Salt Lakes in the Western Australian Landscape

with Specific Reference to the Yilgarn and Goldfields Region

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1 Executive Summary

The terminology applied to freshwater wetlands is applicable to saline wetlands. This terminology has been applied to the arid wetlands in the Yilgarn and Goldfields region.

The saline wetlands within the Yilgarn and Goldfields region represent a wide variety of ecosystems. There are geographical trends from the southwest to the northeast due to meteorological conditions that create temporal variations in wetting cycles and climatic extremes. Juxtapositioned over this trend are different land forms that determine the size and to a certain extent salinity of the wetland. Soil types increase the diversity further by influencing the wetting cycle and ionic composition of the brine when the wetland is wet. Little is known about the diversity of saline wetlands types and the associated biological processes.

This report describes some of the main types of wetlands found in these areas and the main threats to those systems. Some examples were given of representative wetlands.

Many of the lakes in the Yilgarn and Goldfields region have either been used for recipients of groundwater discharge, their catchments cleared for agriculture or modified during the construction of infrastructure. These changes are ongoing and often irreversible.

In order to progress the stated objective of preserving a representative set of saline wetlands in the Yilgarn and Goldfields region, the report concluded that the following strategic projects should be completed.

- Develop a regional management plan based on catchment boundaries.
- Develop a classification system for saline wetlands.
- Determine the extent of wetland amendment in the Yilgarn/Goldfields region.

This would take time and further reduction in diversity would result. The following modifications to the licensing of wetland modifications are suggested.

- Develop guidelines for evaluating changes to saline wetlands (eg Coleman and Meney 1998).
- Revise discharge licences to incorporate management objectives with monitoring requirements.
- Reward and encourage reduced impact amendments of wetlands.

2 Preamble

Salt lakes are a dominant and integral feature of the more arid areas of Western Australia. Large tracts of land go through a cycle of being wet for part of the year, and then to either a salt crust or dusty playa as they dry out. The wetting and drying cycle in these areas is not usually predictable by season. Rain events are often episodic and serve as the trigger for a number of biological and physical changes.

Saline wetlands are often viewed as degraded and worthless areas, suitable for filling and rubbish tips. The public's negative perception of saline wetlands has not been helped by the increased salinisation of the agricultural region. On the positive side, saline problems in the agricultural region have raised the awareness of the mechanisms and processes that move salt from one area to another. Subtle changes to the balance of salt and water moving through the inland environment manifest themselves in ways that may have serious social and economic implications. The magnitude of the salt problem has educated managers that there are processes taking place that involve entire catchments and that can not be solved by 'just' studying the localised issue; a catchment or system approach is needed to solve these problems.

Studies of saline areas have shown that they are far from being wastelands. They have intricate relationships with the groundwater and other wetlands within the catchment. Changes in the function of individual saline wetlands may have long term effects on other areas.

As the biology of saline wetlands is studied, it becomes apparent that we have only superficial knowledge of the plants and animals that live in this (to us) seemingly hostile environment. The current knowledge of saline areas is so meagre that even at the present time conspicuous species are being discovered, let alone the biological functions of these hardy species. Most plants on and around saline wetlands demonstrate distinct zonation, and it has been hypothesised that salinity has an important role in this zonation. However, there is no published research to support this and casual observations show that salinity is not the only factor. Hypersaline biology is a poorly studied reservoir of knowledge.

A natural function of all wetlands is to act as conduits returning salts deposited by rainfall, back to the ocean. At times the movement of salts by human standards is slow, and the wetlands often serve as temporary storage or reservoirs of salt. A number of industries use the natural function of saline wetlands to remove salt from a local environment. For example, the mining industries pump saline discharges into salt lakes in the expectation that the discharge will evaporate and seep into the ground water. In a similar fashion agricultural drains terminate in wetlands to speed the movement of salts (accumulated over eons) on their way to the sea.

This report is based on the systems found in the Yilgarn and Goldfields regions of Western Australia. The Yilgarn block is an area of the upper Swan River catchment that is loosely bound by the towns Kellerberrin in the west to half way between Southern Cross and Coolgardie in the east, Mukinbudin to the north and Narembeen to the south (Murphy 1997). The Goldfields region (more correctly the Eastern Goldfields Region) can be loosely described as the area continuing to the east of the Yilgarn region past Laverton and Zanthus to the east, Sandstone to the north, and Norseman to the south. The western section of the Yilgarn block is intensively cropped. Agricultural landuse changes to extensive grazing stations to the east. The agricultural practice mirrors the rainfall gradient, which decreases to the east. The rainfall in the west is about 300mm per annum falling to 200 mm per annum at the eastern boundary of the Goldfields region. The rainfall in the west typically falls in the winter months whereas the rainfall in the east is episodic in nature, with little rain falling in some years. The landform types and biological regions are more accurately described in the Western Australian Museum Supplement Series.

It is thought that the policy of protecting representative wetlands in these regions is well accepted with land managers, however the application of management practices is piece meal and in some cases misdirected. The pressures on saline wetlands will not decrease over time. The wetlands have a capacity to absorb change to a certain degree before losing their current value. However, this is likely to be exceeded within a short time, if it has not already happened. There is a need to manage the changes against the need to use the wetlands. The first step is to understand the processes or the functions of the wetlands, followed by the likely impact of the pressures. Not enough is known about wetland processes to determine the changes that will occur with the ongoing and expanding use of the arid regions of WA. This report will briefly describe pressing issues and suggest strategies for building an approach that will have value in the short term while working towards an integrated management plan that protects both the conservation and commercial value of the saline wetlands in arid Western Australia.

3 Terminology

There are a number of methods of classifying or describing wetlands. It is important that the terms are defined or else confusion or misunderstanding can arise. The following definitions of commonly used terms are not presented as the best definitions, but appropriate for this report.

For the purposes of this report, terminology as described by Claridge (1991) has been used. The following has been copied fairly liberally from his paper. Hill *et al*. (1996) also used this terminology.

Characteristics:
CHARACTERISTICS are those properties of a wetland, which describe the area in the simplest and most objective possible terms.

Benefits:
Characteristics, singly or in combination, give rise to benefits, which may be functions, uses or attributes, of wetlands. Many functions and uses, and some attributes, may be potential (available to be realised in the future) rather than existing at the present.

> **Functions:**
> A FUNCTION is some aspect of a wetland that, potentially or actually, supports or protects a human activity or human property without being used directly. This may be in form of a contribution to the maintenance of existing processes or natural systems.
>
> **Uses:**
> A USE is some direct utilisation of one or more of the characteristics of a wetland. The benefit of a use is gained by people through some actual physical use of the wetland.
>
> **Attributes:**
> An ATTRIBUTE of a wetland is some characteristic or combination of characteristics which does not necessarily provide a function or support a use, but which is valued by a group within society. An example of an attribute is landscape, which may be a combination of such characteristics as size, location in respect of other physical elements, number of vegetation types, and open water area. (esoteric and aesthetic values)

Values:
The VALUE of a function, use or attribute of a wetland is a measure or expression of the worth placed by society on that particular function, use or attribute. Functions, uses and attributes possess, or can be assigned, values.

In accordance with this terminology, this report is primarily concerned with the benefits of saline wetlands. The characteristics of saline wetlands have only been dealt with in a general fashion, whilst the values are far too complex for the scope of this report.

This report also uses the terminology described by Williams (1998) for the period of flooding of salt lakes. Williams (1998) defined a permanent lake as one that is usually flooded. A temporary lake is one that is frequently dry. Temporary lakes are further divided into intermittent lakes that are predicably wet during certain seasons, and episodic lakes that are wet after an episodic event of an unpredictable nature.

