Department of Water

Development of Framework for Assessing the Cumulative Impacts of Dewatering Discharge to Salt Lakes in the Goldfields of Western Australia.

January, 2009

Prepared for Department of Water

This project was funded by Rangelands NRM

Rangelands NRM
Western Australia

Outback Ecology Services
1/71 Troy Terrace
Jolimont WA 6014
Ph: +61 (08) 9388 8799
Fax: +61 (08) 9388 8633
admin@outbackecology.com

Development of Framework for Assessing the Cumulative Impacts of Dewatering Discharge to Salt Lakes in the Goldfields of Western Australia.

Distribution:

Company	Copies	Contact Name
Department of Water	Electronic Copy	Susan Worley

Document Control for Job Number: DOW-SM-0507

Author	Reviewer	Signature	Date of Issue
Stacey Gregory			28/11/08
	Veronica Campagna	VC	24/12/08
	Fiona Taukulis	FT	29/12/08

DISCLAIMER, CONFIDENTIALITY AND COPYRIGHT STATEMENT

This document is confidential. Neither the whole nor any part of this document may be disclosed to any third party without the prior written approval of Outback Ecology and the Department of Water.

Outback Ecology undertook the work, and prepared this document, in accordance with specific instructions from the Department of Water to whom this document is addressed, within the time and budgetary requirements of the Department of Water. The conclusions and recommendations stated in this document are based on those instructions and requirements, and they could change if such instructions and requirements change or are in fact inaccurate or incomplete.

Outback Ecology has prepared this document using data and information supplied to Outback Ecology by the Department of Water and other individuals and organisations, most of whom are referred to in this document. Where possible, throughout the document the source of data used has been identified. Unless stated otherwise, Outback Ecology has not verified such data and information. Outback Ecology does not represent such data and information as true or accurate, and disclaims all liability with respect to the use of such data and information. All parties relying on this document, do so entirely at their own risk in the knowledge that the document was prepared using information that Outback Ecology has not verified.

This document is intended to be read in its entirety, and sections or parts of the document should therefore not be read and relied on out of context.

The conclusions and recommendations contained in this document reflect the professional opinion of Outback Ecology, using the data and information supplied. Outback Ecology has used reasonable care and professional judgment in its interpretation and analysis of the data. The conclusions and recommendations must be considered within the agreed scope of work, and the methodology used to carry out the work, both of which are stated in this document.

This document was intended for the sole use of the Department of Water and only for the use for which it was prepared, which is stated in this document. Any representation in the document is made only to the Department of Water. Outback Ecology disclaims all liability with respect to the use of this document by any third party, and with respect to the use of and reliance upon this document by any party, including the Department of Water for a purpose other than the purpose for which it was prepared.

Outback Ecology has conducted environmental field monitoring and/or testing for the purposes of preparing this document. The type and extent of monitoring and/or testing is described in the document.

On all sites, there exists varying degrees of non-uniformity of the vertical and horizontal soil and water conditions. Because of this non-uniformity, no monitoring, testing or sampling technique can completely eliminate the possibility that the results/samples obtained through monitoring or testing are not entirely representative of the soil and/or groundwater conditions on the site. Any conclusions based on the monitoring and/or testing only serve as an indication of the environmental condition of the site (including the presence or otherwise of contaminants or emissions) at the time of preparing this document.

It should be noted that site conditions, including the exact location, extent and concentration of contaminants, can change with time.

Subject to the limitations imposed by the instructions and requirements of the Department of Water, the monitoring and testing have been undertaken in a professional manner, according to generally-accepted practices and with a degree of skill and care which is ordinarily exercised by reputable environmental consultants in similar circumstances. Outback Ecology makes no other warranty, express or implied.

Table of Contents

List of Figures

List of Tables

Appendices

1.0 INTRODUCTION

Outback Ecology was commissioned by the Department of Water (DoW) to design a framework for consideration of the cumulative impacts of dewatering discharge to salt lakes in the Goldfields of Western Australia. Since the inception of the project in 2007 information relating to the impacts of dewatering discharge has been collated from studies on a number of salt lakes in the region. This information was used to devise a set of matrices for calculating the environmental risk of dewatering discharge to salt lakes. The purpose of this report was to present the risk matrices for dewatering discharge to salt lakes in the Goldfields of Western Australia and provide the justification for the inclusion of certain categories within the calculation.

1.1 West Australian Salt Lakes

The semi-arid zone of Western Australia has one of the highest concentrations of salt lakes on the Australian continent (Gentilli 1979). Most of these are located within a district known as the Salinaland, or the Salt Lake Division (Gentilli 1979; Jutson 1934). Typically, salt lakes are defined as water bodies with a surface water salinity of 3 g/L or greater (Geddes 1981b; Williams 1998b; 2002). They are temporary systems that fill episodically in response to heavy rainfall (Timms *et al.* 2006), with some remaining dry for decades (Roshier *et al.* 2004; Timms 2005). Following inundation, the onset of the drying phase is relatively rapid due to high evaporation rates and surface water may only last for a few months (Timms *et al.* 2006).

The salt lakes of the Goldfields are the surface expressions of an ancient river system (palaeodrainages) that was extensive during the Tertiary Period (Commander 1999; Gentilli 1979). Patterns of drainage are internal (endorheic), associated with closed systems (Williams 1998b). The catchments are characterised by flat playas (salt lakes) in areas of low topographic relief. They are generally shallow when inundated, rarely exceeding a metre in depth (John 1999b).

The lakes are highly variable in terms of water quality, displaying a wide range of salinity, pH, nutrient and metal concentrations over the hydrocycle (filling and drying phases) (Roshier *et al.* 2004). For example, the salinity of surface waters can range from 3 g/L to 300 g/L (OES unpublished data) and although pH is predominantly alkaline (>7.5), much lower values have been recorded (Williams 1998a). Sodium and chloride are the dominant ions, with the cations tending to follow; Na>Mg>Ca>K while for the anions; $Cl>HCO_3>SO_4$ (Hart *et al.* 1986). Nutrient concentrations in the surface waters are often higher in salt lakes compared to freshwater lakes (Hammer 1986). In relation to metal concentrations, there is little published data available for comparison.

The primary producers within the salt lakes are predominantly the cyanobacteria and the algae (mostly green algae and diatoms) (Borowitzka 1981; John 2003a). However, in salinities above 40 g/L only some species of cyanobacteria and diatoms can survive (Bauld 1986b). Because few phytoplankton (free-floating algae) are able to tolerate the fluctuating water and salinity levels that occur in salt lakes, the majority of the algae exist as benthic microbial communities (BMCs) and primary productivity is therefore confined to the surface sediments (Bauld 1986a).

In relation to aquatic fauna, salt lakes in Western Australia display a high level of endemism and species radiation, compared to other salt lakes in Australia (Halse 2001; Hebert *et al.* 2000; Remegio *et al.* 2001). The Crustacea are the dominant invertebrates and in particular the endemic Anostracan *Parartemia* (Geddes 1981a), along with Ostracoda species (Halse 2002; Pinder 2005). Other taxa include representatives from Copepoda and Cladocera. The temporary nature of inland salt lakes in the arid zone of Western Australia has a strong influence on the structure of the biotic community. Aquatic organisms living in unpredictable environments must develop survival mechanisms such as resting stages (desiccation resistant propagules), which allow them to persist during extended dry phases (Caceres 1997). Lake sediments contain the resting stages of invertebrates (eggs), algae (oospores) and higher plants (seeds) collectively referred to as the egg and seed bank. This component of the salt lake ecosystem plays an important role in the recovery of the wetlands during the filling phase (Brock 1998).

The salt lakes of the Goldfields have been the preferred option for the disposal of surplus groundwater (dewatering discharge) produced during mining operations. The lakes are large and flat, providing an expansive surface area for evaporation. Because of the lack of knowledge and understanding of salt lake ecosystems, there was a perception that they were ‘barren’ and that disposal to these lakes was the most ‘environmentally friendly’ option for dewatering discharge.

2.0 METHODS

To meet the requirements of this project, data and information was collated from various sources to determine the extent of dewatering discharge throughout the state. The discharges to the salt lakes were identified using records provided by the Department of Environment and Conservation (DEC) in Kalgoorlie (**Table 1**). The lakes were mapped and the current dewatering discharge locations were identified.

Table 1: Lakes currently receiving dewatering discharge and those previously receiving dewatering discharge.

Current Discharge Lakes	Previous Discharge Lakes
Lake Carey	Kurrawang White Lake
Lake Way	Lake Fore
Lake Raeside	Lake Tee
White Flag Lake	Banker Lake
Lake Lefroy	Southern Star Lake
Lake Cowan	Lake Miranda
Lake Hope North	Lake Austin
Lake Wownaminya	Lake Koorkoordine
Yarra Yarra Lakes	

Three lakes; Lake Carey, Lake Lefroy and White Flag Lake were chosen as study lakes as there was a considerable amount of information available. The monitoring plan and management of each of these lakes was investigated to determine the key factors to be included in the risk matrices.

In addition to information provided during the case studies of each of these lakes, other sources of information included Dewatering Discharge Licence Reports (DDLRs) which were provided to Outback Ecology by the DEC. Once the matrices were established various agencies within both the DEC and DoW provided feedback and suggested changes to streamline the matrices.

