	NSW	840	10.0	0.03	29.2	30.0	unknown	0,00	36,400	39,000	550	1,100	1,650
10	**Holland Lake**	NSW	200	15.0	0.03	35	34.5	unknown	7,000	5,850	39,000	300	6,000	1,400
11	**Lake Mouquong**	NSW	324	3.0	0.03	32.0	32.0	0	3,000	250,000	100,000	900	4,380	2,200
12	**Lamberts Mer-3**	VIC	16	3.0	0.3	32.67	35.0	0.00	unknown	96,000	35,000	70	109	970
13	**Hawthorn**	VIC	214	10.0	0.03	35.3	36.0	unknown	2,000	4,350	10,000	4,405	6,680	2,100
14	**Lake Ranfurly**	VIC	81	25.0	0.8	34.5	36.0	7	500	120,000	45,000	482	3,654	2,400
15	**Wargan**	VIC	430	50.0	0.05	50	34.0	unknown	1,450	82,500	50,000	10,932	5,500	1,840
16	**Lake Tutchewop**	VIC	1,173	2.0	0.03	70.1	71.0	5.0	7,000	88,000	42,000	19,700	8,000	978
17	**Wakool**	NSW	2,120	40.0	0.3	unknown	72.0	unknown	3,000	29,055	21,000	unknown	100,000	1,548
18	**K Country**	SA	14	6.0	0.03	22.05	20.5	12.00	3,500	unknown	14,000	unknown	530	1,700
19	**Karadoc Swamp**	VIC	855	40.0	0.3	36.67	35.7	unknown	2,000	104,000	50,000	2,725	775	1,980
20	**Yatpool**	VIC	1,000	40.0	0.3	35	36.8	unknown	7,000	3,300	50,000	unknown	unknown	1,980
21	**Woorinen murr.**	VIC	500	10.0	0.03	60	64.0	0.00	7,500	129,600	35,000	28,770	1,400	1,400
22	**Tresco Golf**	VIC	100	10.0	0.03	67.82	67.2	unknown	8,000	30,000	50,000	1,000	300	1,000
23	**Girgarre**	VIC	28	0.7	0.0001	103.7	102.7	2.46	500	86,220	18,000	86	411	1,220
24	**Tresco (Round)**	VIC	50.1	10.0	0.03	67.82	67.2	unknown	40,000	49,980	50,000	1,450	300	(In/Ev=0.3)
25	**Woorinen Holl.**	VIC	181	10.0	0.03	63.0	63.0	unknown	1,000	127,800	50,000	1,827	300	1,400
26	**Mirrool Farm 1061**	NSW	2	40	0.3	121.0	120.81	0.5	unknown	12,350	9,750	unknown	unknown	1702
27	**Mirrool Farm 1068**	NSW	2	10	0.03	unknown	123.47	unknown	no flow	11,700	9,750	unknown	unknown	1702
28	**Lake William**	VIC	108	2	0.01	70.1	70.8	unknown	5,000	118,000	50,000	2,700	11,000	(In/Ev=0.7)

2.5 Ranking Methods

a numerical rank. For each ranking criteria, a point scale was assigned from 0 - 10, with 0 (or lowest score) representing a "best" site in terms of that criteria and 10 (or highest score) representing the "worst" site. It is worth pointing out that any basin for which information is unknown (see Table 1), a points value of 10 is assigned. This places the basin in the "worst" or poorest performing category. This may or may not be the case but in the absence of knowledge or data for the criterion, we would rather assume that the basin is in the poor performance category by assigning highest points value to it rather than to assume that the converse is true. This could potentially prompt further data collection to revise the scores in an effort to reduce the score assigned to the basin.

Ranking objectives could consist of more than one criterion or field. For example, minimum leakage and salt loss from the disposal basin would be a function of several parameters including the difference in head between the basin and groundwater, the vertical hydraulic conductivity and salinity difference between the basin and underlying groundwater. This will be discussed in further detail in Section 3. Given below is a discussion of each of the seven fields used in the ranking process and the numerical ranking system that has been used.

2.5.1 Potential Leakage

This field assesses the potential for discharge of water from the disposal basin into the groundwater system and vice versa and to what extent this may occur. It is obvious that the greater the potential for water to leak from the basin, the higher the potential risk that it will also impact on surrounding areas or the water quality of the underlying aquifer. The potential for leakage can be assessed by considering the hydraulic head difference between the basin and the surrounding groundwater system. The critical parameter is $h_{ba} - h_{gw}$, where h_{ba} is the hydraulic head in the disposal basin and h_{gw} is the hydraulic head in the groundwater system. If $h_{ba} - h_{gw} < 0$, this indicates that flow is likely to be into the disposal basin (i.e., the disposal basin acts as a discharge feature). Conversely, if $h_{ba} - h_{gw} > 0$, this indicates that groundwater flow is likely to be directed out of the basin (i.e., the basin acts as a recharge feature). The scoring system used for this field is given below. The range of values given in Table 2 reflects the range of values that exist in data Table 1.

2.5.2 Vertical Hydraulic Conductivity

Table 2.Scoring tables used in the basin characterisation process

Points	***Potential Leakage*** $h_{ba} - h_{gw}$ ***(m)***	***Vertical hydraulic conductivity (Kv) (m/day)***	***Salinity difference between basin and groundwater (g/L)***	***Ratio of inflow volume to evaporation capacity***	***Basin capacity (ML)***	***Distance times trench (0 or 1)* (m)***	***Hydraulic Pulse transmission time (years)***
0	<(-5)	-	<0	-	-	0	$t=\infty^{+}$
1	(-5) ~ (-2)	<0.00001	0~1	<0.2	>10000	Dis.>25000	time >1000
2	(-2) ~ (-1)	0.00001~0.0001	1~5	0.2~0.5	5000~10000	20000~25000	500~1000
3	(-1) ~ (0)	0.0001~0.001	5~10	0.5~0.8	1000~5000	15000~20000	300~500
4	0 ~ (1)	0.001~0.01	10~20	0.8~0.9	500~1000	10000~15000	200~300
5	1~2	0.01~0.05	20~30	0.9~0.95	100~500	5000~10000	200~100
6	2~3	0.05~0.1	30~40	0.95~1.0	50~100	2000~5000	50~100
7	3~5	0.1~0.5	40~50	1.0~1.05	10~50	1000~2000	25~50
8	5~10	0.5~1	50~100	1.05~1.1	5~10	500~1000	10~25
9	> 10	>1	>100	>1.1	<5	<500	<10
10	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

*** If the basin is in the Murray trench, the effective distance is distance × 1. If the basin is out of the Murray trench, then 0 is given.**

+ Indicates that flow is away from the river. Effective transmission time is infinite.