Further distinctions between lake types can be made about their discharge characteristics. Namely, lakes that discharge to the sea are termed exorheic lakes whilst closed basin lakes are described as endorheic lakes.

The Yilgarn lakes are typically temporary intermittent exorheic lakes whilst the Goldfields lakes are temporary episodic endorheic lakes.

4 The Benefits of Saline Wetlands

4.1 Wetland Functions

Wetlands are an integral part of the balance between groundwater and surface water. Wetlands act as both groundwater recharge and discharge zones. Wetlands are typically areas of high evaporation because of the large amount of surface water. Saline wetlands function much the same as their freshwater counterparts.

Saline wetlands are areas of unknown biological importance (gene pool, species diversity) with many species in the more arid areas being undescribed. Apart from ethical reasons for maintaining the maximum gene diversity, the advent of gene 'splicing' for commercial advantage makes the monetary value of species able to grow using hypersaline water more tangible.

One of the more important functions of saline wetlands is flood control. In areas where periodic heavy rainfalls occur, wetlands form an important buffer function. Large saline wetlands spend much of the time empty of water but during periods of heavy rainfall they store extensive amounts of water. The large surface area means that the mass of water evaporated is also large, as is the amount of brine seeped into the ground water. Saline wetlands serve the useful function of conduits for the movement of salts back to the ocean, either via surface or groundwater flows.

Most wetlands are areas of low water velocity. The low water velocity allows for the sediment in catchment runoff to be contained and not relocated further down the drainage system.

Saline wetlands modify the local climate in a number of ways. The microclimate is stabilised by large water bodies due to the high latent energy capacity of water. When a salt lake has dried to a salt crust, much of the solar energy is reflected creating a different microclimate.

4.2 Wetland Uses

Wetlands commonly act as reservoirs for salts- mostly sodium chloride, magnesium chloride and magnesium sulphate. Several lakes in the Yilgarn area are mined for sodium chloride. There is a possibility that some lakes would have commercial reserves of potassium salts.

There are a number of recreational uses for saline wetlands. The more obvious include the following:

- Sailing, windsurfing
- Motocross
- Prospecting
- Speed attempts
- Bird watching

Wetlands act as reservoirs for groundwater discharge. The discharge, once in the wetland may be evaporated, as is the case in many arid wetlands, transported through the surface drainage system and/or recharges the groundwater. Either way, saline wetlands act as important sinks for the increasingly salty groundwater in the agricultural areas. Mines in the Yilgarn and Goldfields region often intersect saline groundwater as part of their operations. The brine must be pumped to the surface and nearby saline wetlands are often used as receiving basins. The brine dissipates as a combination of evaporation, groundwater recharge or surface flow.

Saline wetlands also serve as research and education sites. They are of particular interest for biological studies because of the relatively extreme conditions that most of the endemic species are capable of tolerating.

Some of the saline wetlands are used for scientific reference. Changes in salt levels or flooding frequency are important climatic indicators.

Mineral processing often requires a large amount of water. Freshwater is preferred but saline water from either groundwater or wetlands will suffice.

4.3 Wetland Attributes

Saline wetlands are an important component of the Australian landscape. Conserving a valid representation of the landscape should have a high social priority. Saline wetlands encompass a wide variety of different functions that should be conserved. During the wetting and drying cycle many species of animals take advantage of niches that are not readily available elsewhere. A number of invertebrates are only found during the periodic flooding of some arid wetlands. Many migratory birds use the arid wetlands to sustain them as they move from one area to another. Chapman and Lane (1997) found in their survey of Western Australian wetlands that some freshwater wetlands supported more avifauna species (but not individuals) than saline wetlands, but the saline wetlands supported greater numbers of certain species.

Episodic flooding of the wetlands is unpredictable, but even so the events can be important in the breeding cycle of many animals. An example of this would the flooding of the central Australian salt lakes earlier this decade where large numbers of birds bred.

To many people the vast vistas of the saline wetlands induce a sense of wilderness. This is readily demonstrated by the numbers of tourists visiting the more arid areas of Australia. Large vistas across salt lakes have a visual impact. A classical case is the sunset view of Island Lagoon on the Stuart Highway, SA where an extensive area of white lake against a green and red backdrop unfolds as the traveller traves along the road. For many tourists this is an unforgettable sight.

The saline wetlands in the more arid regions of Western Australia are a source of many previously undescribed species. There are several species found in the Yilgarn/Goldfields region that numbers only a few dozen individuals worldwide. The need to preserve the existing gene pool is important to many people for esoteric reasons. There are also many functional reasons with a commercial benefit for preserving the gene pool.

Figure 1 Shield shrimp (*Triops australiensis australiensis*)

5 Saline Wetlands in the Yilgarn and Goldfields Region

5.1 Characteristics of Saline Wetlands in the Yilgarn and Goldfields Region

Most characteristics of wetlands can be described in purely hydrological terms. That is, notions of catchment, run off coefficients, gradients, transmissivity and permeability of the playa can be used to define saline wetlands. These characteristics are useful and provide objective information. However the wetland's composition varies, making measurements of the characters less useful as descriptors. Furthermore, it is often variations from the normal and boundary conditions that provide niches for remarkable biological and chemical events to occur.

Understanding hydrological processes are fundamental to understanding a wetland's characteristics. It is important to appreciate that some unique characteristics of a wetland may not be adequately described by incomplete hydrological data, especially that which is only accurate for one time in one event. For instance, salinity measurements are only useful when compared over a range of events. One off measurements give no indication of how the salinity changes with different rain events, as it is not at all obvious that there is a simple relationship between salinity and the magnitude of a rain event. More may be learnt about the intricate hydrological processes of a wetland by studying the obvious morphological description of a wetland, than predicting the morphology from point source hydrological data from which it is difficult to impart any information. Incomplete hydrological data, which most studies fall into, is best used as descriptors of wetland status than to define processes within the wetlands.

An appreciation of the wetland processes can give a greater understanding of the character of the wetland and intricate hydrological processes than generic hydrological data. Generic hydrological data, while fundamental to any description of a wetland, tends to blur the difference between wetlands by classifying them into groups without similar biological or even physical processes.

It has been my experience that two 'supra' characteristics, wetting cycle and salt balance, best differentiate the wetlands in the Yilgarn/Goldfields region. The concept of wetland hydroperiod may be considered a subset of wetting cycle. Of all the wetland processes studied in the region, these two are the most easily defined and observed. More importantly, a description of salinity balance and wetting cycle will provide enough differentiation between wetlands to classify unique and representative wetlands. There are, of course, no definitive answers to the classification of wetlands. At all times, when evaluating wetlands for classification of type or uniqueness, the presence of an extreme character type should be noted. Characteristics that may be important but have largely been omitted are; soil types and chemical characteristics of the wetland water.

The obvious wetland characteristics that determine the salinity balance and the wetting cycle of a wetland are:

- Evaporation
- Rainfall
- Groundwater discharge
- Groundwater recharge
- Catchment management
- Wetland surface discharge
- Wetland surface recharge (runoff coefficients and catchment size)
- Salinity of the groundwater
- Soil type

Claridge (1991) has a much more expanded list.

These characteristics hold for all wetlands, however the relative importance of some characters is different in the arid regions. The wetting cycle and salt balance is described in more detail in the following sections.

5.1.1 Wetting and Drying Cycle

The wetlands in an arid environment obviously spend more time 'dry' than what is normally envisaged for wetlands. When considering wetlands in arid regions, the concept of changes to the surface wetness of a wetland over time *or* between events is important. The wetting cycle of a wetland is principally a function of runoff into and out of the wetland, evaporation, precipitation, as well as, water discharge and recharge.