3.0 RESULTS AND DISCUSSION

3.1 Impacts of Dewatering Discharge

The impact of dewatering discharge on the salt lake is dependant on the quality and quantity of the water entering the lake. While the quality of discharge may be highly variable throughout the region, the majority of the water being discharged onto lakes within Western Australia is hypersaline (>50 g/L). Therefore the focus of this section is on the impacts of hypersaline discharge to the lake environment.

Dewatering discharge sites generally contain higher concentrations of salts, nutrients and certain metals in both water and sediments compared to ‘natural’ lakes. In this report, ‘natural’ is defined as lakes not receiving discharge or unimpacted sites within the lakes (control sites) (Finucane 2001; Foster 2001; Muir *et al.* 2004). Additionally the surface water pH of lakes that receive discharge varies from that of ‘natural’ lakes, reflecting the pH of the discharge water (Outback Ecology 2008c).

Aquatic biota including algae, invertebrates and water birds can be affected by dewatering discharge (Timms 2005). Biodiversity tends to be lower at dewatering discharge sites (Outback Ecology 2008a), attributed to unfavourable conditions such as high flow rates, erosion and extreme salinity. While specific groups of biota, such as algae and invertebrates (URS 2003), have been studied in relation to dewatering discharge, investigations into the impact of dewatering discharge on all levels of the food chain at one time are limited to unpublished dissertations (Campagna 2007) or company reports. It is likely that impacts to the primary producers (including cyanobacteria and algae) may have implications further up the food chain (Boulton *et al.* 1999), although this has not been the focus of studies in the Goldfields of Western Australia.

In addition to the impacts on the lifecycles of the resident biota, a salt crust can form in the immediate vicinity of the discharge outfall as a result of the evaporation of discharge water (Outback Ecology 2007; 2008a). Generally the salt crust dissipates when the lake is inundated, resulting in higher salinity in the overlying surface water. In some cases, the salt crusts are so thick that rainfall does little to dissipate them. Thick salt crusts in conjunction with excessive salinity concentrations may prevent the invertebrate egg bank from hatching during inundation (Campagna 2007; Timms 2005).

If lake margins are flooded by dewatering discharge, or if the soil becomes saturated due to elevated water levels, the likelihood of impact to riparian vegetation is greatly increased (Foster

2001; Outback Ecology 2007). This is related to the combined effects of extreme salinity and waterlogging, which most species have a limited capacity to tolerate. Even *Halosarcia* species which have some tolerance to waterlogging and salinity (Datson 2002; English 2004), have shown decreased vigour and health at sites impacted by dewatering discharge (Datson 2006; Foster 2001).

A change in the length of hydrocycle is common in salt lakes receiving dewatering discharge (Finucane 2001). Generally the wet cycle is prolonged, with the input of discharge water resulting in permanent localised flooding. This can have implications for biota that are adapted to temporary systems, with the potential for native species to be out-competed (Bunn *et al.* 2002; Timms 2005).

Localised erosion of the beach and playa zones is common at some dewatering discharge sites (Finucane 2001), although this is largely dependant on discharge design. Traditionally, discharge water has been released via a pipe onto the lake bed. This has resulted in erosion of the sediments and in some cases the surrounding dunes as the pipes tend to move during flooding. Recently however, rock mulching has become a common practice and, along with more effective trench designs, has ameliorated some of the impacts caused by erosion.

In some cases dewatering discharge can contain a high concentration of suspended solids in the water column. This increases the turbidity of the water and can have serious implications for the biota. Increased turbidity can hamper photosynthesis and contribute to reduced dissolved oxygen levels (Boulton *et al.* 1999). In addition, suspended solids can also contain contaminants such as heavy metals, which may adversely influence ecosystem function.

While not directly related to dewatering discharge, dewatering of a mine void in the vicinity of a salt lake can also have indirect impacts on the playa. Dewatering of the pit can result in a cone of depression, lowering groundwater levels. When this occurs, sediments can become less cohesive, exposing the lake to aeolian erosion and transporting salts into the riparian vegetation.

3.2 Cumulative Impacts of Dewatering Discharge

Currently there are nine dewatering discharges to salt lakes in the Goldfields of Western Australia. To date, the cumulative impacts of these discharges have been minimal. It is likely that the cumulative effects of dewatering discharge would become more pronounced if there was a considerable increase in the amount of discharges that occurred within the region. Cumulative impacts that may be expected include reduced biodiversity. In the case where there have been numerous discharges that occur to one lake, the cumulative impacts at a smaller scale (rather than a regional scale) are generally more pronounced as the effects of dewatering discharge are combined, with the lakes being closed systems.

3.3 Factors Amplifying Dewatering Discharge Impacts

There are several factors which can amplify the effects of dewatering discharge including the local geology, hydrology, hydrogeology, site morphology and topography, anthropogenic structures and climate of the area.

3.3.1 Geology

Ultimately the extent of the impact of dewatering discharge on the environment is controlled by the local geology within the mining void (Foster 2004). This determines the quality and quantity of water being discharged, and whether any parameters are likely to be elevated and result in impacts on aquatic biota. In addition, the quantity of water can influence the impact of the dewatering discharge. For example, those lakes that are filled to capacity by discharge water are likely to display a greater impact than lakes with only sections disturbed.

3.3.2 Hydrology and Hydrogeology

The dewatering discharge tends to be contained in the area of discharge when the lakes are dry (Gregory 2007; van Etten 2004). This is related to the lack of surface water available to disperse the discharge water throughout the lake. During filling events, the discharge is diluted, although the degree to which this occurs is dependant on the volume of water in the lake. In smaller lakes, there is less dispersal and flooding of the riparian zone may occur (Foster 2004). This can result in the death of fringing vegetation, potentially impacting the entire lake. In larger lakes during considerable rainfall, discharge water may be diluted and dispersed throughout the lake to the extent that effects are negligible.

The hydrogeology of the area will also affect the level of impact from dewatering discharge. Those sites with porous sediments will tend to show minimal impacts with materials moving quickly into the sub-surface (Outback Ecology 2008c). In contrast those sites with impermeable sediments may accumulate the constituents of the discharge water. In these circumstances it is possible that constituents will spread throughout the lake on filling, rather than move into the sub-surface.

3.3.3 Morphology and Topography

Site morphology and topography is important in considering the impacts of dewatering discharge. It has been found that embayments and low-lying areas in natural lakes tend to be the most productive in terms of biota (Outback Ecology 2006; 2008c). However, if embayments are used as the point of discharge, it is more likely that the discharge will be contained within the area. Dewatering discharge within the vicinity of a creekline (or freshwater input) can result in flushing of sediments into the lake after rainfall events. Backflow along creeklines has also been known to occur when the creeks are not flowing (Outback Ecology 2008a).

Vegetation on low-lying lake margins, including dunes, are generally worst affected either by flooding with dewatering discharge, sub-surface movement of water into the dune zone or the deposition of wind-blown salt onto the dunes (Foster 2004; Outback Ecology 2008b). Those sites with rocky margins, or steep dunes tend to display less impact than the low-lying sites (Outback Ecology 2007). However, it should be noted that these types of areas are generally not common at salt lakes from the Goldfields.

3.3.4 Anthropogenic Influences

The construction of causeways, tailings storage facilities and exploration pads on the lake can contribute to the impact of dewatering discharge, with some mining activities also resulting in the compaction of lake sediments. Causeways partition lakes, potentially inhibiting flow and restricting the movement of biota throughout the lake (Timms 2005). Structures such as tailings storage facilities situated along the shoreline can lead to the leaching of contaminants onto the lake, which has been observed at Lake Miranda (Finucane 2001) and Lake Yindarlgooda (Campagna 2007).

3.3.5 Climate

The climate of the area can influence the impact of dewatering discharge for a given lake. The occurrence of large rainfall events can contribute greatly to ameliorating the impacts of dewatering discharge by dissolving salt crusts and flushing contaminants from the discharge site. Rainfall aids in the dilution and movement of materials into the sub-surface. These trends were observed at Lake Carey during a considerable filling event in 2004, with sites impacted by dewatering discharge displaying characteristics similar to unimpacted parts of the lake (Outback Ecology 2004).

3.4 Recovery of Lakes from Impacts

Although the impacts of dewatering discharge can be significant it appears that there is potential for the lake systems to recover. Lakes that have been shown to be recovering from the impact of dewatering discharge within the Goldfields include Kurrawang White Lake, Lake Miranda, Lake Austin, Banker Lake, Lake Koorkoordine, Lake Fore, Lake Tee, Southern Star Lake and sections of Lake Carey (Gregory 2007) (**Table 1**). However, with the exception of Lake Miranda, there is little information available on the condition of the lakes prior to dewatering discharge.

Comprehensive baseline studies were conducted at Lake Miranda prior to the commencement of discharge. Approximately two years after discharge ceased, concentrations of salinity, pH, nutrients, chlorophyll *a* and cyanide were all within the range of values collected during the baseline monitoring period. However, the concentrations of some metals remained elevated above baseline conditions indicating some residual impact (Finucane *et al.* 2003).