Whilst horizontal leakage is a function of hydraulic head difference between the basin and the hydraulic head in the aquifer at some point away from the disposal basin, for many basins a significant proportion of the leakage can occur through the basin floor. It is intuitively obvious that vertical hydraulic conductivity of underlying aquifer material or basin sediments must play a role in the resultant vertical leakage processes. In addition, Simmons and Narayan (1997) showed that vertical leakage of salt could be enhanced through a process called free convection, which is a density-driven process. The key dimensionless variable used to predict whether or not density-driven free convection will occur is the Rayleigh number *Ra* given by (Simmons and Narayan, 1997):

$$Ra = \frac{U_C H}{D_T} = \frac{g k_v \beta (C_{\max} - C_{\min}) H}{\varepsilon v_0 (D_0 + \alpha_T V_{amb})} = \frac{\textit{Buoyancy forces}}{\textit{Diffusive/ Dispersive forces}} \tag{1}$$

where U_c is the convective velocity, H is depth of the porous layer, D_T is the transverse dispersion coefficient, D_0 is the molecular diffusivity, g is acceleration due to gravity, k_v is the vertical intrinsic permeability, $= \;_0{}^1$ $(\partial / \partial c)$ is the linear expansion coefficient of density variation with changing concentration, C_{max} and C_{min} are the maximum and minimum values of concentration respectively, is the aquifer porosity, $_0 = \partial \;\; _0$ is the kinematic viscosity of the fluid, $_T$ is the transverse dispersivity and V_{amb} is the ambient velocity due to external head gradients.

The key driving forces for this vertical leakage are the vertical permeability of the aquifer material (or hydraulic conductivity) and the salinity difference between the basin of higher salinity and the groundwater system of lower salinity. In any case, increasing the vertical hydraulic conductivity will enhance leakage and the potential for density-driven convection and increasing the salinity difference will enhance diffusion (as per Fick's Law of diffusion) or promote the onset of even more rapid leakage through convection. Table 2 provides the scoring information for vertical hydraulic conductivity. High vertical hydraulic conductivity values are given highest points, whilst low vertical hydraulic conductivities are given low scores because they reduce leakage. Again, an unknown for any disposal basin in this field is assigned the highest score of 10.

2.5.3 Salinity difference between disposal basin waters and groundwater

As described in Section 2.5.2, large salinity differences between a disposal basin typically of higher salinity than underlying groundwater will enhance movement of salt away from the disposal basin through either Fickian based diffusion or an enhanced density-driven convection process. In any case, the salinity difference is the driving force. The potential for salt transport can be assessed by considering salinity difference between the basin and the underlying groundwater system. The critical parameter is $S_{ba} - S_{gw}$, where S_{ba} is the salinity of the disposal basin waters and S_{gw} is the salinity of the underlying groundwater system. If $S_{ba} - S_{gw} < 0$, this indicates that salt movement is likely to be into the disposal basin. Conversely, if $S_{ba} - S_{gw} > 0$, this indicates that salt transport is likely to be directed out of the basin. As $S_{ba} - S_{gw}$ increases the diffusive flow rates are increases and the propensity for convection is also enhanced. Therefore higher values of $S_{ba} - S_{gw}$ are seen to enhance risk of salinisation of underlying and surrounding aquifers. In addition, a larger value of $S_{ba} - S_{gw}$ also means that the salinity of disposal basin waters are higher than the groundwater system, a situation which should not be encouraged from the point of view of changing the water quality in the underlying aquifer. Similarly, a lower value of $S_{ba} - S_{gw}$ indicates a better "compatibility" between basin waters and the groundwater in the region, a situation that is considered more favourable from the environmental risk viewpoint (Table 2).

2.5.4 Ratio of inflow volume to discharge volume

The ratio of inflow volume to outflow or discharge volume is a primary measure of a basins capacity to store inflow water without overtopping. Inflow is primarily a function of drainage disposal water and rainfall. In some cases, inflow from the groundwater system may also occur at low basin levels where the basin base is below the watertable. Annual estimates for both inflow and outflow are used since detailed daily operation records for most disposal basins are not available.

In the outflow budget, seepage is generally unknown and difficult to estimate although in many cases it provides a significant outflow volume from the basin. Without seepage included discharge is underestimated in most cases, making the estimate for inflow to outflow more conservative and therefore higher in value. Another issue is that of reuse. Basin operators can usually provide some indication as to whether there is reuse of disposal basin waters, although generally not the volume (Sinclair Knight Merz, 1998a). Like groundwater seepage, reuse represents an outflow from the basin that is difficult to quantify. To account for both seepage and reuse would result in unknown values for many basins, and scores of 10 if they are included. The scoring table (Table 2) used here makes use of the most easily identified inflow and outflow volumes, namely, drainage inflow and evaporative outflow. Evaporative outflow volumes are calculated using the surface area of the lake and the evaporation rate. It is appreciated that inclusion of seepage and reuse would result in the ratio decreasing and a corresponding decrease in the point score.