The drying/wetting cycle may be seasonal, as it is in the southern and western areas of the Yilgarn/Goldfields area, grading into an episodic cycle where the wet period follows an exceptional wet winter or a tropical influence. Typically the Yilgarn/Goldfields region are influenced by the winter low-pressure systems but the influence is moderated in the northeastern sector of the Yilgarn/Goldfields area. Williams (1998) uses the term 'intermittent' to describe a seasonally predictable wetting cycle, and 'episodic' to describe a non seasonal wetting cycle but which may be event predictable.

Depending on the salinity characteristics of the wetland, the wetlands may either be covered by annual grasses with the occasional Chenopod during the dry period, or at the other extreme, covered with a substantial salt crust. The form a wetland takes when it is 'dry' influences the biology when it is 'wet'. A large amount of humus during the dry implies that the sediment will have a reserve of organic material to produce nitrogen and other nutrients when it is wet. The resulting wetland community will be geared to using these nutrients and will be structured differently than a community with a depleted supply of nutrients or ratio of N:P.

The saline wetlands in the Yilgarn region have a more predominant intermittent (seasonal) flooding and surface discharge component than the Goldfield's wetlands. The larger wetlands in the Goldfields region tend to be very large featureless playas with fringing vegetation dependant on intermittent wetting. The surface area of a single wetland may be in the region of 900 square kilometres. Evaporation and seepage far exceeds the rainfall and runoff. This is the most obvious characteristic of the saline wetlands in the Goldfields/Yilgarn region. The wetting and drying cycle of Lake Carey which has been described in a later section is thought to be typical of the these wetlands. Groundwater discharge and surface discharge are not thought to be prominent processes in these systems.

Associated with the larger wetlands in the Goldfields are much smaller "claypans" or even samphire flats. These are usually slightly elevated behind gypseous or other semiporous dunes, and typically have a lower salinity character. Not much is known about these claypans. It is thought that the wetting cycle mirror's the larger "lakes", but with the subsurface soil becoming drier and being less saline than that of the larger lakes. It is known that the species of flora associated with these smaller pans are often not found in the adjacent larger lakes.

The volume of brine that is evaporated from a wetland versus the volume seeped helps determine the wetland salinity. As a generalisation, it is this process which relates the wetting cycle to the salt balance of a wetland.

5.1.2 Salt Balance

The salt balance in a wetland is made up of salt load and salt concentration. Salt load is the mass of salt within a wetland. The salt concentration is the mass per volume of brine within the wetland. These two concepts are similar but describe two distinct aspects of salt within the environment. For instance, it is possible to increase the salt load within a wetland without increasing the salt concentration. Similarly by changing the water balance it is possible to change the concentration without a significant change in the salt load.

As with the wetting cycle, time is an important determinant of the salinity of a wetland. A playa covered by vegetation during the dry period is likely to have a freshwater to brackish ecosystem while flooded. A salt encrusted playa in the dry period may be brackish to hypersaline during a wet cycle. The wide range of outcomes for a salt encrusted wetland is influenced by the salt load, and the sequence and magnitude of the events during and prior to the wet cycle. It is not immediately obvious what the salinity of a dry period salt encrusted playa may be during its wet cycle. In a later section, Lake Carey is given as an example of unexpected salinity profiles.

A larger component of the salt load is transported by surface flooding to the ocean from the Yilgarn region than the principally groundwater recharge route in the Goldfields. The Yilgarn region has for the large part distinct channels joining salt lake systems. Salt tends to accumulate in these lakes to form a substantial crust on the lakebed or playa. This results in the salt concentration of discharges being less important than the total salt load. The reason for the accumulation of salts is not known but is probably a combination of factors such as catchment size, runoff rates, wetland geomorphology and land management practices. The lakes in the Goldfields rarely have a surface discharge route, and other than in exceptional rain events, the water rarely moves beyond the immediate receiving lake. The major unanswered question is why do the Yilgarn lakes accumulate a large salt load when there is an obvious surface discharge compared to the Goldfields lakes.

5.2 *Existing Pressures and Protecting the Benefits*

A wide range of human activities changes the benefits of wetlands in the Yilagrn/Goldfields region. From my experience the major activities that influence wetlands in decreasing order of magnitude are;

1. Catchment landuse, in particular point source and diffuse release of saline water from agricultural land.
2. Infrastructure such as roads and railways. These are normally of low impact but are permanent interruptions to the landscape.
3. Discharge from mines. Most mines have a limited life but often the discharge is into a relatively pristine environment making the discharge of nutrients, salt and pollutants more sensitive.
4. Mine infrastructure can have a substantial impact over a short time. The problem of mine voids and tailing dumps can be an issue.
5. A recreational use of saline wetlands constitutes a threat mainly to the surrounding vegetation. Most of the vegetation is easily damaged.
6. Mining exploration is a minor but substantial use of saline wetlands but it is mainly over a short non-continuous period.
7. Landfill of saline wetlands hopefully is a minor use of saline wetlands but still occurs on a casual basis mainly on private land.

Discharges and physical changes to saline wetlands have been dealt in more detail in the following sections.

5.2.1 Discharge of Groundwater

Most of the mines in the Yilgarn and Goldfields region are extracting minerals below the groundwater level. As part of their operation, groundwater is pumped to the surface. In most cases the groundwater is saline and in some cases up to eight times seawater (200 g/L). Sometimes the groundwater is used as part of the process, for mine dust control (a risky environmental use) or reinjected into the groundwater table at some distance from the mine site (rare). Most often the water is pumped to a nearby saline lake where it both evaporates and recharges the groundwater.

The discharge from agricultural land is slightly different in that rarely is the groundwater actively pumped to the surface. Salinisation of groundwater in agricultural areas is more diffuse and there is only a point source discharge when drains and such are constructed. Nevertheless, rising groundwater and increasing salinisation of groundwater issuing from agricultural land is a much greater threat to the natural balance of saline lakes than mining discharge. Unfortunately most of the lakes in the agricultural region have already been amended in some manner.

Coleman and Meney in a Report to the Department of Environmental Protection (1998) considered that the following physical descriptors were fundamental mechanisms of a wetland. It was thought that if the following characteristics of a wetland were not significantly changed by a discharge then the biological processes and existing uses of the wetlands would also be protected.

- Hydroperiod
- Salt load

- Salt concentration
- Ionic composition
- pH
- Pollutants
- Nutrients
- Sediment

The list has been slightly modified in this report to include the ‘supra’ characteristics, wetting cycle and salt balance.

5.2.2 Physical Disturbance

Quite often saline wetlands are modified for a use without consideration of the other benefits of wetlands. One of the more obnoxious uses in the past has been to use salt lakes as rubbish tips. The more common uses of saline wetlands that may detract from other benefits are:

- Recreation
- Mining and exploration
- Railway and road construction

Users of saline wetlands often detract from the aesthetic value of the wetlands. The construction of infrastructure, such as mine pits, causeways and roads, significantly change the surface and subsurface hydrology of the wetlands.

The mechanism for the change may be a physical barrier to water movements, compaction of the playa’s subsurface or hydrological ‘wells’ due to pits.

A number of wetland functions could be changed, examples of which would be floodwater retention, salinity and sedimentation. Changes in the hydrology could also change the biological processes taking place within the wetland. Causeways, for instance, often cause a virtual separation of lake basins. The causeways stop the wind from moving low salinity brine to one side. Often much lower salinity brines are found on the windward side of the causeway. The net effect is that the salinity profile across the breadth of the lake caused by density stratification is condensed, making it likely that some species of planktonic organisms lose their low salinity niche. A further problem is that when there are culverts within a causeway, the culverts are often too few and too high up the bank to be effective.

