THE IMPLICATIONS OF DISCHARGING TO SALT LAKES – MONITORING IMPACT AND RECOVERY

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ABSTRACT

In the Goldfields of Western Australia, excess water produced where mining is conducted below the water table, is commonly disposed into nearby salt lakes. The implications of mine water discharge to salt lakes have remained unknown. Since 2000, many mining companies have been actively researching the impact of discharge to the salt lakes and this paper summarises the results of these studies. Accurately determining these impacts on aquatic biota and chemistry has been complicated, as the salt lakes are temporary in nature and can remain dry for decades. This means that determining the productivity and the uniqueness of the salt lake is difficult. In addition, for most cases there was no collection of baseline data prior to commencing dewatering discharge. However, it appears from water and sediment chemistry that there can be changes in pH, and increased metal, salt and nutrient load. This has implications for aquatic biota, and reductions in species richness have been recorded. These impacts can be amplified by site morphology, site hydrology, climatic conditions and anthropogenic structures. It should be noted that some of these impacts appear to be temporary and recovery of the system does occur naturally.

INTRODUCTION

Studies relating to the ecology of salt lakes in inland Western Australia have been on the increase, primarily as a result of the greater levels of mining in and around these systems. The salt lakes of the Goldfields region have been the preferred location for the disposal of surplus groundwater (‘dewatering discharge’) produced during mining operations. This is because the lakes typically provide a large surface area for dispersal and eventual evaporation. This paper addresses the impacts of dewatering discharge on the ecology of inland salt lakes of the Goldfields, by monitoring the abiotic parameters that regulate aquatic biotic. In this paper we also consider the design of monitoring programs to assess these impacts and to monitor recovery on the cessation of dewatering discharge.

SALT LAKES IN WESTERN AUSTRALIA

The arid and semi-arid zones of Western Australia have one of the highest concentrations of salt lakes on the Australian continent (Gentilli 1979). Most of these are located within an area known as the Salinaland, or the Salt Lake Division (Jutson 1934; Gentilli 1979). Typically, salt lakes are defined as having a surface water salinity of 3 g/L or greater (Geddes 1981; Williams 1998; 2002). Many are temporary water bodies that fill infrequently (episodic) in response to heavy rainfall events (Roshier and Rumbachs 2004; Timms 2005; Timms *et al.* 2006). Once filled, their drying cycle is rapid as a result of high evaporation rates, with pooled surface water often lasting only a few months (Timms *et al.* 2006). The lakes are generally shallow and rarely exceed a metre in depth (John 1999).

The salt lakes of the Goldfields region are the end point of drainage for the surrounding areas. They are the surface expression of an ancient palaeodrainage system that developed during the Late Cretaceous period (Morgan 1993) and were extensive throughout the interior of the state during the Tertiary period (Johnson *et al.* 1999). These palaeodrainage systems radiate from a broad drainage divide that bisects the Yilgarn Craton (Anand and Paine 2002). Surface drainage is endorheic or internal (Williams 1998), with each of these lakes acting as closed systems.

The water quality (physicochemical parameters) in salt lakes tends to be highly variable with a wide range of salinity, pH and nutrient fluctuations over the hydroperiod (Roshier and Rumbachs 2004). For example, salinity in the surface water of the Goldfields salt lakes ranges from 3 g/L (close to freshwater) to 300 g/L (hypersaline) (Gregory 2007). Sodium and chloride are the dominant ions and generally the sequence of cation dominance follows: Na>Mg>Ca>K, while for the anions, $Cl>HCO_3>SO_4$. These waters are classified as alkaline (Williams and Buckney 1976) and nutrient concentrations are generally high in comparison to freshwater ecosystems (John 2003b; URS 2003; Gregory 2007).

In terms of biota, the primary producers within salt lakes belong to the Cyanobacteria (blue-green algae), Chlorophyta (green algae) and Bacillariophyta (diatoms) (Borowitzka 1981; Hammer 1981; John 2003a). The productivity of these systems is often confined to the benthic microbial communities (BMCs - biological associations with lake sediments) (Bauld 1981; 1986). The majority of BMCs are composed of cyanobacteria and diatoms, which in some cases form extensive, cohesive mats (Bauld 1981). However in large playas these BMCs usually consist of thin films of diatoms only (Boggs *et al.* 2007; Campagna 2007).