Outback Ecology has monitored the recovery of Kurrawang White Lake, Banker Lake and sections of Lake Carey following the cessation of dewatering discharge. While the period of discharge and the length of time since active discharge were not consistent, some common trends were observed. Salt loads and salt crusts at these lakes have decreased over time, as have concentrations of some metals. Aquatic biota present in surface waters have not been monitored at these lakes due to the lack of filling events, however diatom productivity (including diversity and abundance) has increased over time, indicating the potential recovery of this group of algae. Recovery also appears to be aided by larger rainfall events leading to dispersion and dilution of the discharge (Outback Ecology 2006; 2007; 2008c). It should be noted however the condition of these particular lakes prior to discharge were unknown, and recovery is in relation to the conditions recorded during discharge.

3.5 Calculating the Risk of Dewatering Discharge

Once the impacts of dewatering discharge were quantified, two matrices were devised to measure the risk to the salt lakes from the dewatering discharge process. Both matrices consider the impacts of the operations from a regional and individual lake perspective.

3.6 Original Lake Status Matrix

The objective of this matrix is to determine the status and condition of the lake prior to the commencement of dewatering discharge (**Table 2**). This matrix assesses the level of information currently available on the lake including the portion of the lake already influenced by other operations and the lake size. Also, consideration is given to the uniqueness of the lake, using the physical and biological characteristics to identify if the lake is distinct in comparison to other lakes.

Table 2: Matrix proposed to determine the original status of the lake prior to dewatering discharge.

Cumulative % of Lake Impacted	Score	Lake Size	Score	Unique Physical Conditions	Score	Unique Biological Conditions	Score	Information Collected					
								Water Regime	Score	Water/Sed Quality	Score	Biota	Score
> 80 %	60	> 500 km^2	1	No	1	No	1	Comprehensive studies completed	1	Comprehensive studies completed	1	Comprehensive studies completed	1
31 - 80%	40	100 km^2 - 500 km^2	40	Yes	100	Yes	100	Basic studies completed	5	Basic studies completed	5	Basic studies completed	5
1 - 30%	60	10 - 100 km^2	60	Insufficient Information	100	Insufficient Information	100	No studies completed	20	Oppurtunisitc study completed	10	Oppurtunisitc study completed	10
0%	80	< 10 km^2	80							No studies completed	20	No studies completed	20

3.6.1 Cumulative Percentage of Lake Impacted

There are four options to select within this category depending on the proportion of the lake showing impact from external sources; *0 %, 1-30 %, 31-80 %* and *>80 %*. Cumulative impacts are considered within this category and may include other dewatering discharges, mining infrastructure and recreational or pastoral activities. Generally, the highest scores are given to those lakes which have not been previously impacted by external sources. However, a high score is also given to a lake which is almost entirely impacted (i.e. >80 %).

3.6.2 Lake Size

Within this category scores are allocated dependent on the size of the lake (i.e. *>500* km^2*, 100 – 500* km^2*, 10 – 100* km^2*, <10* km^2). The highest scores are given to smaller lakes, as the impact of dewatering discharge is likely to be greater on the smaller systems in comparison to larger lakes. This is because the larger lakes have a greater buffering capacity due to the larger volumes of water entering the lake. In addition there are generally sections of the lake which remain unimpacted. Biota in these sections is able to recolonise the lake and aid in the recovery of the lake. In contrast, the whole of the smaller lakes tend to be impacted, reducing the capacity for these lakes and particularly biota to recover.

3.6.3 Unique Physical Conditions

This category relates to the occurrence of physical characteristics which are distinct or unique within a particular lake. For the purposes of this report physical conditions are considered to be a unique sediment or water chemistry, structure, or physical feature which may not be common in the region. The option of *Yes* is selected when there is an indication that the lake may contain unique characteristics such as impermeable sediments, unique chemistry or filling frequency.

When there is little difference in lake characteristics compared to others in the region then *No* is selected. In the case where the lake surveys have been minimal and the data gathered is inadequate, *Insufficient Information* is selected. In this category the highest scores are given to the lakes which may have unique conditions. Lakes with no known information in relation to unique conditions are also rated highly. Information has been provided in **Appendix A** to enable the proponents to determine if their particular lake contains unique physical characteristics.

3.6.4 Unique Biological Conditions

This category relates to the occurrence of biological characteristics which are distinct or unique within a particular lake. This may include a unique community structure of algae, invertebrates and habitat for waterbirds or fauna endemic to a given lake. Information has been provided in **Appendix A** to enable the proponents to determine if their particular lake contains unique biological characteristics.

3.6.5 Information Collected

This category relates to the amount of information that has been collated by the proponent and is divided into three sections; Water Regime, Water/Sediment Quality and Biota. The option of *Comprehensive studies* indicates that both the wet and dry phases of the hydrocycle have been sampled on multiple occasions. *Basic studies* is the option chosen for lakes where the wet phase of the lake has been sampled on one occasion, while the dry phase has been assessed a number of times. Within both comprehensive and basic studies, sites should be replicated throughout the lake. *Opportunistic study* is chosen when grab samples have been taken, the sampling is event driven and there is no replication throughout the lake. The last option is that *No studies* have been completed. Lakes for which there is no known information score the greatest number of points within this matrix.

Water Regime

With regard to the Water Regime category, to obtain the lowest possible score (i.e. *Comprehensive studies completed)* the type of information that should be known about the lake includes;

- the bathymetry of the lake, which would enable low-lying areas and flow patterns to be identified,
- the permeability of lake sediments as this controls the length of time that the water pools at the particular site,
- the hydrocycle, or the period of wetting and drying of the lake,
- the prevailing wind direction, as this can influence movement of the discharge, and
- the capacity of the lake and the changes in water levels that occur upon filling.

Basic studies would be chosen when only some of this information is known.

Water and Sediment Quality

To determine a score in this category information regarding water and sediment quality of the lake should be known. Parameters tested should include but not be limited to;

- pH,
- salinity,
- nutrients,
- metals and metalloids, and
- sediment texture.

Given the high level of variability in water and sediment quality within these systems, it is important to collect data over different stages of the hydrocycle. This will cover the range parameters (both minimum and maximum concentrations) that are likely to occur, enabling the proponent to obtain the lowest possible score for this section (*Comprehensive studies completed*). However, allowances should be made if the lake has remained dry for an extended period of time and the focus should instead be on sediment quality.

Biota

The biota present during filling events includes cyanobacteria and algae (phytoplankton and benthic microbial communities), macrophytes (aquatic algae and plants), aquatic invertebrates and water birds. Similar to water quality, changes in the structure of the biotic community over the hydrocycle will vary. When scoring this category the inclusion of information on all groups is desirable and would aid in obtaining maximum scores (i.e. *Comprehensive studies completed*). Once again, allowances should be made in cases where there has been no prior opportunity to collect this type of information, or no previous biological studies have been conducted on the lake. In this situation, every effort should be made to estimate the biodiversity and productivity of the lake. This may also be achieved by examining the benthic microbial communities (specifically diatoms) and assessing the presence of resting stages (algae and invertebrates). This type of monitoring would result in the classification of *Basic studies completed*.

3.7 Dewatering Discharge Matrix

This matrix is used to rate the dewatering discharge process in terms of the likely impact it will have on the environment (**Table 3**). It considers the volume of water to be discharged, the proximity to other dewatering discharge, the salinity of the water, whether heavy metals are likely to be an issue, the duration of the discharge and the discharge site location. Similar to the

Original Status Matrix, those discharges which are perceived to result in a greater impact receive higher scores. Within this matrix the five major categories are discussed in more detail below.

Table 3: Matrix proposed to determine the characteristics of the dewatering discharge and site location.

Cumulative Discharge Volume (ML/year)	Score	Proximity to Other Discharges	Score	Salinity of Discharge (mg/L)	Score	Concentration of Metals	Score	Discharge Site	Score
<1000	1	> 20 km	1	Hyposaline (3 000 - 20 000)	1	Similar to Natural Values	1	Open Playa	1
1 000 - 5 000	5	1 - 20 km	5	Mesosaline (20 000 - 50 000)	5	Unknown or Exceed Natural Values	10	Creekline Opening	5
5 000 - 10 000	10	< 1 km	10	Hypersaline (> 50 000)	10			Embayment	10
> 10 000	20								

3.7.1 Cumulative Discharge Volume (ML/year)

The amount of water that is to be discharged onto the lake should be estimated on an annual basis (i.e. *>10 000 ML/yr*, *5 000 – 10 000 ML/yr*, *1 000 – 5 000 ML/yr*, *<1000 ML/yr*). If the lake receives more than one source of discharge, the sum of all the discharge volumes is to be added to the estimated volume. Sites with a higher rate of discharge per annum receive higher scores.

3.7.2 Proximity to Other Discharges

This category has been included to gauge the combined influences of other discharges within the vicinity of the proposed discharge. The distance calculation should be based on the distance between proposed discharge footprints rather than discharge locations. In this category, footprints which overlap (i.e. *<1 km*) score the highest as the effects of the discharge are amplified by the occurrence of two dewatering discharges within close proximity to each other. Those discharge footprints which are further away from each other (i.e. *1 – 20 km* or *>20 km*) score less as the impacts of the discharge are dissipated somewhat. Where there is no other discharge within the particular lake *>20 km* should be chosen.