Causeways and pipeworks also provide (feral) predators with easy access to islands or areas that they previously did not frequent. This has caused the demise of populations of small animals in some cases.

The process of constructing infrastructure may disturb the breeding cycle of animals, such as birds.

Figure 2 Constuction of causeway across salt lake changing water flow pattern

6 Examples of Wetland Characteristics in the Yilgarn/Goldfields Region

6.1 Lake Polaris/Koorkoordine

Lakes in this part of the Yilgarn region are in the upper catchment of the Avon River and are often joined by an ill-defined watercourse. Lake Polaris and Lake Koorkoordine are two examples of typical wheatbelt lakes. The two lakes are discussed together as the boundary between the more northern Lake Koorkoordine and Lake Polaris is not well defined.

The upper part of Lake Polaris forms a watercourse for the lower regions and Lake Koorkoordine during winter and small flood events. Some ponding or intermittent flooding occurs every winter. The surrounding samphire flats are obviously saturated during winter (tyre marks, bog holes etc). During episodic events such as floods, Lake Polaris is a lake discharging water towards the north to Lake Koorkoordine and then Lake Deborah. Finally the water floods down through the wheat belt to the Avon River, via the Mortlock River. According to local anecdotal evidence (N Eiffler, Shire of Yilgarn) six flood events have occurred in the last thirty years that have resulted in flood water (and salt) moving from Lake Koorkoordine to Lake Deborah, and in some cases further. The 1978 flood was a significant event and it was rated at 320 m^3/second at its peak.

One geographical trend is that the wetlands to the west tend to form surface conduits for their catchments, whereas the arid wetlands form groundwater recharge zones, albeit the flows are much smaller.

Lake Polaris has an estimated area of 30ha and Lake Koorkoordine has an estimated area of in excess of 450 ha. The Mains Roads Department has estimated that the catchment for Lake Polaris is in the region of 1207 km^2.

The peak flow for a one in twenty year flood is 300 m^3/sec and the peak flow for a one in 50-year flood is 410 m^3/sec. Summer flow down the lake/creek bed is negligible unless there is a significant rain event in the catchment. The major flood events are often in the summer when a tropical rain depression or cyclone extends into the area. The flow for any one month is often nil.

Closer to the salt lakes, the vegetation gradually changes from mallee eucalypt forest to more salt tolerant species. The shrubland species closer to the salt are typically from the genera *Halosarcia, Atriplex* and *Maireana*. Grasses and annuals are common in all height profiles.

The salt crust in Lake Koorkoordine has not been measured but judging by the ability to take light vehicular traffic in some areas during summer it may be up to 20 centimetres in depth. Lake Polaris does not have a significant salt crust.

Both lakes are hypersaline. Lake Koorkoordine is probably hypersaline at all times whereas Lake Polaris in the upper regions, at least, becomes brackish to freshwater during high rainfall events.

The Lakes act as a conduit for salt moving down the surface drainage system to the sea. There is a cycle of the salt accumulating in the lakes, precipitating as evaporation takes effect and then redissolving with the next rain event. This may happen a number of times before a major event whereupon massive amounts of water and salt are moved further down the catchment. There will always be a consistent movement of hypersaline brine moving through the drainage system beneath the surface.

6.1.1 Analysis of Lakes Polaris and Koorkoordine

Wetting Cycle

The two Lakes are primarily evaporation areas for water from surface and groundwater discharge. During high rainfall events, they form part of the Avon River system, moving both water and salt towards the coast.

Seepage is a major factor in the movement of water, but is secondary to evaporation and perhaps to the flow further down the system. (This information was provided by modelling the mass balances for the Lakes but has not been included in this report.)

There is some indication of wicking of moisture from the Lakes to the edges, particularly on the eastern edge of Lake Koorkoordine.

Salt Balance

The salt load is not critical in Lake Koorkoordine except for the effect on the physical depth of salt on the floor of the Lake and causing local flooding. Salt concentration is less important in Lake Koorkoordine due to the existing high concentrations. Basically, both Lakes, in particular Koorkoordine, are insensitive to additional discharge pressures due to the existing high levels of salt in the system. Lake Koorkoordine would always have been hypersaline as it forms a natural conduit for surface and groundwater discharge to move further down the system. Therefore salt balance is not as important for this wetland system depending on the discharge volume and quantity.

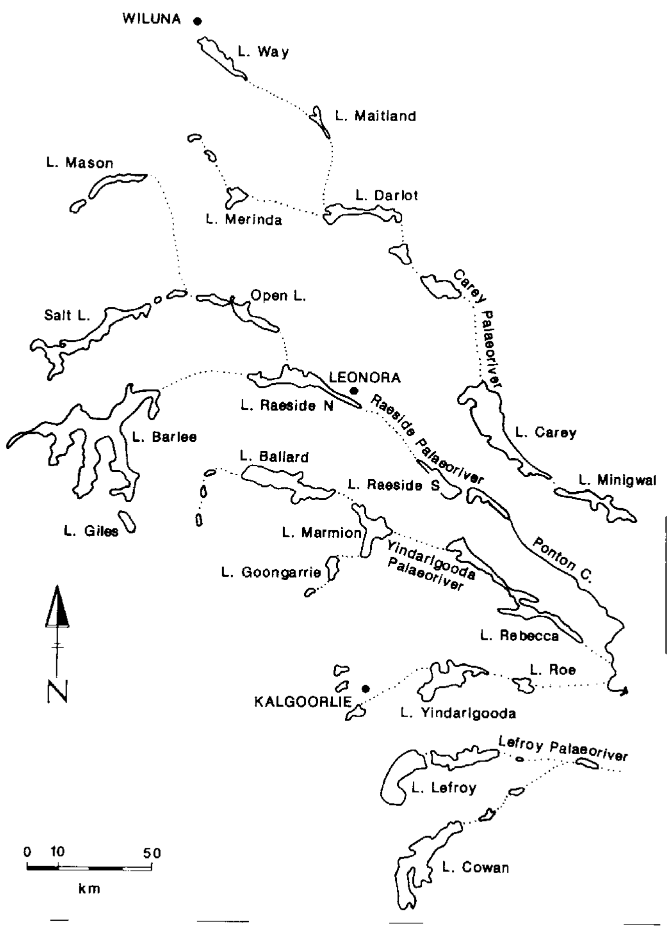
The sensitivity of the system to discharge from mining and agriculture is based on the analysis of what would be the effect of a greater flow through the conduit. The wetting cycle is the major factor in this system. In particular, the hydroperiod for fringing vegetation and the potential of local flooding.

6.2 Lake Carey

Lake Carey is one lake in a chain of lakes that follow an ancient drainage basin called the Carey Paleoriver (Timms (1992),Figure 3). The Carey Paleoriver is one of five parallel paleodrainage systems that drain eventually into The Great Australian Bight. The area containing these systems is known as Salinaland and stretches roughly between Wiluna and Kalgoorlie. The lakes above these ancient drainage systems are slowly moving westward, with the westward ends being deflated by wind erosion, and the resulting sand accumulating at the eastern end. The lakes may not be directly over the paleorivers due to their wind-generated migration. Timms (1992) stated that the floor of these lakes may be solid rock and sometimes covered with fine silt.

Sampling pits dug into the floor of Lake Carey have generally given the profile of fine silt, changing to clay at a depth of approximately 30 cm, intersected by ‘pipes’ of gravel made principally of gypsum crystals. There is often a bed of coarse gypsum crystals at an approximate depth of 50 cm.