2.5.5 Basin capacity

In addition to the ratio of inflow volume to discharge volume, another indicator that should be considered is basin storage capacity. A low ratio of inflow to discharge volume is considered good, but might also indicate that the basin doesn't have significant storage potential in the first place and as such inflows are minimised. Even a very small disposal basin can have a low inflow to outflow ratio. The area of the basin could be used as an indicator, but has already been used in the evaporative volume calculations for basin discharge. Another useful indicator is basin volume capacity. It is easy to appreciate that a basin with larger holding capacity would be a better site than one with a smaller holding capacity in terms of potential storage ability (Table 2).

2.5.6 Distance between basin and streams, rivers or environmentally sensitive land

The return of saline leakage from disposal basins to the River Murray via groundwater is an important issue. In general, a basin located in close proximity to the River Murray or other streams and environmentally sensitive land is considered to be a poor site from an environmental risk viewpoint. It is worth pointing out that whilst this is a hazard, there is also an argument that basins that can be flushed to the river at times of high flow are more sustainable than those that cannot. In this respect, a basin that is located close to the River Murray would be considered advantageous. However, this is a separate issue that requires several other factors to be considered and is beyond the scope of this study.

Whether the basin is located inside the Murray trench or outside of it is considered. If the basin is located within the Murray trench, flow is generally directed towards the Murray River. The distance between the basin and the river is used to allocate a point score to that basin. Conversely, if the basin is located outside the Murray trench, the basin is assigned a 0 point score, since flow would not necessarily be directed towards the River Murray. If other environmentally sensitive land was identified near the basin, even if it was located outside the trench, the distance between the basin and that region was used. The points for this criterion is given in Table 2.

2.5.7 Hydraulic pulse transmission time

This criterion is related to the one described in Section 2.5.6. As discussed in Evans (1989), a perched groundwater mound may develop beneath a disposal basin over time, resulting in leakage to deeper aquifers and then the subsequent transmission of a hydraulic pulse and solute pulse through the aquifer to a lower hydraulic potential discharge location. In most cases in the Murray-Darling Basin, the discharge location is the Murray River. The rate of movement of the hydraulic pulse can be calculated using Darcy's Law. The approximate time taken before first arrival at river of actual water disposed in basin can be found using the simple distance, velocity and time calculation:

$$\text{Time } \textit{(years)} = (\text{Distance to river})/(K_h \text{x} \Delta h_{b/gw}/\text{Distance to river})/365$$

Where K_h is the horizontal hydraulic conductivity of the aquifer (m/day), $h_{b/gw}$ is the horizontal hydraulic head drop between basin and river (m) and the distance to the river is measured in metres. The points assigned for this criterion are given in Table 2. It should be noted that this time is significantly higher than the approximate time before displacement of existing regional groundwater and salt occurs. At earlier times, the salt load to the river would be determined by the salinity of groundwater nearby the river as it is displaced into the river. At later times, due to various other mixing processes (diffusion, dispersion, recharge etc.) it is difficult to estimate the salinity of water entering the river. It is not simply the salinity of the surface water in the disposal basin. The issue of total salt load to the river caused by displacement of existing regional groundwater and then arrival of actual salt disposed in the disposal basin is not a trivial exercise. It requires detailed modelling for proper assessment. Therefore, characterisation of disposal basins using total salt load to the river as a key variable is difficult and prone to significant error. This aspect has not been considered in this study.

3. Ranking Results

For each of the ranking objectives defined in Section 2.2, a total score was calculated by forming a weighted average of the criteria that are used to form that objective. For example, to calculate a total score for the objective of *minimum leakage and salt loss* from the basin, three criteria, namely, potential leakage, vertical hydraulic conductivity and salinity difference between basin and groundwater are used. For each basin, a score out of 10 was assigned for each of these three criteria. An average was formed to provide a total score also out of 10 for the basin. The basins were then ranked based upon that total score. Table 3 provides the ranking table for the disposal basins for this ranking objective. Whilst there is an obvious range of total scores for the objective of minimum leakage and salt loss, it should be noted that there are several bands observed where a group of basins all received the same total score. This makes it hard to distinguish between basins in that band. What is useful, however, is to be able to then look back at the data which was used to provide the total score and to identify which attribute lead to the score the basin ultimately received. In several cases, an unknown data value may have been the cause of a 10 point score within a data field. Further data collection would be required to move the basin up to a more favourable position within the ranking list.

For the ranking objective of *maximum saline water storage capacity*, both the inflow to evaporative outflow ratio and the total basin storage capacity are used. A large range in total scores for the basins is observed in Table 4. Highest scoring basins appear to suffer due to lack of data available for them.

The ranking list that combines both *minimum leakage and salt loss* together with maximum saline water storage is given in Table 5.

For the ranking objective of *minimum impact on the River Murray, neighbouring streams and other environmentally sensitive land,* both the distance from those features (typically the River Murray) and the time taken for the hydraulic pulse to travel between the disposal basin and the River Murray are used. As seen in Table 6, about ten disposal basins received a total points value for this objective of zero. This is because they lie outside the Murray trench. Again, several basins clearly receive high point values due to unknowns as a result of missing data for pulse transit time. This is due to lack of data relating to either hydraulic head gradients or horizontal hydraulic conductivity values.

In some situations, it may be useful to consider all of these ranking objectives together to assess basin performance and potential environmental impact. Table 7 provides a ranking table which is a hybrid combination of all ranking objectives, namely, *minimum leakage and salt loss* together with *maximum saline water storage capacity* and *minimum impact on the River Murray, neighbouring streams and other environmentally sensitive land.* It is generally believed that a hybrid of increasing complexity such as this reveals less useful information than the simpler ranking objectives. The purpose of the ranking list should be to see how basins perform in a relative sense on specific ranking objectives. In any case, a basin which scores poorly using a hybrid combination for the ranking objective should ultimately be re-examined in detail to see why it received a higher total points score.