3.7.3 Salinity of Discharge (mg/L)

Using the salinity classification system of Hammer (1986), scores are allocated according to the average salinity levels of the dewatering discharge (i.e. *Hypersaline*, *Mesosaline* and *Hyposaline*). Within this category, the more saline water receives a higher score.

3.7.4 Concentrations of Metals

The probability of elevated concentrations of heavy metals within the discharge water should be identified prior to the discharge commencing. Discharges which replicate natural conditions (i.e. *Similar to Natural Conditions*) score less than those which contain elevated concentrations of metals (i.e. *Unknown or Exceed Natural Conditions*). Common parameters of concern in dewatering discharge in the Goldfields include arsenic, lead, copper, nickel and zinc.

3.7.5 Discharge Site

Discharge sites located in *Embayments* pose a greater risk to the salt lake than the sites located near *Creeklines* and *Open Playa* sites. The morphology of the discharge site can influence the level of impact that the discharge is likely to have as constituents tend to accumulate at discharge sites located in an embayment, in contrast to those discharge sites located near creeklines which tend to flush contaminants away from the discharge site. Like creekline sites, open playa sites tend to be free draining resulting in the flushing of contaminants from the site. In the case where the discharge is into a small lake ($<10\ km^2$), embayments should always be chosen because there is little opportunity for flushing to occur in smaller lakes. The classification of the discharge site into *Embayment*, *Creekline* or *Open Playa* should consider the zone of influence of the discharge as well as the discharge pipe.

3.8 Risk of Dewatering Discharge Operations

This matrix rates the level of risk to the salt lake from the particular dewatering discharge operations based on the Original Status Score and the Dewatering Discharge Score (**Table 4**). Within this matrix, there are three levels of risk; Low, Medium and High. It should be noted that if there are any changes to the discharge operations over time, the risk level should be recalculated.

Table 4: Matrix devised to calculate the risk of the dewatering discharge operations to the particular salt lake.

		Dewatering Discharge		
Original Status Score		<23	24 - 42	>43
	<167	L	L	M
	168 - 288	L	M	H
	>289	M	H	H

3.8.1 Low Risk

Dewatering discharge operations that obtain a low risk value are likely to pose a minimal threat of irreversible impact to the salt lake and are likely to proceed with little restriction. Natural recovery of the lake from these types of operations is likely to occur at a fairly rapid rate. These operations should continue to be monitored, with any changes resulting in the recalculation of risk to the environment.

3.8.2 Medium Risk

Dewatering discharge operations falling into this category pose a moderate risk to the salt lake environment. If an operation falls in this category then appropriate management strategies should be considered to reduce the level of risk to the environment. In this instance the proponent should be encouraged to consider changing the discharge site, considering erosion and sediment control measures or including an appropriate management plan if they have not done so already. Proponents may also decide to conduct additional monitoring to reduce the Original Status Score of the lake. Medium risk operations can be managed in such a way as to reduce any potential impacts to the receiving environment.

3.8.3 High Risk

Operations in this category are likely to result in considerable impact to the salt lake environment. The proponent should reconsider their discharge operations and the associated options for reducing their risk category if possible (i.e. implementing a management plan or changing the discharge location). If all of these options have been taken into account and the risk is still high, there is a possibility that their operations should not be given approval. However, approval with strict conditions may be suitable and should be assessed on a case by case basis.

The Management Options Matrix should be used if the resultant risk of an operation falls in the Medium or High risk categories.

3.9 Management Options Matrix

The purpose of this matrix is to outline the management actions taken by the proponents in relation to the dewatering discharge activities in order to reduce the level of risk to the salt lake (**Table 5**). The resultant score from this matrix is subtracted from the score obtained in the Dewatering Discharge Matrix and the residual risk is determined using **Table 4**.

Table 5: Management Options Matrix for reducing the risk of dewatering discharge.

Sediment Control	Score	Erosion Control	Score	Management Plan Approved	Score	Monitoring Plan Approved	Score	Cumulative Impacts Considered	Score
No	0	No	0	No	0	No	0	No	0
Yes	5	Yes	5	Yes	10	Yes	5	Yes	5

3.9.1 Sediment Control

This category identifies if there is any proposed treatment of the dewatering discharge prior to the release of the discharge water to the environment. If the proponent demonstrates that some form of sediment control has occurred prior to release to the salt lake, then *Yes* should be chosen (score of 5). Sediment control will usually involve the water sitting in some form of settling pond prior to release into the lake. If there has been no consideration of sediment control the proponent will obtain a score of zero (*No*).

3.9.2 Erosion Control

When the proponent has demonstrated that erosion control measures are in place to prevent damage to the shoreline, vegetation and lake bed from the dewatering discharge the maximum score is given. This may include the construction of a rock pier, extension of the discharge pipe further onto the lake or rock mulching. No score is allocated when there are no erosion control measures in place.

3.9.3 Management Plan Approved

The proponent can reduce the risk from the dewatering discharge operations by completing a management plan. To obtain the maximum score (*Yes* – 10 points) this plan needs to be approved by the decision-making authority. The plan should identify the impacts of the dewatering discharge, set trigger values or performance indicators, detail monitoring plans and identify management actions if trigger values are exceeded. Further information on the content of the management plan is presented in **Appendix B**.

3.9.4 Monitoring Plan Approved

To obtain a score in this category, a monitoring plan needs to have been submitted and approved by the decision-making agency. The plan should detail the parameters to be monitored, the frequency of monitoring and how the results will be reported. The monitoring plan should take into consideration the likely impacts of dewatering discharge as discussed in Section 3.1. The potential components of a monitoring plan are presented in **Appendix C**.

3.9.5 Cumulative Impacts Considered

To obtain a score in this category the proponent must demonstrate that a reasonable effort has been made to consider cumulative impacts of dewatering discharge. This is particularly important in lakes that receive more than one discharge or in discharge lakes located in close proximity to each other. In this instance consultation with other users of the lake is required.

3.10 Residual Risk

Once a score has been obtained using the Management Options Matrix, this is subtracted from the score obtained using the Dewatering Discharge Matrix. This new score is then used to determine the residual risk of the operations once the management options for dewatering discharge have been considered as described in the flow chart below (**Figure 1**).

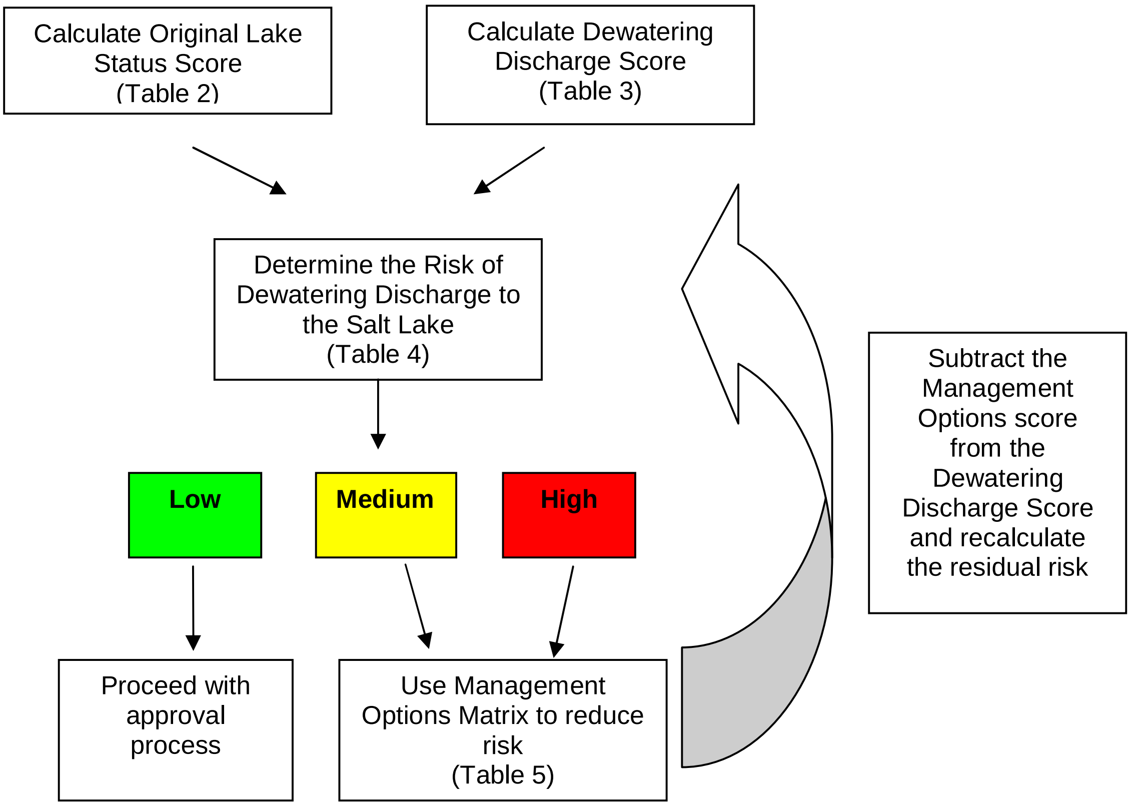

Figure 1: Flowchart for determining the risk of dewatering discharge to a salt lake environment.

The system has been tested using two hypothetical examples including Lake Carey and Lake Johnston (**Appendix D**), to demonstrate the implementation of the framework put forward in this report.