Figure 3 Lake Carey Paleoriver and Salinaland (Timms 1992)



Paleorivers in Salinaland- Goldfields

The surface area of Lake Carey has been estimated as being 750km^2 with an internally draining catchment of 9 000 km^2 (Golder Associates pers. comm.). Other estimates place the Lake's area as 9 800 km^2 but the difference is attributed to the multitude of islands within the Lake. The islands would significantly reduce the volume of the Lake but not the catchment area.

There is no known study of Lake Carey, but the more southern Lake Lefroy near Kambalda is better known. Chlorine isotopes in groundwater from the Roe paleodrainage at Kalgoorlie (Commander et al, 1991) indicate that there are two distinct brines. The old brines from the palaeodrainage and younger surface-derived brines with some mixing between the two. Clarke (1994) has provided a synthesis of the work on Lake Lefroy and it can be reasonably expected that the same processes happen at Lake Carey unless there is evidence to the contrary.

Some of the low lying islands within Lake Carey are capped with a gypsum crust several meters thick that shows signs of being formed beneath a shallow sea. The presence of what superficially looks like hard aggregates of sponge spicules (Golder personal communication and personal observation) further supports the view that a large saline water body covered the area in the past. The floor of the present day Lake Carey is made of elastic clay. The transmissivity of the elastic clay surface is not expected to be high. The surface of the Lake contains very little organic matter, although in some locations there is a thin layer of black sediment beneath the surface indicating decomposition of organic material. The Lake bed, however, is not homogenous as in some places the surface seems to be very hard, whilst in others the surface is soft and puggy. For instance, in an area to the south of Angel Fish Island, the surface of the Lake is particularly soft indicating perhaps a groundwater discharge zone. Small 'pipes' of large gypsum crystals allow for rapid lateral movement of brine beneath the surface.

On top of the playa of clay forming the lake surface are a number of islands. It would appear that some of these islands are historical artifacts of sedimentary layers usually associated with outcrops that have not eroded. At the base of these islands are alluvial/colluvial dunes, typically sickle shaped with the concurve side to the northwest. The orientation of these dunes is due to the prevailing winds during wet periods. These dunes on the Lake and along the shores are typically coarse grained and appear to have a high gypsum content. The deposits and the playa surface are quite distinct and discrete.

There is no vegetation on the Lake surface. Vegetation appears in the dune zone along the boundaries of the Lake. A species list for the border of Lake Carey would include:- *Halosarcia peltata, H. undulata* 'Nigracauda'*, H. indica ssp bidens, H. undulata, H. calyptrata, H. halocnemoides ssp halocnemoides,* and *H.* 'Angelfish Island'. The latter is a previously undescribed species and has only been found at Lake Carey. There is typically a definite zonation of the Halosarcia species along the fringe of the saline lakes.

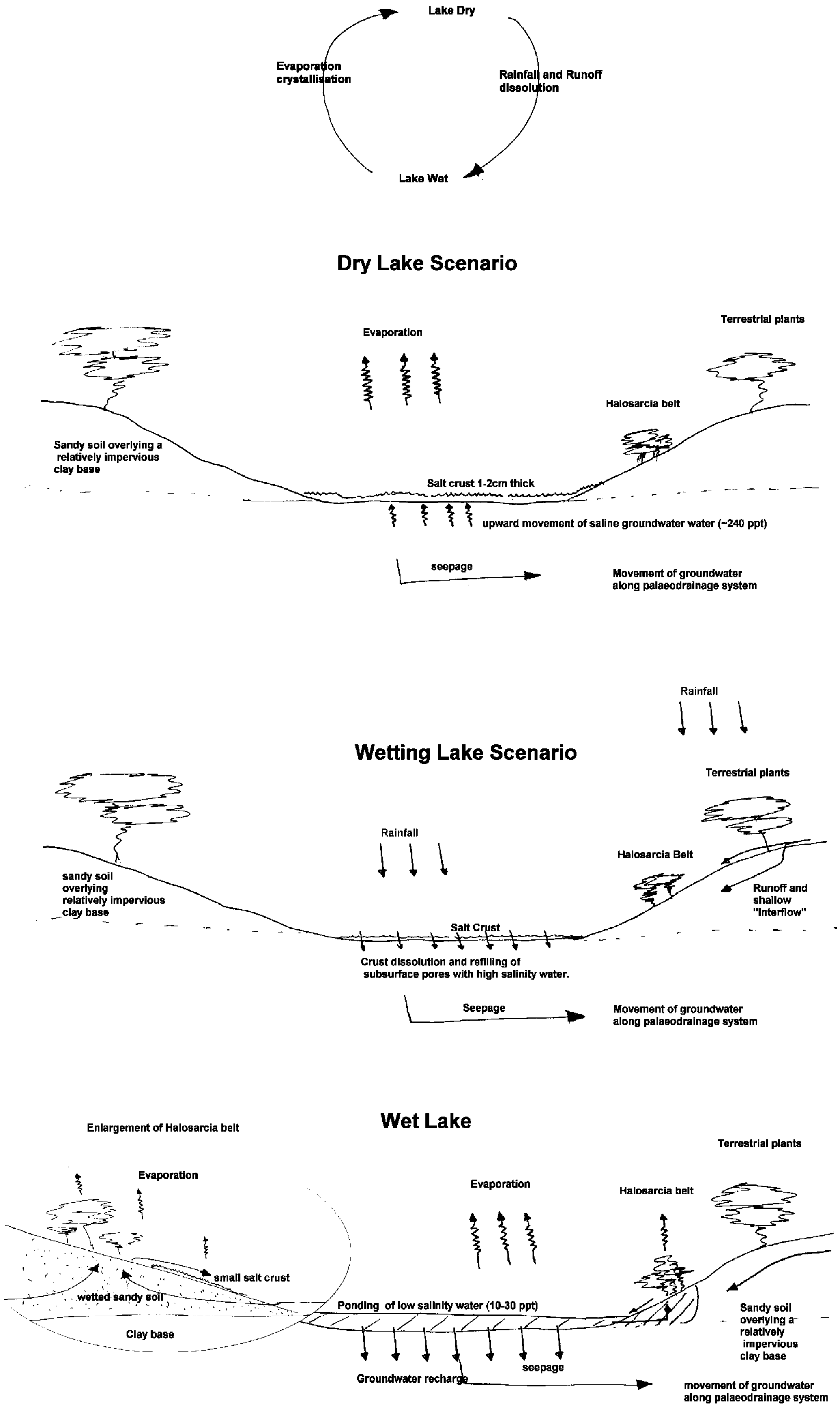
6.2.1 Analysis of Lake Carey

Wetting Cycle

Seepage is a major factor in the movement of water and salt in Lake Carey. There is no obvious surface discharge to another system and all brine lost to it must either evaporate or seep from the Lake. The ionic composition of the surface water compared to the groundwater (50m) indicates that the Lake acts as a "seepage basin". The surface water has a much higher proportion of the less soluble ions such as calcium, whereas the deeper water has a larger proportion of magnesium ions. The salts that would have accumulated over the years in these arid areas have been concentrated below the surface of the lake playas. The saline wetlands serve as salt sinks for arid regions that would have otherwise not have a mechanism to complete the recycling of salt back to the ocean. In other wetter regions the surface flow is the vehicle for returning salts whereas in the Goldfield's region the groundwater is the vehicle. The mechanism is only suitable for minor amounts of water and salt. If the wetlands are used in excess as repositories for saline groundwater it is possible that there will be an accumulation of salts on the surface and the existing ecology will be stressed and organisms displaced.