Finally, it is of interest to develop a simple indicator system to see how basins perform in all categories. We have now considered 5 ranking objectives. It is useful to see whether a particular basin received low or high scores in all, some or none of the ranking objectives. Consider a ranking objective such as *minimum leakage and salt loss.* The "best" basin received a total score of 2.7. The "worst" basin received a total score of 7.0. Three bands can be defined for this case to separate basins into categories of "good", "OK" and "bad". By subtracting the lowest score in the rank list from the highest and dividing the difference by three, the basin score distribution can be partitioned into these three categories. The lowest scoring band (or third) is defined as "good" (scores of 2.7-4.1 inclusive), the medium band is defined as "OK" (scores of 4.1-5.5 inclusive) and the highest scoring band is defined as "bad" (scores of 5.5-7.0 inclusive). A similar approach is used for all five ranking objectives and each basin is assigned into one of these three categories for each of those objectives.

Basins are then ranked from lowest (most number of "goods", least number of "bads") through to highest (most number of "bads"). Table 8 shows this ranking.

Table 3. Objective 1: Ranked list for minimum water and salt loss

Scenario 1. Minimum Water and Salt Loss

Calculated Component					List of Points				
ID Number	Name of Basins	Differ. head b&g (m)	Kv m/day	Differ. salinity B&GW	Differ. head b&g (m)	Kv m/day	Differ. salinity B&GW	Total Point	Normalised Point /10
9	**Fletchers Lake**	-0.8	0.03	- 3	3	5	0	8	
13	**Hawthorn**	-0.7	0.03	- 6	3	5	0	8	**2.7**
10	**Holland Lake**	0.5	0.03	- 33	4	5	0	9	**3.0**
22	**Tresco Golf**	0.6	0.03	- 20	4	5	0	9	**3.0**
24	**Tresco (Round)**	0.6	0.03	- 0	4	5	0	9	**3.0**
20	**Yatpool**	-1.8	0.3	- 47	2	7	0	9	**3.0**
3	**Katarapko**	1.3	0.013	- 24	5	5	0	10	**3.3**
7	**Noora basin**	1.2	0.03	- 17	5	5	0	10	**3.3**
23	**Girgarre**	1.0	0.0001	68	4	2	8	14	**4.7**
4	**Berri**	1.5	0.013	15	5	5	4	14	**4.7**
8	**Rufus River**	31.8	0.03	- 19	9	5	0	14	**4.7**
21	**Woorinen murr.**	-4.0	0.03	95	1	5	8	14	**4.7**
26	**Mirrool Farm 1061**	0.2	0.3	3	4	7	3	14	**4.7**
28	**Lake William**	-0.7	0.01	68	3	4	8	15	**5.0**
16	**Lake Tutchewop**	-0.9	0.03	46	3	5	7	15	**5.0**
5	**Disher Creek**	2.4	8.64	- 34	6	9	0	15	**5.0**
25	**Woorinen Holloways**	0.0	0.03	78	3	5	8	16	**5.3**
12	**Lamberts Mer-3**	-2.3	0.3	61	1	7	8	16	**5.3**
11	**Lake Mourquong**	0.0	0.03	150	3	5	9	17	**5.7**
6	**Bulyong Island**	-0.4	0.013	unknown	3	5	10	18	**6.0**
27	**Mirrool Farm 1068**	unknown	0.03	2	10	5	3	18	**6.0**
14	**Lake Ranfurly**	-1.5	0.8	75	2	8	8	18	**6.0**
1	**Woolpunda**	25.0	0.001	42	9	3	7	19	**6.3**
19	**Karadoc Swamp**	1.0	0.3	54	4	7	8	19	**6.3**
18	**K Country**	1.6	0.03	unknown	5	5	10	20	**6.7**
15	**Wargan**	16.0	0.05	33	9	5	6	20	**6.7**
17	**Wakool**	unknown	0.3	8	10	7	3	20	**6.7**
2	**Loveday**	0.4	0.2	unknown	4	7	10	21	**7.0**

Ranking Criteria
(Min. loss both water and salt)

Points	Differ.head (b&gw) (m)	Kv m/day	Differ. TDS (b&gw) g/L
0	<(-5)		<0
1	(-5)~(-2)	<0.00001	0~1
2	(-2)~(-1)	0.00001~0.0001	1~5
3	(-1)~0	0.0001~0.001	5~10
4	0~1	0.001~0.01	10~20
5	1~2	0.01~0.05	20~30
6	2~3	0.05~0.1	30~40
7	3~5	0.1~0.5	40~50
8	5~10	0.5~1	50~100
9	>10	>1	>100
10	unknown	unknown	unknown

Table 4.Objective 2: Ranked list for maximum saline water storage

Scenario 2. Maximum Saline Water Storage

Calculated Component				List of Points			
ID Number	Name of Basins	In/Eva	Basin Capacity (ML)	In/Eva	Basin Capacity (ML)	Total Point	Normalised Point /10
21	Woorinen murr.	0.20	28770	1	1	2	1.0
15	Wargan	0.70	10932	3	1	4	2.0
16	Lake Tutchewop	0.70	19700	3	1	4	2.0
3	Katarapko	0.29	7600	2	2	4	2.0
19	Karadoc Swamp	0.05	2725	1	3	4	2.0
6	Bulyong Island	0.10	1210	1	3	4	2.0
25	Woorinen Holloways	0.12	1827	1	3	4	2.0
24	Tresco (Round)	0.30	1450	2	3	5	2.5
22	Tresco Golf	0.30	1000	2	3	5	2.5
9	Fletchers Lake	0.08	550	1	4	5	2.5
2	Loveday	0.53	2200	3	3	6	3.0
28	Lake William	0.70	2700	3	3	6	3.0
11	Lake Mourquong	0.61	900	3	4	7	3.5
12	Lamberts Mer-3	0.70	70	3	6	9	4.5
7	Noora basin	0.17	unknown	1	10	11	5.5
4	Berri	0.38	unknown	2	10	12	6.0
13	Hawthorn	1.49	4405	9	3	12	6.0
1	Woolpunda	0.51	unknown	3	10	13	6.5
5	Disher Creek	0.53	unknown	3	10	13	6.5
14	Lake Ranfurly	1.88	482	9	5	14	7.0
10	Holland Lake	2.14	300	9	5	14	7.0
23	Girgarre	1.20	86	9	6	15	7.5
8	Rufus River	1.07	unknown	8	10	18	9.0
18	K Country	2.23	unknown	9	10	19	9.5
17	Wakool	3.05	unknown	9	10	19	9.5
26	Mirrool Farm 1061	unknown	unknown	10	10	20	10.0
27	Mirrool Farm 1068	unknown	unknown	10	10	20	10.0
20	Yatpool	unknown	unknown	10	10	20	10.0