In terms of aquatic fauna, salt lakes in Western Australia display a high level of endemism and species radiation in comparison to other salt lakes throughout Australia (Hebert and Wilson 2000; Halse 2001; Remegio *et al.* 2001). Aquatic invertebrate fauna are dominated by crustaceans , in particular the endemic brine shrimp, *Parartemia* (Anostraca) (Geddes 1981; Brendonck and Williams 2000; John 2003a). Representative from the Ostracoda also occur (Pinder 2005) and this group is considered one of the most diverse groups of crustaceans (Halse 2002). Other taxa recorded within the lakes include the Copepoda and Cladocera (water fleas). For most of these lakes which are hypersaline systems, it is usually the *Parartemia* and ostracods that persist into the later stages of the hydroperiod (i.e. period in which the lake is wet) (Williams *et al.* 1990). Generally for episodically-filled lakes, diversity is lower than freshwater lakes (De Deckker 1983) and factors such as the constant habitat homogeneity (i.e. similar sediments and vegetation at most sites within a lake) that tends to occur in these lakes also restricts the fauna diversity somewhat (Timms 1997).

Aquatic organisms that live in unpredictable environments, as a result of climatic conditions, must develop survival mechanisms that include short lifecycles, the production of desiccation-resistant stages or the ability to disperse (Caceres 1997; Simovich and Hathaway 1997). The resident biotic community in temporary systems often remains buried in the sediment as resting stages (Brendonck and Williams 2000), and may not emerge until conditions are suitable. Resting stages are found in the upper layer of lake sediments and are considered to be “active” (Caceres and Hairston 1998). The resting stages found in these lakes consist of dormant eggs of invertebrates (resting eggs), the spores of algae or the seeds of macrophytes such as *Ruppia*. The presence and viability of this dormant egg/seed bank is vital to the resilience and therefore the recovery of these systems after disturbance, including extended dry periods or anthropogenic impacts (Brock 1998; Brock *et al.* 2003).

RECENT RESEARCH

The following is a summary of work undertaken by Outback Ecology and associated personnel, in relation to salt lake research in Western Australia over the past two years;

- Ongoing work; currently Outback Ecology are involved with annual monitoring programs of 12 salt lakes within the Goldfields region. The majority of this work examines the impact of dewatering discharge on the lake biota, in relation to changes in sediment and water chemistry.
- Department of Water; a project which assesses the cumulative impacts of dewatering discharge on the salt lakes of the Goldfields region.
- PhD Research (Curtin University); an integrated study of the limnology of Lake Yindarlgooda examining the factors that uphold the integrity of inland waters. The study incorporates the physicochemical and the biotic limnology of the lake. The impact to the ecosystem from secondary salinisation caused by mining processes was assessed using the dominant biotic communities, including the use of *Parartemia* resting stages in hatching trials.
- Masters Research (a MERIWA funded project); this study investigated the physicochemical properties of both water and sediment, as well as biotic parameters such as algae and invertebrates, from 24 salt lakes within the Goldfields. This information was then examined using multivariate analysis and a classification system was established using these parameters.

OUTCOMES

This section summarises the results of the aforementioned work in regard to the impacts of dewatering discharge on the salt lakes. In the context of this report, the term “impact” is used to identify a negative effect from discharge on the aquatic ecosystem.

The impacts from dewatering discharge

The impact from dewatering discharge to the environment is dependant on the quality and quantity of water entering the lake. While discharge water quality may be highly variable throughout the region, the majority of the water released onto Western Australian inland salt lakes comes from palaeochannels and is hypersaline. The focus in the following sections is therefore on the impacts of hypersaline water on the salt lake environment.

Sampling sites established within the vicinity of dewatering discharge have higher concentrations of salts, nutrients and certain metals, in both water and sediments compared to ‘natural’ sites (i.e. lakes not receiving dewatering discharge) (Finucane 2001; Foster 2001; Muir *et al.* 2004; Gregory 2007). Additionally, there is usually a shift in the surface water pH at some of the discharge sites, reflecting the pH of the discharge water (Outback Ecology 2008c). Nutrient levels, particularly nitrogen, are typically elevated and increases in metals and metalloids reflect local geology and therefore the groundwater of the area (Mann 1982; Morgan 1993).

Aquatic biota, including water birds, invertebrates and algae are affected by hypersaline discharge (Timms 2005). Species richness and productivity of groups such as with diatoms and invertebrates, is generally lower at the discharge sites. This can be attributed to a number of factors. For example; unfavourable substrates for diatom establishment resulting from high flow rates from the dewatering discharge and eventual erosion of the surface sediment are common (Gregory 2007). Increases in salinity beyond that of the threshold of many of the biota may decrease the diversity and productivity of the wetland. For example, the increased salinity, and heavy metal concentrations, can prevent the hatching of the resting stages.

If they do hatch, there is a chance that the offspring will be unable to reach maturity to reproduce, consequently resulting in the depletion of the egg bank. The high number of invertebrates that hatch during the “boom” period after rainfall in these salt lakes are an important source of food for nomadic water birds (Roshier *et al.* 2002), and the loss of their inland habitat can be detrimental to the survival of many species. Therefore, alterations to the biological communities in these systems, commencing with the primary producers, such as algae, will invariably affect higher order consumers such as waterbirds.