3.11 Areas for Further Investigation

There are a number of areas which require further investigation in relation to the impacts of dewatering discharge:

1. The fate of the metals and salts in the discharge water requires further research. Initial studies indicate that some of the discharge constituents move across the lake and some are transported down through the sediment profile. It is likely that this is influenced by the hydrogeology of the discharge site, however information is lacking for most of the salt lakes in the Goldfields.
2. Accumulation of metals in biota is difficult to determine in temporary systems due to the short lifecycle of organisms inhabiting these environments. Therefore the extent

to which biota are being affected (if at all) by increased metal concentrations is not known.

3. The affect of dewatering discharge on the sediment properties (physical and chemical) and subsequent changes that may occur has yet to be assessed.
4. The nature of the salt crust may influence the impact of dewatering discharge and the dispersal of salts and metals throughout the lake, although impacts on biodiversity require further investigation.
5. In most cases baseline conditions have not been established for the receiving lakes and it is difficult to determine if recovery post discharge has returned the lake to pre-discharge conditions.
6. Information relating to the life histories, ecology and environmental requirements of salt lake biota in Western Australia is limited.
7. The affects of prolonged flooding as a result of dewatering discharge on the viability of resting stages of aquatic biota is also restricted.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The matrices presented in this report have been devised to determine the level of risk associated with the cumulative and individual impacts of dewatering discharge to salt lakes in the Goldfields of Western Australia. The system involves determining the original status of the lake and the level of impact likely to occur from dewatering discharge. This information is then used to determine a level of risk associated with the particular operations. If this operation falls within a medium or high category, a number of options are presented in order to reduce the risk. The majority of these options are management based and can be easily implemented to reduce the perceived risk of the discharge.

Although the system has been reviewed by various divisions within both the DoW and DEC, the system still requires active testing before it can be made widely available. Also, it is likely that continued research into the field of salt lake ecology will contribute further to the development and potential refinement of this system.

5.0 REFERENCES

ANZECC (2000) 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2, Aquatic Ecosystems - Rationale and Background Information (Chapter 8).' (Environment Australia, Paper 4: Australia)

Bauld J (1986a) Benthic microbial communities in Australian Saline Lakes. In 'Limnology in Australia'. (Eds P De Deckker and WD Williams) pp. 95-112. (DR W. Junk Publishers: Australia)

Bauld J (1986b) Benthic microbial communities in Australian saline lakes. In 'Limnology in Australia'. (Eds P De Deckker and WD Williams) pp. 95-112. (Dr. W. Junk Publishers: The Netherlands)

Borowitzka LJ (1981) The microflora : adaptations to life in extremely saline lakes. In 'Developments in Hydrobiology, Salt Lakes'. (Ed. WD Williams) pp. 33-46. (Dr W Junk: Netherlands)

Boulton AJ, Brock MA (1999) 'Australian freshwater ecology: processes and management.' (Cooperative Research Centre for Freshwater Ecology: Adelaide, South Australia)

Brock MA (1998) Are temporary wetlands resilient? Evidence from seed banks of Australian and South African Wetlands. In 'Wetlands for the Future'. (Eds A McComb and JA Davis): Perth)

Brock MA, Shiel RJ (1983) The composition of aquatic communities in saline wetlands in Western Australia. *Hydrobiologia* **105**, 77 - 84.

Bunn SE, Arthington AH (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* **30**, 492 - 507.

Caceres CE (1997) Dormancy in invertebrates. *Invertebrate Biology* **116**, 371 - 383.

Campagna VS (2007) Limnology and biota of Lake Yindarlgooda - an inland salt lake in Western Australia under stress. Doctoral thesis, Curtin University of Technology.

Campagna VS, John J (2003) 'Limnology and biota of Lake Yindarlgooda.' Curtin University, Perth Western Australia.

Chaplin S (1998) The brine shrimp *Parartemia* sp. nova a (Lefroy-Cowan) in the Johnston Lake: effects of salinity, temperature and pH on life history. Unpub. BSc. Hons thesis, Curtin University of Technology.

Commander P (1999) Hydrogeology of salt lakes in Western Australia. In 'Salt Lake Ecology Seminar'. Perth Zoo Conference Centre. (Centre for Land Rehabilitation)

Datson B (2002) 'Samphires in Western Australia: A field guide to Chenopodiaceae tribe Salicornieae.' (Department of Conservation and Land Management Perth)

Datson B (2006) 'Lake Carey: fringing flora monitoring.' Actis Environmental Services, Perth.

De Deckker P (1983) Australian salt lakes: their history, chemistry, and biota - a review. *Hydrobiologia* **105**, 231-444.

English JP (2004) Ecophysiology of salt and waterlogging tolerance in selected species of *Halosarcia* PhD thesis, University of Western Australia.

Finucane S (2001) Monitoring the environmental impacts of mine water discharge to Lake Miranda. In 'Proceedings of the Salt Lake Workshop'. Bentley Technology Park, Perth, Western Australia. (Centre for Land Rehabilitation, University of Western Australia)

Finucane S, Boisvert M, Ariyaratnam K (2003) Water Quality Monitoring at Lake Miranda. In 'Workshop on Water Quality Issues in Final Voids, Salt Lakes and Ephemeral Streams'. Perth, WA. (ACMER)

Foster J (2001) The impact of hypersaline mine water discharge on ecosystem function in Kambalda region playas - geochemical aspects. In 'Salt Lake Workshop'. Technology Park, Bentley. (Ed. D Jasper). (Centre for Land Rehabilitation)

Foster J (2004) Salt lakes and mine dewatering discharge: cause, effect and recovery. In 'Goldfields Environmental Management Group'. Kalgoorlie, WA. (GEMG)

Geddes MC (1981a) The brine shrimps *Artemia* and *Parartemia*: comparative physiology and distribution in Australia. *Hydrobiologia* **81**, 169-179.

Geddes MC, De Dekker, P., Williams, W. D., Morton, D. W., & Topping, M. (1981b) On the chemistry and biota of some saline lakes in Western Australia. In 'Developments in Hydrobiology, Salt Lakes.'. (Ed. WD Williams) pp. 201-222. (Dr. W. Junk Publishers: Netherlands)

Gentilli J (1979) 'Western Landscapes.' (University of Western Australia Press: Perth)

Gregory SJ (2007) The classification of inland salt lakes in Western Australia. Masters thesis, Curtin University of Technology.

Gregory SJ (2008) 'The classification of inland salt lakes in Western Australia.' Minerals and Energy Research Institute of Western Australia, Perth, WA.

Halse SA (2002) Diversity of Ostracoda (Crustaceae) in inland waters of Western Australia. *Verh. Internat. Verein. Limnol.* **28**, 914-918.

Halse SA, & McRae, J. M. (2001) *Calamoecia trilobata* n sp (Copepoda: Calanoida) from salt lakes in south-western Australia. *Journal of the Royal Society of Western Australia* **84**, 5-11.

Hammer UT (1986) 'Saline Ecosystems of the World.' (Dr. W Junk Publishers: The Netherlands)

Handley M (1991) The biota of inland salt lakes of the Kambalda Region and coastal salt lakes of Esperance, Western Australia - a comparative study. Honours thesis, Curtin University of Technology.

Handley M (2003) The distribution pattern of algal flora in saline lakes in Kambalda and Esperance. Masters thesis, Curtin University of Technology.

Hart BT, McKelvie ID (1986) Chemical limnology in Australia. In 'Limnology in Australia'. (Ed. PW De Dekker, W. D.) pp. 3-32. (Australian Society for Limnology, CSIRO.)

Hebert PDN, Wilson CC (2000) Diversity of the genus *Daphniopsis* in the saline waters of Australia. *Canadian Journal of Zoology.* **78**, 794-808.

John J (1999a) Aquatic flora. In 'Baseline ecological study of Lake Lefroy'. (Eds JM Osborne and JN Dunlop). (School of Environmental Biology, Curtin Universtiy of Technology: Perth)

John J (1999b) Limnology of Lake Carey with special reference to primary producers. In 'Salt Lake Ecology Seminar'. Perth Zoo Conference Centre, Perth, Western Australia. (Centre for Land Rehabilitation)

John J (2003a) The biology and chemistry of temporary waters. In 'Workshop on Water Quality Issues in Final Voids, Salt Lakes and Ephemeral Streams'. Perth. (Ed. ACMER). (Acmer)

John J (2003b) Chemical and biological characteristics of salt lakes in Western Australia. In 'Workshop on Water Quality Issues in Final Voids, Salt Lakes and Ephemeral Streams.'. Perth, Western Australia, 12-13 May. (Ed. ACMER). (ACMER)

John J, Dunlop N, Goldberg J, Lowe E, Osborne J (2000) 'Baseline aquatic biology survey of Lake Miranda ' Sir Samuel Mines NL, Perth.

Jutson JT (1934) The physiography (geomorphology) of Western Australia. *Bulletin, Geological Survey of Western Australia* **95**, 1 - 366.

Lowe RL (1974) 'Environmental requirements and pollution tolerance of freshwater diatoms. .' Environemntal Monitoring Services, 670-4-7400 USEPA, Washington, D.C.

Muir BG, Hill L, Moodie S (2004) 'Lake Johnston Operations - annual environmental report, September 2004.' LionOre Australia (Nickel) Limited Perth, Western Australia.