Ranking Criteria
(Maximum Storage)

Points	In/Eva	Basin Capacity (ML)
1	<0.2	>10000
2	0.2~0.5	5000~10000
3	0.5~0.8	1000~5000
4	0.8~0.9	500~1000
5	0.9~0.95	100~500
6	0.95~1.0	50~100
7	1.0~1.05	10~50
8	1.05~1.1	5~10
9	>1.1	<5
10	unknown	unknown

Table 5. Objective 3: Ranked list for minimum water and salt loss and maximum storage

Scenario 3. Minimum Water and Salt Loss & Maximum Storage

(Scenario 1 +Scenario 2)

Calculated Component								List of Points						
ID Number	Name of Basins	Differ. head b&g (m)	Kv m/day	Differ. salinity B&GW	In/Eva	Basin Capacity (ML)		Differ. head b&g (m)	Kv m/day	Differ. salinity B&GW	In/Eva	Basin Capacity (ML)	Total Point	Normalised Point /10
9	**Fletchers Lake**	-0.8	0.03	- 3	0.08	550.00		3	5	0	1	4	13	**2.6**
3	**Katarapko**	1.3	0.013	- 24	0.29	7600.00		5	5	0	2	2	14	**2.8**
22	**Tresco Golf**	0.6	0.03	- 20	0.30	1000.00		4	5	0	2	3	14	**2.8**
24	**Tresco (Round)**	0.6	0.03	- 0	0.30	1450.00		4	5	0	2	3	14	**2.8**
21	**Woorinen murr.**	-4.0	0.03	95	0.20	28770.00		1	5	8	1	1	16	**3.2**
16	**Lake Tutchewop**	-0.9	0.03	46	0.70	19700.00		3	5	7	3	1	19	**3.8**
13	**Hawthorn**	-0.7	0.03	- 6	1.49	4405.00		3	5	0	9	3	20	**4.0**
25	**Woorinen Holloways**	0.0	0.03	78	0.12	1827.00		3	5	8	1	3	20	**4.0**
28	**Lake William**	-0.7	0.01	68	0.70	2700.00		3	4	8	3	3	21	**4.2**
7	**Noora basin**	1.2	0.03	- 17	0.17	unknown		5	5	0	1	10	21	**4.2**
6	**Bulyong Island**	-0.4	0.013	unknown	0.10	1210.00		3	5	10	1	3	22	**4.4**
10	**Holland Lake**	0.5	0.03	- 33	2.14	300.00		4	5	0	9	5	23	**4.6**
19	**Karadoc Swamp**	1.0	0.3	54	0.05	2725.00		4	7	8	1	3	23	**4.6**
11	**Lake Mourquong**	0.0	0.03	150	0.61	900.00		3	5	9	3	4	24	**4.8**
15	**Wargan**	16.0	0.05	33	0.70	10932.00		9	5	6	3	1	24	**4.8**
12	**Lamberts Mer-3**	-2.3	0.3	61	0.70	70.00		1	7	8	3	6	25	**5.0**
4	**Berri**	1.5	0.013	15	0.38	unknown		5	5	4	2	10	26	**5.2**
2	**Loveday**	0.4	0.2	unknown	0.53	2200.00		4	7	10	3	3	27	**5.4**
5	**Disher Creek**	2.4	8.64	- 34	0.53	unknown		6	9	0	3	10	28	**5.6**
23	**Girgarre**	1.0	0.0001	68	1.20	86.00		4	2	8	9	6	29	**5.8**
20	**Yatpool**	-1.8	0.3	- 47	unknown	unknown		2	7	0	10	10	29	**5.8**
1	**Woolpunda**	25.0	0.001	42	0.51	unknown		9	3	7	3	10	32	**6.4**
8	**Rufus River**	31.8	0.03	- 19	1.07	unknown		9	5	0	8	10	32	**6.4**
14	**Lake Ranfurly**	-1.5	0.8	75	1.88	482.00		2	8	8	9	5	32	**6.4**
26	**Mirrool Farm 1061**	0.2	0.3	3	unknown	unknown		4	7	3	10	10	34	**6.8**
27	**Mirrool Farm 1068**	unknown	0.03	2	unknown	unknown		10	5	3	10	10	38	**7.6**
18	**K Country**	1.6	0.03	unknown	2.23	unknown		5	5	10	9	10	39	**7.8**
17	**Wakool**	unknown	0.3	8	3.05	unknown		10	7	3	9	10	39	**7.8**