The movement of Lake Carey's surface water and salts in relationship to evaporation, seepage and precipitation has been hypothesised in Figure 4. Briefly, the Lake dries, forming a crust of salt that accumulates throughout the dry period. Subsequent rainfall dissolves the salt, recharging the subsurface zone and creating a virtual stratification of high salinity brine beneath the surface and lower salinity ponding on the surface.

Figure 4 Lake Carey wetting cycle



Salt Balance

The Lake is not hypersaline for all stages of its wetting cycle. At times the Lake is covered by brine that has a much lower salinity than seawater. Because the Lake's floor is flat and typically covered by small pools of water, the phenomena of salinity pockets frequently occur. The occurrence of low salinity 'cells' within the Lake on a frequent basis has allowed the development of freshwater biota in what is often thought of as a saline wetland. This would not have occurred if the salt load and concentration were homogenous across the Lake.

Figure 5 Wet zone on Lake Carey's edge (tape measure showing 1 metre)

It was noticed that the *Halosarcia* belt along the fringe of the Lake was in a zone of saturated sandy alluvial soil as distinct from the clay lakebed (Figure 5). As evaporation took place, salts accumulated on the surface of the soil between the Lake playa and the *Halosarcia* belt. The *Halosarcia* zone is located by its relationship to the Lake. Changes to the depth of brine and salt loading in the Lake may impact on the *Halosarcia*. As will changes in the salinity of the brine immediately adjacent to the vegetation fringe.

Lake Carey is the recipient of discharge water from various mines. The discharge makes use of the Lake's capability of removing surface water and salts to the groundwater aquifer. There is potential for the Lake to be used in this fashion without detracting from the natural functions of the Lake. A change in hydroperiod is not an issue for small discharges into this Lake because the evaporation and seepage far exceed the current discharge rate into the Lake. The main danger to the natural functions within the Lake is that the discharges will increase the salinity of the Lake's water during small and minor floods.

6.3 Claypans

Claypans appear to be smaller versions of the lake system with which they are in close proximity. Claypans are often very active biologically and provide unique habitats for some plants and animals.

Figure 6 Claypan with rare *Halosarcia chartaceae* found only on a small number of claypans in the Goldfields

Typically, claypans are elevated above the nearby lakes creating a hydraulic gradient. Therefore the claypans typically have a lower salinity and perhaps a shorter period when they are wet. Some claypans have a hypersaline region but in general have a lower salt load and concentration than the nearby systems.

Because claypans are flat and relatively impervious compared to the surrounding soils they are normally wetter than the surrounding soil. Salt tolerant grasses often grow prolifically in these areas providing a good source of food for macropods and other animals.

Unfortunately claypans are often the site for rubbish dumping, recreational car and bike driving and discharges from mines and agricultural areas. These uses are largely inappropriate for vegetated claypans and their limited area makes them easy to overwhelm by a single user. A single discharge can change the wetting cycle and contribute enough salt to change the loading and concentration.

Claypans are isolated, often unique. A handful of claypans might have the only representatives of a species of samphire found no where else in the world. These claypans are small in comparison to their lower and more saline companion lakes, often only 100 metres or so across. Claypans often reflect the vegetation on their companion lakes, but just as often have evolved an entirely different suite of plants of their own. Claypans are vulnerable because of their size. They also form small niches for organisms. As a general rule, clay pans should be preserved and not used for discharge or infrastructure

7 Management of Saline Wetlands

7.1 Threats to saline wetlands in the arid regions

The main threats to saline wetlands are changes to the catchment, physical changes to the wetlands, and increased discharge from mining and agriculture into wetlands.

- Catchment planning is occurring in most agricultural areas although it is not as common in the Goldfields region. Adverse catchment changes on a large scale are not a new threat to the saline wetlands. Historical changes due to clearing will continue to change the balance of salt and water flowing into and out of wetlands. Catchment management and planning should be made a priority. This is especially important since many of the wetlands in the more arid regions are relatively pristine.

- Physical changes to saline wetlands are common, due mainly to mining, road and rail infrastructure. A greater awareness of the dangers and study of the potential impacts need to be completed before changes are made. Seepage is important in the function of arid wetlands and changes to the groundwater movements will have a massive impact on the wetting and drying cycle. Horizontal and vertical stratification of brines is an important provider of niches in arid saline wetlands.

- Discharges to saline wetlands are common and have a significant impact on saline wetlands. Some discharges have a diffuse source such as increased groundwater discharge due to rising groundwater levels in agricultural areas. Others are readily identifiable such as discharges from deep drainage and mine dewatering. The first priority should be to decide whether the discharge is going to have a significant impact, before going into a process of evaluating values (eg Hill, Semeniuk, Semeniuk, Del Marco p128). It is important that administrative procedures don’t treat discharges as point source pollutants and consider wetlands as part of catchments.

Saline wetlands are an important aspect of our natural heritage and there are many benefits to be gained by maintaining a representative range of arid wetlands. It is obvious that some practices to do with saline wetlands are clearly wasteful. These practices have been the result of ignorance of the functions of wetlands and sometimes oblivion to the value of the arid zone saline wetland’s uses and attributes.

The wetlands in the Yilgarn area have already been changed significantly, particularly in the western region. The extent of change in the Goldfields region is unknown but clearly significant.

7.2 Management objectives

Saline wetlands in the Yilgarn and Goldfields regions represent a range of wetting cycles and salinities. Changes in the balance of evaporation, seepage and overland flows can create valuable ecological niches within wetlands. Geddes *et al*.(1981) noted that the Western Australian lakes had equal or greater fauna species diversity than their eastern state counterparts. This variation is seen as an asset to the natural heritage of Western Australia. The variation however makes it difficult to artificially partition wetlands into discrete groups.

A primary management objective should be to preserve 'adequate' representation of the range of wetlands found in the arid regions of Western Australia.

It is difficult to achieve this objective because there is a sparsity of knowledge of the characters, functions and attributes of these wetlands. More is known about the uses. Without this knowledge, it is difficult to determine what is the range of wetlands and what is an 'adequate' representation that needs to be preserved.

The objective can only be achieved by a concerted effort to define the range of wetland types in the Yilgarn/Goldfields region and broadly grouping them into representative types. A regional approach is needed.

7.3 Management strategies

- Develop a regional management plan based on catchment boundaries.

    A regional catchment plan would enable a much broader understanding of the changes happening to the wetland and serve as a collection point for information. At present, evaluation of discharges and other changes to saline wetlands does not specifically evaluate other changes to the wetlands before or after the proposed amendment. Some of the larger wetlands may have a number of resource developments and public infrastructure constructions occurring at the same time, and evaluating point source pollutants underestimates the total change to the wetland. A regional approach to developments would be more accurate in predicting the changes to the wetlands by accounting for accumulative impacts <u>and</u> a repository for data collected on the catchment. In the process of evaluating changes to wetlands, much information is collected and archived where it is not referred to again. There are obvious advantages to having this information available to the proponents of the successive developments.

    There is a need for an administrative group to act as a focus for the collection and dissemination of information.

- Develop a classification system for saline wetlands

  Geddes *et al*.(1981) found in their study of the saline wetland fauna in the southern areas of Western Australia that the faunal composition of the wetlands did not seem to be affected by basin size, depth or ephemerality. Ionic composition and pH seemed to be more significant. Salinity and geographical differences seemed to be the major factors in speciation within the wetlands. They grouped their samples into four major geographical areas but the work was not at all definitive.