Outback Ecology (2004) 'Lake Carey regional study, July 2004.' Internal Report for the Lake Carey Catchment Management Group.

Outback Ecology (2006) 'Aquatic assessment of Kurrawang White Lake, Lake Kopai and Greta Lake.' Internal report for Placer Dome Australia, Perth, Western Australia.

Outback Ecology (2007) 'Southern Cross Operations - biological assessment of Banker Lake.' Internal report for St Barbara Limited, Perth, WA.

Outback Ecology (2008a) 'Biological assessment of White Flag Lake.' Internal report for Barrick (Kanowna) Pty Ltd, Perth, Western Australia.

Outback Ecology (2008b) 'Biological monitoring at Lake Carey.' Internal report for AngloGold Ashanti Australia Limited - Sunrise Dam Gold Mine, Perth, WA.

Outback Ecology (2008c) 'Lake Carey regional study.' Internal report for the Lake Carey Catchment Management Group (LCCMG), Perth, WA.

Pinder AM, Halse, S.A., McRae, J.M. and Shiel, R.J. (2005) Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity. *Hydrobiologia* **543**, 1-24.

Remegio EA, Hebert PDN, Savage A (2001) Phylogenetic relationships and remarkable radiation in *Parartemia* (Crustacea: Anostraca), the endemic brine shrimp of Australia: evidence from mitrochondrial DNA sequences. *Biological Journal of the Linnean Society* **74**, 59-71.

Roshier DA, Rumbachs RM (2004) Broad-scale mapping of temporary wetlands in arid Australia. *Journal of Arid Environments* **56**, 249 - 263.

Taukulis FE (2007) Diatom communities in lakes and streams of varying salinity from south-west Western Australia: distribution and predictability. Doctoral thesis, Curtin University of Technology.

Taukulis FE, John J (2006) Diatoms as ecological indicators in lakes and streams of varying salinity from the wheatbelt region of Western Australia. *Journal of the Royal Society of Western Australia* **89**, 17-25.

Timms BV (2005) Salt lakes in Australia: present problems and prognosis for the future. *Hydrobiologia* **552**, 1-15.

Timms BV, Datson BV, Coleman M (2006) The wetlands of the Lake Carey catchment, northeast Goldfields of Western Australia, with special reference to large branchiopods. *Journal of the Royal Society of Western Australia* **89**, 175 - 183.

URS (2003) 'Cosmos Nickel Project - Monitoring of mine water discharge to Lake Miranda, 2003 post-discharge environmental monitoring programme.' Sir Samuel Mines NL., Perth, Western Australia.

van Etten E (2004) 'Monitoring program to assess impacts of discharge from Golden Crown mine pits into Lake Austin: report and baseline data at June 2003.' Centre for Ecosystem Management, Edith Cowan University, Perth, Western Australia.

Williams WD (1998a) 'Guidelines of lake management, Vol. 6. Management of inland saline waters.' (International Lake Environment Committee, United Nations Environment Programme)

Williams WD (1998b) 'Volume 6 - Management of Inland Saline Waters.' (International Lake Environment Committee Foundation: Japan)

Williams WD (2002) Environmental threats to salt lakes and the likely status of inland saline ecosystems in 2025. *Environmental Conservation* **29**, 154 - 167.

Appendix A

Background Information for Determining Uniqueness of Salt Lakes

Determining Unique Conditions

It is anticipated that the data collected on water/sediment quality and biota will be used to determine the level of uniqueness. Data presented in the sections below was sourced from research conducted during the Minerals and Energy Research Institute of Western Australia (MERIWA) project, on the classification of inland salt lakes in Western Australia (Gregory 2008) and from a range of other sources (Campagna 2007; Handley 1991; 2003; Taukulis 2007). It is proposed that this data may be used to determine whether a particular lake contains unique characteristics in comparison to other lakes in the same region.

Water/Sediment Quality

It is proposed that the data presented in the following sections will aid in demonstrating whether the lake of interest is a unique or distinct environment. For water and sediment quality, **Table 1** and **Table 2** display a range of values (including the minimum and maximum values) collected for different parameters from salt lakes in the Goldfields region. Unique conditions may be identified by observation of site-specific values which fall outside the ranges presented in these tables. The values presented in these tables will require regular updating as more information is collected, increasing the statistical robustness of the data set.

Table 1: Water quality ranges for unimpacted salt lakes in the Goldfields (n=number of records). All values are reported in mg/L except where stated.

Parameter	Min	Max	n
Aluminum	BD	44	48
Arsenic	BD	0.1	50
Barium		0.1	1
Bicarbonate	18	165	10
Boron	0.8	4.4	5
Cadmium	BD	0.4	50
Calcium	34	7 900	136
Chloride	1 248	141 337	16
Chromium	BD	0.5	10
Cobalt	BD	0.5	9
Copper	BD	0.8	54
Gold	BD	0.004	30
Iron	BD	120	19
Lead	BD	1.9	53
Magnesium	52	36 000	134
Mercury	BD		46
Nickel	BD	3	50
pH (pH units)	6.3	10.6	37
Potassium	8	6 900	129
Selenium	BD		8
Silica		1.4	1
Silver	BD		5
Sodium	780	330 000	134
Strontium	14	21	2
Sulphate	2	11 000	14
TDS (g/L)	2	370	85
Total N	0.73	39	48
Total P	0.02	0.18	49
Zinc	BD	0.6	50

BD = Below Detection

Table 2: **Sediment quality ranges for unimpacted salt lakes in the Goldfields (n=number of records for each parameter). All values are reported in mg/kg except where stated.**

Parameter	Min	Max	n
Aluminium	1 360	12 700	25
Antimony	BD	0.25	17
Arsenic	BD	11	49
Barium	BD	200	42
Beryllium	BD	0.5	25
Bicarbonate (meq/kg)	BD	220	74
Boron	50	400	17
Cadmium	BD	3	49
Calcium	120	245 000	74
Carbonate (meq/kg)	BD	1.71	78
Chloride	420	313 000	74
Chromium	7.2	690	51
Cobalt	BD	34	44
Copper	BD	61	51
Iron	4 200	50 400	26
Lead	BD	58	49
Magnesium	20	78 300	84
Manganese	9	650	42
Mercury	BD	1	42
Nickel	1.3	172	51
pH (pH units)	4	8.8	143
Selenium	BD	2.5	25
Silicon (%)	23.4	37.8	8
Sodium	370	280 000	70
Strontium	39.4	4360	17
Sulfur	810	8 880	3
Sulphate	460	74 600	74
Thorium	BD	3.3	17
Total Nitrogen	BD	5 000	273
Total Organic Carbon (%)	BD	6.9	78
Total Phosphorus	BD	560	279
Total Soluble Salts	6 530	540 000	98
Uranium	1.3	44.8	17
Vanadium	11	238	25
Zinc	BD	88	51

BD = Below Detection

Cyanobacteria and Algae

For groups of biota such as cyanobacteria and algae, frequently-recorded taxa have been presented in the following sections. In salt lakes, algae most commonly occur within benthic microbial communities (BMCs). They occur in association with lake sediments and often comprise of filamentous forms (including cyanobacteria and green algae) and diatoms (Bauld 1986b). The focus of the majority of studies conducted by Outback Ecology has been on the microalgae diatoms, as they tend to persist over a range of seasons throughout the hydrocycle. The most commonly represented diatom species found within salt lakes from the Goldfields are presented in **Table 3** sourced from information provided by Taukulis (Taukulis 2007) and Taukulis and John (Taukulis *et al.* 2006). Lakes that are dominated by taxa not presented on this list may be unique in relation to diatom communities.

Table 3: The ten dominant diatom species recorded from salt lakes in the Goldfields.

Species	No. of Occurrences
Navicula sp. aff. *incertata*	152
Amphora coffeaeformis	143
Hantzschia sp. aff. *baltica*	135
Luticola mutica	57
Navicella pusilla	52
Hantzschia amphioxys	50
Navicula sp. aff. *salinicola*	47
Nitzschia punctata	28
Navicula elegans	22
Pinnularia borealis	21

Components of the BMCs include the Cyanophyta (blue-green algae) and Chlorophyta (green algae), which have been found to form cohesive mats on the surface sediments of salt lakes, mostly in areas of freshwater recharge. Cyanobacteria may include the following: *Schizothrix*, *Phormidium, Oscillatoria* and *Microcoleus* (Borowitzka 1981; Handley 2003; John 2003b) (**Table 4**). The filamentous *Schizothrix* appears to be one of the most frequently-recorded genera in Western Australian salt lakes (John 2003b). Although not as common as Cyanophyta, representatives of the Chlorophyta group are also known to occur (De Deckker 1983; Williams 1998b) (**Table 5**). However, it should be noted that conditions may not be conducive for these taxa to be found in association with the lake sediments and this would not be considered a unique characteristic.

Table 4: Common Cyanophyta genera recorded in salt lakes of the Goldfields.