Table 6.Objective 4: Ranked list for minimum impacts on the River Murray

Scenario 4. Minimum Impact on River Murray

Calculated Component					List of Point			
ID Number	Name of Basins	Distance to streams (m)	Viability time (years)	In/out Murray trench	Distance multiply Mu. trench	Viability (years)	Total Point	Normalised Point /10
1	**Woolpunda**	10,500	BRM	0	0	0	-	**0.0**
7	**Noora basin**	19,000	BRM	0	0	0	-	**0.0**
8	**Rufus River**	2,200	BRM	0	0	0	-	**0.0**
9	**Fletchers Lake**	0,00	BRM	0	0	0	-	**0.0**
10	**Holland Lake**	7,000	BRM	0	0	0	-	**0.0**
12	**Lamberts Mer-3**	unknown	BRM	0	0	0	-	**0.0**
15	**Wargan**	1,450	BRM	0	0	0	-	**0.0**
17	**Wakool**	3,000	BRM	0	0	0	-	**0.0**
18	**K Country**	3,500	BRM	0	0	0	-	**0.0**
21	**Woorinen murr.**	7,500	BRM	0	0	0	-	**0.0**
22	**Tresco Golf**	8,000	BRM	0	0	0	-	**0.0**
11	**Lake Mourquong**	3,000	BRM	1	6	0	6	**3.0**
16	**Lake Tutchewop**	7,000	13424.7	1	5	2	7	**3.5**
4	**Berri**	500	BRM	1	8	0	8	**4.0**
2	**Loveday**	100	BRM	1	9	0	9	**4.5**
5	**Disher Creek**	20	BRM	1	9	0	9	**4.5**
27	**Mirrool Farm 1068**	no flow	unknown	1	0	10	10	**5.0**
23	**Girgarre**	500	397.8	1	8	4	12	**6.0**
20	**Yatpool**	7,000	unknown	1	5	10	15	**7.5**
3	**Katarapko**	500	22.8	1	8	8	16	**8.0**
13	**Hawthorn**	2,000	unknown	1	6	10	16	**8.0**
19	**Karadoc Swamp**	2,000	unknown	1	6	10	16	**8.0**
14	**Lake Ranfurly**	500	3.9	1	8	9	17	**8.5**
6	**Bulyong Island**	35	0.3	1	9	9	18	**9.0**
24	**Tresco (Round)**	40,000	unknown	1	8	10	18	**9.0**
25	**Woorinen Holloways**	1,000	unknown	1	8	10	18	**9.0**
26	**Mirrool Farm 1061**	unknown	unknown	1	8	10	18	**9.0**
28	**Lake William**	5,000	unknown	1	8	10	18	**9.0**

Ranking Criteria

(Min. impact on River MUrray)

Points	Distance times trench	Viability time (years)
0	<(-1)	BRM
1	>25000	Time>1000
2	15000~25000	500~1000
3	15000~20000	300~500
4	10000~15000	200~300
5	5000~10000	200~100
6	2000~5000	50~100
7	1000~2000	25~50
8	500~1000	10~25
9	Dis.<500	<10
10	unknown	unknown

Trench=0 indicats the basin is out Murray trench

Trench=1 indicats the basin is in the Murray trench

BRM ---- Backwards to River Murray

Table 7.Objective 5: Minimum water and salt loss, maximum storage and least impact on River Murray

Scenario 5. Minimum Water and Salt Loss, Maximum Storage & Least impact on River Murray

(Scenario 1 + Scenario 2 + Scenario 4)

Calculated Component										List of Points								
ID Number	Name of Basins	Differ. head b&g (m)	Kv m/day	Differ. salinity B&GW	In/Eva	Basin Capacity (ML)	Distance to streams (m)	Viability time (years)	In/out Murray trench	Differ. head b&g (m	Kv m/day	Differ. salinity B&GW	In/Eva	Basin Capacity (ML)	Distance multiply Mu. trench	Viability (years)	Total Point	Normalised Point /10
9	Fletchers Lake	-0.8	0.03	-3	0.08	550	0,00	BRM	0	3	5	0	1	4	0	0	13	1.9
22	Tresco Golf	0.6	0.03	-20	0.30	1000	8,000	BRM	0	4	5	0	2	3	0	0	14	2.0
21	Woorinen murr.	-4.0	0.03	95	0.20	28770	7,500	BRM	0	1	5	8	1	1	0	0	16	2.3
7	Noora basin	1.2	0.03	-17	0.17	unknown	19,000	BRM	0	5	5	0	1	10	0	0	21	3.0
3	Katarapko	1.3	0.013	-24	0.29	7600	500	22.8	1	5	5	0	2	2	8	0	22	3.1
10	Holland Lake	0.5	0.03	-33	2.14	300	7,000	BRM	0	4	5	0	9	5	0	0	23	3.3
15	Wargan	16.0	0.05	33	0.70	10932	1,450	BRM	0	9	5	6	3	1	0	0	24	3.4
16	Lake Tutchewop	-0.9	0.03	46	0.70	19700	7,000	13424.7	1	3	5	7	3	1	5	0	24	3.4
12	Lamberts Mer-3	-2.3	0.3	61	0.70	70	unknown	BRM	0	1	7	8	3	6	0	0	25	3.6
13	Hawthorn	-0.7	0.03	-6	1.49	4405	2,000	unknown	1	3	5	0	9	3	6	0	26	3.7
11	Lake Mourquong	0.0	0.03	150	0.61	900	3,000	BRM	1	3	5	9	3	4	6	0	30	4.3
24	Tresco (Round)	0.6	0.03	-0	0.30	1450	40,000	397.8	1	4	5	0	2	3	8	8	30	4.3
1	Woolpunda	25.0	0.001	42	0.51	unknown	10,500	BRM	0	9	3	7	3	10	0	0	32	4.6
8	Rufus River	31.8	0.03	-19	1.07	unknown	2,200	BRM	0	9	5	0	8	10	0	0	32	4.6
19	Karadoc Swamp	1.0	0.3	54	0.05	2725	2,000	unknown	1	4	7	8	1	3	6	4	33	4.7
2	Loveday	0.4	0.2	unknown	0.53	2200	100	BRM	1	4	7	10	3	3	9	0	36	5.1
4	Berri	1.5	0.013	15	0.38	unknown	500	BRM	1	5	5	4	2	10	8	2	36	5.1
25	Woorinen Holloway	0.0	0.03	78	0.12	1827	1,000	397.8	1	3	5	8	1	3	8	8	36	5.1
5	Disher Creek	2.4	8.64	-34	0.53	unknown	20	BRM	1	6	9	0	3	10	9	0	37	5.3
28	Lake William	-0.7	0.01	68	0.70	2700	5,000	397.8	1	3	4	8	3	3	8	8	37	5.3
6	Bulyong Island	-0.4	0.013	unknown	0.10	1210	35	0.3	1	3	5	10	1	3	9	10	41	5.9
20	Yatpool	-1.8	0.3	-47	unknown	unknown	7,000	unknown	1	2	7	0	10	10	5	9	43	6.1
23	Girgarre	1.0	0.0001	68	1.20	86	500	397.8	1	4	2	8	9	6	8	8	45	6.4
27	Mirrool Farm 1068	unknown	0.03	2	unknown	unknown	no flow	397.8	0	10	5	3	10	10	0	8	46	6.6
17	Wakool	unknown	0.3	8	3.05	unknown	3,000	BRM	0	10	7	3	9	10	0	10	49	7.0
18	K Country	1.6	0.03	unknown	2.23	unknown	3,500	BRM	0	5	5	10	9	10	0	10	49	7.0
14	Lake Ranfurly	-1.5	0.8	75	1.88	482	500	3.9	1	2	8	8	9	5	8	9	49	7.0
26	Mirrool Farm 1061	0.2	0.3	3	unknown	unknown	unknown	397.8	1	4	7	3	10	10	8	8	50	7.1