  It is suggested that a classification model could be developed using wetting cycle and salt balance evaluations. There is information available already to make initial classifications using rainfall and evaporation isohyets, mean and median rainfalls, catchment to water body size and geological maps. The functions described by Coleman and Meney (1998) could be used to determine lake types.

  The final classification could include sensitivity to different types of impacts, which would speed up the process of evaluation.

- Develop guidelines for evaluating changes to saline wetlands.

  An interpretation of what should be evaluated has been described in Appendix 1. Any evaluation of saline wetlands should also include the integration of catchment management objectives and accumulative impacts of other uses of the wetland. The guidelines should lead to a best practice manual for dealing with specific issues such as discharge The evaluation process should demonstrate a knowledge, and appreciation of wetland functions, not just present a set of empirical data. Collation of modelled proposed outcomes with the final realised outcome. This information could be stored with the regional management database so that the evaluation process improves with time.

  Fundamental to the evaluation process should be an appreciation of the role of saline wetlands.

- Revise Discharge Licences

  The most obvious weakness of most licences is that the monitoring program is not part of a management plan. For instance, most mines monitor the discharge religiously but have no contingency plans for 'out of specification' discharges. The quantity, with the possible exception of nutrients, and quality of brine discharged is well documented, but the effects of the discharge on the environment are not well monitored at all. The discharge of brine into natural systems should be within a comprehensive management plan that includes refinable criteria, contingency plans and an appreciation of environmental values that will be impacted.

- Determine the extent of wetland amendment in the Yilgarn/Goldfields region

  Very little is known about the extent of change to the arid saline wetlands. Many wetlands are receiving discharges of one sort or another. Many have been amended by roads, causeways and in some cases mines. An understanding of the extent of change will enable the preservation of saline wetlands to be balanced with resource development.

- Reward and encourage reduced impact amendments of wetlands

  If the conclusion is reached after evaluating the wetland characteristics that there is no major change to the wetting cycle or salt balance, then it is quite conceivable that the amendment will not have a significant impact on the receiving wetland. These discharges should be licensed but not incur a substantial penalty as has been proposed in the past. It is a good management strategy to encourage the selection of appropriate receiving wetlands rather than allowing discharges to wetlands where a significant if local impact is expected.

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9 Appendix 1 Evaluation Guidelines

9.1 Physical Changes

It is important that physical changes to saline wetlands do not change the salt balance or wetting cycle within that wetland as a whole or a part of that wetland.

Poor positioning and not enough culverts in causeways that cross saline wetlands often impact on the processes within that wetland. The culverts are often too few and too high up the bank. The culverts should be at playa level or below to allow flow of water at low flood levels. They should also be easy to maintain so that silt can be removed.

Consideration should be made of the prevailing water movements and the construction of infrastructure should maximise the movement of lake water. The prevailing water movements can be rapidly ascertained by studying the build up of sediment along the banks of the lake. The infrastructure should not be designed only for episodic maximum events but perhaps more importantly, smaller intermediate events as well.

9.2 Discharges to saline wetlands

Discharges appear to be the wetland use that poses the main threat to the integrity and continuity of the saline wetlands in the Yilgarn and Goldfields region. The impact that a discharge may have on a wetland is quite variable and a range of outcomes is possible.

Current studies indicate that changes to salt balance and the wetting cycle are the most significant factors affecting saline wetlands. If it is proposed that a wetland be amended the following wetland characteristics should be evaluated. Obviously not all of the following are relevant to all types of wetland uses, and those that are not relevant should be justifiably omitted.

- *Hydroperiod* is the changes to the surface water of the wetland over time. It is the composition of the evaporation, seepage, runoff and discharge over time. It involves quite complex modelling. It is important to consider seasonal variation when studying hydroperiod.
- *Salt load* is the total salt content of the wetland. It should be modified for seepage and surface discharge.
- *Salt concentration* is the concentration of salt in the wetland and is the combination of the salt load and water load.
- *Ionic composition* is the proportion of ions in the wetland water/brine. This changes quite significantly. The potential for changing composition should be evaluated if additional water is to be discharged into the wetland.
- *pH* is an important measure of chemistry of the wetland water.
- *Pollutants* such as metals and man made chemicals are a real threat to saline wetlands. The potential of these being released should be evaluated. Hydrocarbons are often leaked with discharge water.
- *Nutrients* change the biological composition of the wetlands and if there is to be a marked change in the nutrient concentration the impact should be evaluated. Groundwater from minesites is often contaminated with high levels of nitrogen from sumps at the working faces.
- *Sediment* changes the ability of the receiving wetland to act as a hydraulic buffer. High levels of sediment can change the flooding characteristics and hydroperiod of the wetland.
- *Conservation values* include the presence or potential of endangered species or some special attribute of the wetland that may be affected by changing the use of the wetland. Some species, particularly the animals are difficult to sample and their absence from samples does not mean they are not present.

The first three characteristics are to do with salt balance and wetting cycle, the next four are to ensure that the discharge brine has the same composition as the receiving waters. The eighth factor is to do with increased solids in the watercourse causing changes in flow and increased silting. The evaluation of conservation should be a scan of the species present in the immediate surroundings and if a species has some conservation status a more specific study should be made of its sensitivity to changes to its environment. As more information becomes available it should be possible for saline wetlands to define limits for each factor.

Once these characteristics have been evaluated for individual wetlands it should be possible to make reasonable conclusions about the changes that may be made to the saline wetland.

9.2.1 Evaluation of Discharge Impact

The groundwater in the Yilgarn/Goldfields region is normally well above 50 g/L dissolved salts. The issues for discharge are either an increased hydroperiod or increased salt loading leading to increased salt concentration. The changes that the discharge will make to the wetland need to be evaluated on a seasonal basis and preferably on a monthly period. It is possible to model changes using estimations of evaporation, seepage, runoff and the known discharge characteristics. Percentage variation from normal levels can be calculated giving a reasonable tool for evaluating the magnitude of the change to the wetland. The accuracy of these predictions is always questionable, but by validating the model with similar existing discharges, a reasonable level of confidence can be obtained.

9.2.2 Discharges into large lakes

Saline discharges into very large lakes often superficially satisfy the evaluation criteria for the simple reason that a single point source discharge is unlikely to be significant over the entire lake whatever the quantity. When evaluating large lakes there are two issues to be kept in mind.

1. There may be a number of discharges into the same lake. Two examples where there are multiple discharges into the same large lake would be Lake Carey and Lake Lefroy. There is a real danger that the Lakes will be modified by the aggregate of the discharges where one discharge would not have an effect. It is strongly suggested that discharges into lakes not be considered in isolation. Possibly a two tiered evaluation should be used, looking at the accumulated effects in the first instance and the second, evaluating the effects of a specific discharge.

2. The second issue is to do with seasonal variation. It is important that the effect of a discharge on a wetland not be considered for one point of time or a single flood episode. Often discharges are justified on a large scale event which really has very little relevance to the functions of the wetland.

Again the large arid zone lakes are a good example. During a dry period, a small discharge will contribute salt to the existing salt crust and have very little impact. Most of the brine will seep into the groundwater. During a wet period, a small discharge will have a significant effect on the local area but will not extend to non-continuous areas of the lake. During a medium size event, the discharge will have a significant effect on a large area as the discharged brine elevates the salinity of the wetland water. During a major flood event, very little change will be made to the entire water body. Table 1 below gives a worked example for a small discharge into Lake Carey and demonstrates the variable impact from a small discharge onto a large lake playa. Lake Carey, as well as other lakes, supports an important microenvironment for species living in salinities below 20 g/L during flood events. These species may survive in much higher salinities during the dry period but require the lower salinities to breed and grow. In these types of lakes there is an argument for constraining the discharge from dispersing over the lake playa.