Lake	*Schizothrix*	*Oscillatoria*	*Chroococcus*	*Spirulina*	*Phormidium*	*Anabaena*	*Synecoccus*	*Microcoleus*	*Pleurocapsa*	Nosotcales
Lake Lefroy[2]	x	x	x	x	x	x				
Lake Zot[2]	x						x			
Lake Cowan[2]	x	x	x					x		
Lake Carey										
Lake Eaton[3]		x	x		x	x		x	x	
Lake Yindarlgooda[4]					x			x		x
Un-named Lake	x									
Lake Hope North[5]	x									

[1](John *et al.* 2000), [2](John 1999a), [3] (Handley 1991; 2003), [4].(Campagna 2007; Campagna *et al.* 2003) and [5](Chaplin 1998).

Table 5: Common Chlorophyta genera recorded in salt lakes of the Goldfields.

Lake	*Oedogonium*	*Chlorella*	*Klebsormidium*	*Dunaliella viridis*	*Dunaliella salina*
Lake Miranda[1.]	x				
Lake Eaton[3]		x			
Lake Yindarlgooda[4]			x	x	
Lake Carey					x

[1](John *et al.* 2000), [3] (Handley 1991; 2003) and [4](Campagna 2007; Campagna *et al.* 2003).

Aquatic Invertebrates

Determining the uniqueness of the salt lake in terms of aquatic invertebrate communities can be difficult as there are limited opportunities for collection, due to the temporary nature of these systems. Changes in community structure due to the varying salinity concentrations over the hydrocycle should also be taken into consideration. Studies conducted to date have shown that invertebrate communities in Western Australian salt lakes are dominated by the Crustacea, and typically consist of taxa from the following orders; Anostraca, Ostracoda, Cladocera and Copepoda (Brock *et al.* 1983; De Deckker 1983; Geddes 1981b). In addition, representatives from the Insecta, Rotifera and Gastropoda groups are also common (Brock *et al.* 1983; Geddes 1981b; John 2003b). Data compiled during the MERIWA study (Gregory 2008), and sourced from Campagna (2007) is presented in **Table 6**, and represents the most commonly recorded taxa identified from lakes in this region. It should be noted however, that higher level identification for some of this data was not required and the information provided should be used as a guide only.

Table 6: The ten most commonly recorded invertebrate taxa from salt lakes in the Goldfields.

Taxa	No. of Occurrences
Chironomidae	34
Reticypris sp.	33
Cyclopoida	30
Daphniopsis	21
Diacypris whitei	20
Coxiella gilesi	16
Diacypris dictyote	14
Branchionus sp.	13
Diacypris sp.	12
Parartemia spp.	11

Appendix B

Requirements of a Management Plan

Management Plan

For the proponent to reduce their Risk Matrix Score by the maximum amount an appropriate management plan for the lake ecosystem needs to be submitted. To obtain this score the management plan must provide information on topics explained in the next section including, current status, the potential impacts of dewatering discharge, proposed performance indicators and criteria, and monitoring and reporting requirements. The aim of this information is to provide the licensing agency with the type of information which the proponent should include in the management plan.

Current Status

The management plan should include information on the current status of the lake, and any background information with regard to water/sediment quality and aquatic biota. It should also outline any other operations potentially impacting the lake.

Potential Impacts

The management plan should outline;

- the estimated area of impact or footprint of the dewatering discharge,
- seasonal changes to the footprint of the dewatering discharge,
- how the discharge will change throughout the hydrocycle of the lake,
- the likely changes in water/sediment quality as a result of dewatering discharge,
- the likely changes to the biotic communities due to dewatering discharge,
- downstream impacts from the dewatering discharge, and
- cumulative impacts if more than one dewatering discharge is occurring onto the lake.

Performance Indicators and Criteria;

The management plan should define performance indicators and criteria in relation to the dewatering discharge. In the case of water/sediment quality these criteria should be developed according to baseline information collected prior to the dewatering discharge for specific parameters. A change of 20 % (above the maximum or below the minimum values listed for specific parameters) is considered to be appropriate by ANZECC in terms of acceptable variation (ANZECC 2000). The proponent should set appropriate management criteria if these values are exceeded. In this case, a suggested response to an indicator which has been exceeded might be;

- further testing to determine if the value recorded was a one-off spike or is consistently elevated,
- if the parameter remains elevated over an extended period (for example longer than three months), investigate the source. Take into account that this may be linked to certain geologies within the mining pit,
- if the contamination continues (for example after six months), it may be appropriate to begin discharging to another pit or store the discharge water in a turkeys-nest dam for further testing and investigation, and

- if contaminants settle out of solution it may be possible to remove contaminants before they enter the lake.

Although monitoring of aquatic biota should occur to determine the productivity and the uniqueness of the salt lake system, the value of biota as performance indicators at the point of discharge tends to be limited. This is related to the temporary nature of these systems, and often diatoms may be the only biota living within the sediments during extended dry periods. Most discharge sites do not record diatoms due to unfavourable conditions for establishment (including extreme salinity, erosion and unsuitable substrate type). In addition, there is considerable natural variation in diatom populations within salt lakes throughout the Goldfields, with some areas displaying naturally depauperate communities.

Riparian vegetation may be used as an effective performance indicator. The collection of baseline data over a number of seasons would allow for accurate identification of seasonal changes in the vegetation community. The use of unimpacted sites as a comparison to impacted sites may also be used to monitor performance. In this instance changes in plant cover, density and diversity may be used as key performance indicators and triggers for further investigation. Areas of further investigation include soil monitoring to determine changes in soil properties, or measurements related to prevailing winds, which can transport salts from the discharge onto nearby vegetation.

The thickness of the salt crust within the vicinity of the dewatering discharge site may be used as a performance indicator (taking into account mining history and any previous dewatering discharge impacts). In most cases the salt crust remains less than 10 cm thick and may dissipate during heavy rainfall conditions. Any thickness greater than 10 cm is likely to take longer to dissipate. At this thickness it would be advantageous to conduct dissolution trials and consideration of methods to encourage the salt crust to dissipate at a faster rate.

Monitoring

This section should outline the proposed monitoring program, including abiotic and biotic parameters to be sampled, methods and the frequency of assessment. The results of the monitoring program should be compared to performance indicators to monitor impacts of the dewatering discharge.

Reporting

The information obtained from the monitoring program should be reported against performance indicators and reported in the annual DDLR. Any proposed changes to the performance indicators and subsequent monitoring should also be presented within this report.

Appendix C

Components of a Monitoring Plan

Monitoring of Salt Lakes

To adequately assess the original condition of the lake (pre-discharge), monitor the impact and ultimately the recovery of a salt lake following cessation of dewatering discharge it is important to have a robust baseline data set.

Baseline Data Collection

Collection of adequate baseline data prior to the approval of discharge will allow for the following questions to be answered:

1. Are there any unique, rare or protected flora/fauna inhabiting the salt lake?
2. Have the abiotic baseline conditions in relation to water/sediment quality of the lake been established?
3. Are the flow paths and water flow within the lake known and have they been mapped?
4. Have monitoring objectives and targets for managing the lakes been derived?

The collection of adequate baseline data will involve the following:

1. Collection of data over a number of seasons, both in the wet and dry phases of the hydrocycle, to allow for an understanding of the abiotic and biotic components of the lake.
2. Sampling the potential impact zone and comparable unimpacted sections of the lake is required. A range of different habitats should be included in the sampling program. Sites with similar geology and morphological characteristics should be sampled, as these parameters can have a profound affect on the physical and chemical properties of the lakes.
3. Identification of abiotic parameters that are likely to be of concern in the dewatering discharge should be identified (chemical indicators), and included in the analyses of the water/sediment quality during baseline monitoring.

Baseline data requirements as a minimum should include the assessment of the abiotic and biotic components listed in **Table 1**. It should be noted that while the productivity and biodiversity of the system can not be accurately measured without a filling event, it is possible to obtain some idea of the potential productivity of the system during dry conditions via hatching trials. Trials are conducted in the laboratory with re-wetted lake sediments, initiating germination and hatching of the dormant egg and seed bank. When choosing sample sites for inclusion into a regular monitoring program, consideration should be given to access during wet conditions.

Table 1: Abiotic and biotic components of a potential baseline monitoring program for both the dry and wet phases of the hydrocycle for a particular salt lake.

Ecosystem Component	Stage of Hydrocycle	
	Wet Phase	**Dry Phase**
Water Quality	✓	
Sediment Quality	✓	✓
Algae/Macrophytes		
Phytoplankton	✓	
Benthic Microbial Community	✓	✓
Dormant Oospores/Seeds	✓	✓ (hatching trial)
Invertebrates		
Aquatic Invertebrates	✓	
Dormant Eggs	✓	✓ (hatching trial)
Riparian Vegetation	✓	✓
Water birds	✓	✓

Water/Sediment Quality

As a minimum pH, salinity, nutrients and metals should be assessed in surface waters and sediments. These should be sampled over the course of the hydrocycle as the changes in parameters can be substantial.

Cyanobacteria and Algae

The primary producers within the salt lakes are the cyanobacteria and algae. Algal communities within the salt lakes are an important food source for invertebrates and are widely accepted as useful monitoring organisms to detect changes in conditions (Lowe 1974). These groups should be sampled at the beginning and the end of the hydrocycle to identify the dominant species and link any changes in community structure to the physical and chemical environment.

Aquatic Invertebrates

Aquatic invertebrates should be monitored over the course of the hydrocycle to determine the dominant taxa. By observing community dynamics, the ecological requirements of each group of taxa can be estimated, allowing for an understanding of recovery conditions required post discharge.