Table 8. Indicator table ranked from most number of "goods" through to most number of "bads"

Basin Number	Name of the basins	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1	Woolpunda	Bad	Bad	Bad	Good	Ok
2	Loveday	Bad	Good	Ok	Ok	Ok
3	Katarapko	Ok	Good	Good	Bad	Ok
4	Berri	Ok	Ok	Ok	Ok	Ok
5	Disher Creek	Ok	Bad	Ok	Ok	Ok
6	Bulyong Island	Ok	Good	Ok	Bad	Ok
7	Noora	Ok	Ok	Ok	Good	Good
8	Rufus River	Ok	Bad	Bad	Good	Ok
9	Fletchers Lake	Good	Good	Good	Good	Good
10	Holland Lake	Good	Bad	Ok	Good	Ok
11	Lake Mouquong	Ok	Ok	Ok	Good	Ok
12	Lamberts Mer-3	Ok	Ok	Ok	Good	Ok
13	Hawthorn	Good	Ok	Ok	Bad	Ok
14	Lake Ranfurly	Ok	Bad	Bad	Bad	Bad
15	Wargan	Bad	Good	Ok	Good	Ok
16	Lake Tutchewop	Ok	Good	Ok	Ok	Ok
17	Wakool	Bad	Bad	Bad	Good	Bad
18	K Country	Bad	Bad	Bad	Good	Bad
19	Karadoc Swamp	Bad	Good	Ok	Bad	Ok
20	Yatpool	Good	Bad	Ok	Bad	Bad
21	Woorinen murr.	Ok	Good	Ok	Good	Good
22	Tresco (Golf)	Good	Good	Good	Good	Good
23	Girgarre	Ok	Bad	Ok	Ok	Bad
24	Tresco (Round)	Good	Good	Good	Bad	Ok
25	Woorinen Holl.	Ok	Good	Ok	Bad	Ok
26	Mirrool Farm 1061	Ok	Bad	Bad	Bad	Bad
27	Mirrool Farm 1068	Ok	Bad	Bad	Ok	Bad
28	Lake William	Ok	Good	Ok	Bad	Ok

4. Discussion

It is useful to provide some general comments on the ranking system. When the ranking system was designed, a concerted effort was made to make data fields independent from one another. It is inevitable, however, that certain fields will be inter-dependent. For example, in the category of inflow to outflow volume ratios, the area of the basin was used to compute the total discharge flux as a result of evaporation. The total holding capacity criterion is also a function of area as well as basin depth. Similarly, vertical hydraulic conductivity used in the leakage criterion is generally correlated with horizontal hydraulic conductivity used in pulse transmission time calculations. These interdependencies cannot be avoided but do mean that some “doubling up” effects might be encountered resulting in higher scores in some cases.

As previously mentioned, lack of data in fields can result in higher scores indicating poorer performance in a relative sense. However, such sites might also be treated with higher priority for further data collection. As pointed out by Sinclair Knight Merz (1998a), basins for which data have been consistently collected are most likely the result of monitoring due to high salinities or problems in the area. Similarly, those without data also receive high scores based on the lack of information. Given the current ranking system and the missing data in some fields, it can become difficult to differentiate basins which suffer from “real” physical problems from those which we simply do not know enough about. In any case, the ranking lists produced here still identify the sites that we might choose to look at more closely to make such distinctions. This raises issues regarding the collection of further data and verifying the accuracy of data currently used within the ranking methods. Given the number of basins in the current ranking and the number of basins within the AGSO Inventory which could be ranked in an automated method, the resources required to fill all data fields completely and accurately would be enormous. It would be unrealistic to expect that all data in a database or inventory are of equal accuracy and although the data used in this report was largely collected from the AGSO Inventory, the data within the inventory is collected from a number of individual reports. Such a collection is prone to errors of many types which are usually unknown and unaccounted for. However, given two or three equally ranked basin sites, further work would be needed to then compare the data fields and their accuracy within any given ranking. A review of the objectives for a ranking exercise would be warranted before any further data surveys are conducted specifically for upgrading a ranking list.

There are still various factors that must be considered in sustainable management of a disposal site, not all of which are simply physical factors. For example, current and future use of the disposal basin, the surrounding environment and its environmental value, social and political attitudes towards the use of the basin, and the economics and costs involved in any management decision. These factors will be a critical part of any decision making process and in this light, the rankings provided in this report only provide a first order feel for the performance of different disposal basins. The study highlights how basins compare to each other and sites that need to be looked at a little more closely for further information about possible negative impacts. The ranking lists provide a starting point for further detailed investigations and in this context they are very useful.