Table 1 Estimated surface area of a flooded Lake Carey affected by a salinity increase of 10g/L under a number of different scenarios including variables such as varying water depths, seepage rates and discharge rates.

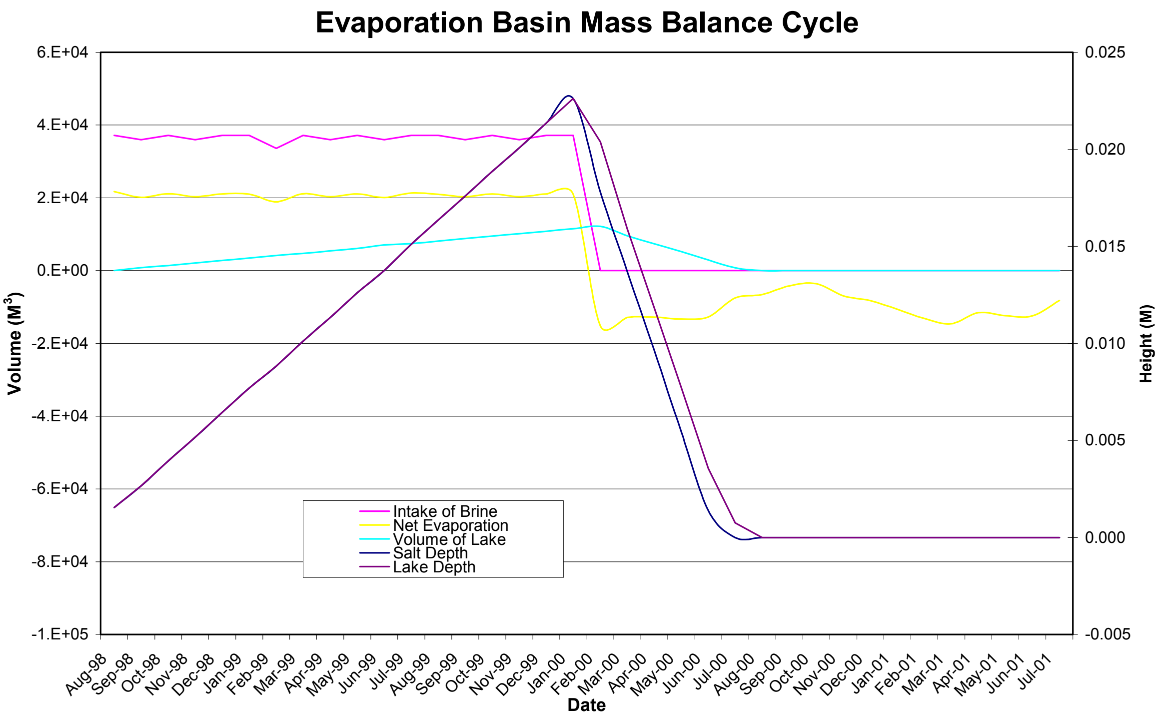
Depth of Lake Water[1] (m)	Volume of Lake Water per Hectare (m3)	Increase[2] in salinity g/L	Tonnes of Salt per hectare	Accumulated Discharged salt on Lake surface[3] (t)	Area[4] Affected	Lake Carey %	Seepage mm/day	Discharge Volume kL/day
0.05	500	10	5	5200	1040	1.4%	0. 5	550
0.1	1000	10	10	5200	520	0.7%	0. 5	550
0.05	500	10	5	16000	3200	4.3%	0. 5	1200
0.1	1000	10	10	16000	1600	2.1%	0. 5	1200
0.05	500	10	5	0	0	0.0%	1.0	550
0.1	1000	10	10	0	0	0.0%	1.0	550
0.05	500	10	5	0	0	0.0%	1.0	1200
0.1	1000	10	10	0	0	0.0%	1.0	1200
1	10000	5	50	16000	320	0.4%	0. 5	1200

[1] Scenario depth
[2] Estimated increase in TDS without major detrimental changes.
[3] This is the tonnes of salt remaining on the surface of Lake Carey after one year of discharge as modelled by this report.
[4] Area of Lake Carey covered by depth (column 1) with elevated TDS (column 3) to absorb discharge tonnes not returned to groundwater (column 5).

9.2.3 Constrained versus Unconstrained Discharge

There are several advantages in discharging brine into a constrained area (eg bunded) within a larger size lake. The main advantage is that whatever the discharge rate or net evaporation, the damage is constrained to a limited area. During rainfall events, the high salinity brine will not meander over the Lake, dictated by the direction of the wind. Depending on the area chosen, salt may gradually accumulate in the bunded area over the life of the mine. However, as soon as the discharge stops, the salt load in the bunded area will decrease due to seepage, and within a reasonable amount of time the recharge will be complete with no or very little accumulated salt. Figure 7 models the change in salt height in the scenario with the higher discharge rate and smallest recharge after eighteen months of discharge and an equal period of no discharge. The model predicts that within 5 months of stopping the discharge, there would be little or no salt load remaining in the Lake. This is a worse case scenario to illustrate a case where uncontrolled discharge would have altered areas of the Lake but when contained, there would be no significant impact on the Lake's function.

Figure 7 Decrease in salt height after eighteen months of discharge within a constrained area[1]



The disadvantage of discharging into a bunded area, is the cost of constructing the bunded area, and of pumping into it. The distance of the pond from the mine site will be dictated in part by the hydrological impact of locating a body of water near the mine site. This may not be a difficulty as the head of water will be very small for the greater part of the year and not significantly different from the Lake itself at any time.

It is not possible to anticipate the length of time permissible for a discharge to remain within a bunded area. However, a discharge pond of an area of 100 ha returns a zero salt load in less than six months. It can be expected that any reasonably constructed banks of a pond will still remain intact after two years of no maintenance.

It is believed that constraining the discharge within a bunded area designed to fail in a flood event has many advantages and should be further investigated.

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[1] discharge 1200kl per day, 100 ha area, seepage 0.5mm/day

9.3 Alternative to discharging

The following is a very brief review of alternative methods of disposing of saline groundwater that has been pumped to the surface. The following are essentially variations of recharging the aquifer.

9.3.1 Active Recharge

This option is where the brine is actively pumped into the groundwater aquifer either the same aquifer it came from or another. This option would cause a mound in the groundwater and it is thought that this option would be the least likely to work and the most likely to cause further problems downstream.

9.3.2 Evaporation and Recharge

Much of the brine that is pumped to the surface is not saturated. If the brine is at seawater concentration it can be concentrated ten times before it reaches saturation for sodium chloride. Evaporation in the areas under discussion is quite high and the effective evaporation is positive for most if not all of the year.

It would be feasible in some circumstances for the brine to pumped to the surface, concentrated on the surface, repumped into the same aquifer and still maintain a cone of depression around the mine. Some mines are effectively doing this already when they pump the brine into a nearby mine void. It sometimes is the most cost effective.

9.3.3 Evaporation and Void Filling

This option is a slightly different version of the previous and may be useful where there is not an already existing void. An evaporation basin can be constructed near the mine, and in many cases this may be 100 hectares in size. The groundwater is pumped into the bunded area for the life of the mine. At the end of the mine's life the bunds are removed and the void backfilled with the salt evaporated from the brine. The void would fill with brine over time dissolving the salt and recharging the groundwater with the dissolved salt. The long term effect on the groundwater would be minimal compared to the existing impact of the void. The costs would be more than the other options but many of the mines are looking at costs of over $500 000 to build a pipeline to a lake where the environmental effects are suspect in any case.