Riparian Vegetation

The structure and diversity of the riparian vegetation should be determined prior to the approval of dewatering discharge. Measures of plant density, diversity and percentage cover (taking into account plant health) are useful when determining the impact of dewatering discharge. These parameters should be measured seasonally to determine the range of baseline conditions over time.

Water Birds

During the wet phase of the hydrocycle water birds present on the lakes can be prolific, related to periods of high productivity by algae and invertebrates. Species utilising the lake environment and their associated behaviour (including nesting) should be observed.

Considerations

It is not always possible to collect baseline data due to the long history of mining that has occurred at some salt lakes in the Goldfields. In these circumstances pre-discharge data should be collected at sites from within the lake which have been the least affected by any previous mining operations and dewatering discharge. If the entire lake has been influenced by dewatering discharge, then proxy lakes may be utilised, if they are suitably comparable. Proxy lakes should for example be located within the same palaeodrainage system or have similar hydrogeological and morphological characteristics.

Data collected during baseline monitoring programs should be used to set trigger values for water/sediment quality parameters that can be used during dewatering discharge operations. ANZECC suggests that these values are derived from data collected monthly over a two year period (ANZECC 2000). The trigger value is set as the 80th percentile of the site-specific data set. Once a trigger value has been derived, further investigation or management options may be required if the value is exceeded. It should be noted that consideration should be given to the difficulty of obtaining 24 data points (obtained from monthly sampling for a period of two years) for surface waters in temporary systems. In this case it may be more appropriate to increase the number of sample sites assessed to obtain the required data set.

Operational Monitoring

Throughout the discharge process the same parameters collected during the baseline study should continue to be assessed during mining operations. Monitoring should occur at both impacted and unimpacted sites to identify natural seasonal variations versus discharge related impacts. While the analysis of surface water and sediments is relatively straightforward, in the immediate vicinity of the discharge aquatic biota are generally absent, due to unfavourable conditions. However, monitoring of biota should continue, at proximal sites to determine the extent of the discharge impacts.

While sediments and water should be monitored on a monthly basis, biannual assessment may be more appropriate for biota. In addition opportunistic sampling of abiotic and biotic components during filling events should occur as these events are often rare.

Post Closure Monitoring

Monitoring of the lake should continue after the cessation of dewatering discharge. Recovery of salt lakes post operational closure should be monitored over time and monitoring to identify trends and potential residual impacts related to the discharge. Indications of recovery may include a decrease in water and sediment salinity, a reduction in the extent and thickness of the salt crust at the discharge point, and possible decreases in the concentration of nutrients and metals. In addition there may be an increase in biodiversity, or changes in the structure of biotic communities that may indicate the recovery of impacted areas within the lake.

45

Appendix D

Hypothetical Examples

Hypothetical Examples

The risk assessment matrices were tested using hypothetical examples relevant to Western Australian salt lakes in the Goldfields. It is envisaged that the system and the associated framework should be tested further before being made publicly available.

Hypothetical 1 – Lake Carey

Company X proposes to discharge excess mine water into Lake Carey. It is estimated that 6000 ML/year of hypersaline water will be discharged into the lake on an annual basis. The area is known to be highly mineralised and contain high concentrations of some metals. The proposed discharge site is located in the southern section of the lake near a large creekline.

Original Lake Score

Currently there are a number of active locations discharging into Lake Carey. In addition exploration is underway at a number of locations on the lake fringe. Given the high level of historical impacts there are no unique biological or physical conditions associated with the site selected for the discharge. Over time the lake has been extensively studied in terms of biota, water/sediment quality, with biannual sampling carried out since 1999. However, only basic studies have been completed in relation to water regime, due to limited filling events. Following the collation of this information, the Original Lake Score was calculated to be 65 **(Table 1)**.

Table 1: Original Lake Matrix for the Lake Carey hypothetical example.

Cumulative % of Lake Impacted	Score	Lake Size	Score	Unique Physical Conditions	Score	Unique Biological Conditions	Score	Information Collected					
								Water Regime	Score	Water/Sed Quality	Score	Biota	Score
> 80 %	60	> 500 km^2	1	No	1	No	1	Comprehensive studies completed	1	Comprehensive studies completed	1	Comprehensive studies completed	1
31 - 80%	40	100 km^2 - 500 km^2	40	Yes	100	Yes	100	Basic studies completed	5	Basic studies completed	5	Basic studies completed	5
1 - 30%	60	10 - 100 km^2	60	Insufficient Information	100	Insufficient Information	100	No studies completed	20	Oppurtunisitc study completed	10	Oppurtunisitc study completed	10
0%	80	< 10 km^2	80							No studies completed	20	No studies completed	20

Dewatering Discharge Score

The Dewatering Discharge Score was also calculated for the Lake Carey hypothetical example (based on similar discharges to the lake) and was 35 (**Table 2**). This score took into account factors such as the proposed discharge volume, salinity concentration of the discharge and the discharge site.

Table 2: Dewatering Discharge Matrix for the Lake Carey hypothetical example.

Cumulative Discharge Volume (ML/year)	Score	Proximity to Other Discharges	Score	Salinity of Discharge (mg/L)	Score	Concentration of Metals	Score	Discharge Site	Score
<1000	1	> 20 km	1	Hyposaline (3 000 - 20 000)	1	Similar to Natural Values	1	Open Playa	1
1 000 - 5 000	5	1 - 20 km	5	Mesosaline (20 000 - 50 000)	5	Unknown or Exceed Natural Values	10	Creekline Opening	5
5 000 - 10 000	10	< 1 km	10	Hypersaline (> 50 000)	10			Embayment	10
> 10 000	20								

Risk of Discharge Operations to Lake Carey

The level of risk posed by this hypothetical operation to Lake Carey is low indicating the threat to the receiving environment is minimal (**Table 3**). However, the proponent will be required to monitor the dewatering discharge to ensure their operations remain at this level.

Table 3: Risk Assessment Matrix for the Lake Carey hypothetical example.

		Dewatering Discharge		
		<23	**24 - 42**	**>43**
Original Status Score	**<167**	L	$\boxed{L}$	M
	168 - 288	L	M	H
	>289	M	H	H

Hypothetical 2 – Lake Johnston

In this hypothetical example, Company Y would like to discharge hypersaline water from their mine void onto Lake Johnston. It is estimated that 6 000 ML/year will be discharged into the lake. The discharge water is hypersaline, and the quality of the water in terms of metals is unknown. Discharge will occur onto an open playa site.

Original Lake Score

In this hypothetical example the Original Lake Score for Lake Johnston, prior to discharge was 360. This high score was due to the lack of information available on aquatic biota, water regime and water and sediment quality. Also the lake has not been impacted by any previous mining operations and is considered to be in a relatively pristine condition.

Table 4: Original Lake Matrix for the Lake Johnston hypothetical example.

Cumulative % of Lake Impacted	Score	Lake Size	Score	Unique Physical Conditions	Score	Unique Biological Conditions	Score	Information Collected					
								Water Regime	Score	Water/Sed Quality	Score	Biota	Score
> 80 %	60	> 500 km^2	1	No	1	No	1	Comprehensive studies completed	1	Comprehensive studies completed	1	Comprehensive studies completed	1
31 - 80%	40	100 km^2 - 500 km^2	40	Yes	100	Yes	100	Basic studies completed	5	Basic studies completed	5	Basic studies completed	5
1 - 30%	60	10 - 100 km^2	60	Insufficient Information	100	Insufficient Information	100	No studies completed	20	Oppurtunisitc study completed	10	Oppurtunisitc study completed	10
0%	80	< 10 km^2	80							No studies completed	20	No studies completed	20

Dewatering Discharge Score

Using the Dewatering Discharge Matrix, the calculated score for the hypothetical dewatering discharge to Lake Johnston was 32 (**Table 5**).

Table 5: Dewatering Discharge Matrix for the Lake Johnston hypothetical example.

Cumulative Discharge Volume (ML/year)	Score	Proximity to Other Discharges	Score	Salinity of Discharge (mg/L)	Score	Concentration of Metals	Score	Discharge Site	Score
<1000	1	> 20 km	1	Hyposaline (3 000 - 20 000)	1	Similar to Natural Values	1	Open Playa	1
1 000 - 5 000	5	1 - 20 km	5	Mesosaline (20 000 - 50 000)	5	Unknown or Exceed Natural Values	10	Creekline Opening	5
5 000 - 10 000	10	< 1 km	10	Hypersaline (> 50 000)	10			Embayment	10
> 10 000	20								

Risk of Discharge Operations to Lake Johnston

Based upon the above information the risk of discharging to Lake Johnston is High (**Table 6**). This was to be expected, as the lake had not received discharge previously and is relatively pristine.

Table 6: Risk Assessment Matrix for the Lake Johnston hypothetical example.

		Dewatering Discharge		
		<23	**24 - 42**	**>43**
Original Status Score	**<167**	L	L	M
	168 - 288	L	M	H
	>289	M	H	H

According to these results, this company would need to look at further management options such as implementing a monitoring plan to reduce the risk of operations to the receiving environment. It should be noted that the lowest risk that the operation could receive is medium due to the high Original Lake Score.