5. Summary and Conclusions

In this study, saline disposal basins across three states in the Murray-Darling Basin are characterised and ranked using a representative sample of basins from both the Mallee and Riverine regions of the Basin. Five key ranking lists have been produced to reflect more accurately key features of the disposal basin and their potential impact, namely:

1. Minimum leakage and salt loss from basin
2. Maximum capacity for storage of water
3. Minimum leakage and salt loss and maximum capacity (combining 1 and 2)
4. Minimum impact on River Murray, neighbouring streams and other environmentally sensitive land
5. Minimum loss of water and salt, maximum capacity and minimum impact on River Murray (combining 1, 2 and 4)

The criteria used within this study are an extension of those developed by Hoxley (1993). In addition, new characterisation criteria are developed to reflect the potential leakage caused by density-driven convection (Simmons and Narayan, 1997) as well as to include time scales for return flows to the river system. Unlike the ranking work carried out by Hoxley (1993), this study also employs a series of separate characterisation and ranking objectives. In this way, several disposal basin ranking lists for each defined ranking objective are produced and a basin's overall performance score can be linked directly to specific attributes of the system. This is more informative than a single ranked list produced using a "lumped sum" approach.

The number of "unknown" fields is still an issue that biases results in the ranking lists. Where data were not available, it was felt that the conservative approach of assigning a higher score was more appropriate than assigning a lower score. This means that a basin might receive an unfairly high score in a ranking however it indicates that data collection or measurement is necessary to better assess its position within a ranking list. This might prompt further communication of "local knowledge" by basin operators and managers to protect the reputation of a disposal basin. To collect data specifically to fill "unknown" data fields within this ranking study would be expensive and would require a review of the objectives and audience of the approach before any further work was initiated. In any case, should further data collection take place it should be undertaken through government departments and local water management boards and authorities who could supervise data collection and compilation.

The current ranking system also has some inconsistencies due to accuracy of the available data. Some fields may also be more significant than others and there is also a minor problem with potential “doubling up” effects where two or more fields are not completely independent of one another. These issues cannot be avoided. Nevertheless, the basin scores presented in this report are considered to be representative of the potential risk to the environment presented by a disposal basin under each ranking objective. For all cases, the higher the score, the greater the risk. Whether a high score is due to a lack of data or to potential physical problems may not be apparent until a detailed investigation of the data used to form the ranking list is undertaken.

The results provided for the ranked lists only provide semi-quantitative information about the disposal basins and should be interpreted in this manner. Further work is required to verify the outcomes of the ranking procedure. Therefore, the lists presented within this report should not be used to make direct comparisons between disposal basins at this early stage. Whilst the ranking criteria and objectives presented here are likely to encompass the most important features of a disposal basin’s performance, it is by no means complete. It is recommended that further work and discussions between interested parties are required to establish and collectively agree upon a more complete set of criteria and objectives that would form the basis for further disposal basin comparisons. An extended or modified form of the methodology developed in this report could then be readily applied to a larger number of disposal basin sites within the Murray-Darling Basin and updated as more data becomes available for the disposal basins.

References

Department of Water Resources, NSW, 1988. Report on stratigraphy and subsurface hydrology of the Wakool-Tullakool Salinity Sub-Surface Drainage Scheme Stage 2 Evaporation Basin.

Evans, R.S., 1989. Saline water disposal options, Bur. Miner. Res., J. Aust. Geol. Geophys., 11, 167-186.

Hostetler, S., and Radke, B., 1995. An inventory of saline water disposal basins, Murray Basin, AGSO Record 94/4, Australian Geological Survey Organisation, Canberra.

Hoxley, G., 1993. Criteria for the Evaluation of Disposal Basins - for discussion purposes. RWC report TN/86/93, February 1993.

Narayan, K.A., and Armstrong, D., 1995. Simulation of groundwater interception at Lake Ranfurly, Victoria, incorporating variable density flow and solute transport, J. Hydrol. ,165, 161-184.

Simmons, C.T., and Narayan, K.A., 1998. Modelling density dependent flow and solute transport at the Lake Tutchewop saline disposal complex, Victoria, Journal of Hydrology, 206(3-4), pp 219-236.

Simmons, C.T., and K.A. Narayan, 1997. Mixed convection processes below a saline disposal basin, J. Hydrol., 194, pp 263-285.

Simmons, C.T., Narayan, K.A., Woods, J.A., and Herczeg, A.L., 2000. Using hydrochemical and numerical modeling approaches to estimate leakage from the Mourquong saline disposal basin, Murray Basin, Australia, Hydrogeology Journal (submitted).

Sinclair Knight Merz, 1998a. Disposal basin database: Results of Field Survey and Revision of Basin Ranking, report prepared for Goulburn Murray Water by Sinclair Knight Merz, April 1998.

Sinclair Knight Merz, 1998b. Disposal basin database: Summary of field investigations 1996/97, report prepared for the Murray Darling Basin Commission by Sinclair Knight Merz, April 1998.

Sinclair Knight Merz, 1995. Girgarre Salinity Control Project, report prepared for Goulburn Murray Water by Sinclair Knight Merz, June 1995.

Woodward-Clyde, 1998. An environmental assessment for expanding the Stockyard Plain disposal basin, report prepared by Woodward-Clyde, September 1998.

Watkins, N., 1991. Loxton salinity mitigation studies, Noora Drainage Disposal Basin regional impact studies: results of a drilling and pump testing programme, March-August 1991, South Australia Engineering and Water Supply Department., EWS 91/24, 5p.

Williams, R.M., 1993. Evaluation of disposal basins by ranking in New South Wales, Department of Water Resources Technical Services Division report, TS 93.024, April 1993.