Flooding of salt lake margins and saturation of the soils as a result of dewatering discharge, increases the likelihood of impact on the fringing vegetation (Foster 2001; Outback Ecology 2007). In the Goldfields, fringing vegetation of salt lakes occurs in distinct zones, reflecting particular combinations of soil conditions, salinity and waterlogging (Barrett 2006; van Etten and Vellekoop 2006). A particular example is the combined effects of salinity and water-logging dictating the occurrence of *Halosarcia* species (English 2001; English 2004) and the extent of their zones (van Etten and Vellekoop 2006). Increases in soil salinity and waterlogging as a result of dewatering discharge has been found to have an adverse affect on even the most tolerant of vegetation, including *Halosarcia* spp. (Timms *et al.* 2006). Increased salinity and waterlogging of the riparian zone also has detrimental impacts on the microbial soil crusts that play an important role in stabilising the dunes, preventing erosion and increasing water flow to the lakes.

A change in the duration of the hydrocycle is a common occurrence in salt lakes receiving dewatering discharge (Finucane 2001). The wetting phase (persistence of surface water) is prolonged, and the discharge water may promote the development of a saturated salt crust, reducing the evaporation rate of the water (Newson and Fahey 2003) and leading to permanent flooding.

Localised erosion of playa zones by the discharge water stream is a common problem within the vicinity of discharge sites (Finucane 2001). However, the degree to which this can occur depends on the design of the discharge outfall. For example, traditionally discharge water was released via a pipe line directly onto the lake, potentially leading to erosion of sediments and the surrounding dunes. Recent designs, such as the practice of rock mulching, aim to reduce erosion along the shore line of the lake.

In some cases, dewatering discharge can contain a high degree of suspended solids, which increases turbidity and has serious implications for biota that inhabit surface waters. Increased suspended solids may restrict photosynthesis and dissolved oxygen levels in the water column (Boulton and Brock 1999). In addition, suspended solids may also contain contaminants such as heavy metals, which have the potential to adversely affect aquatic biota (ANZECC 2000). In an environment where excessive siltation is detrimental to the aquatic biota (Williams 2005) efforts need to be made to limit any increases in sediment loading.

Factors amplifying dewatering discharge impacts

There are several factors which can amplify the effects of dewatering discharge, including local geology, hydrology and hydrogeology, site morphology and topography, local climate conditions and the presence of structures related to mining operations.

Geology

The local geology within the mining void determines the quality and quantity of water being discharged, and these are the key parameters that may influence the surrounding ecosystem. The quantity of water in relation to the storage capacity of the lake can also influence the impact of the dewatering discharge, with lakes that are maintained at capacity being likely to display a greater impact than lakes with only portions disturbed (Gregory 2007).

Hydrology and Hydrogeology

Discharge water is often contained within the localised discharge area when the lakes are dry (van Etten 2004; Gregory 2007). With the onset of rainfall, the discharge water is diluted and distributed more widely. Clearly, the impact of discharge water on surface water quality after dilution is dependant on the volume of water in the lake. In smaller lakes there is less capacity for dispersion to occur (Foster 2004), which may result in the death of fringing vegetation and greater impacts on aquatic biota. In contrast, in larger lakes, potential contaminants in the discharge water may be diluted to the extent that effects on abiotic and biotic factors are negligible.

The hydrogeology of the site will also determine the level of impact from the dewatering discharge. Sites with permeable sediments tend to show minimal impacts as materials move quickly into the sub-surface. In comparison, sites with impermeable sediments may accumulate the constituents, such as metals and salts, of the discharge water on the lake surface. In this case, it is possible that the constituents may be distributed throughout the lake surface on filling, rather than moving through the sub-surface profile.

Salt lakes in the Goldfields region overly hypersaline palaeodrainage, and are areas of discharge for groundwater. Therefore salt crusts are a natural and common occurrence as they reflect the natural groundwater conditions. The addition of hypersaline dewatering discharge will increase the concentrations of salts and can lead to saturation of surface water, resulting in a thicker, precipitated, salt crust within these lakes.

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 of natural lake systems tend to be the most productive in terms of biota (Outback Ecology 2006; 2008c). However, if embayments are used as the discharge point, the potential for flushing contaminants from the discharge point is greatly reduced. By placing dewatering discharge outfalls within the vicinity of creeklines, flushing of parameters throughout the lake is possible during substantial rainfall events. However, previous studies have shown that there is the potential for backflow of hypersaline discharge water to occur when conditions are dry (Outback Ecology 2008a).

Vegetation present along low-lying lake margins, including dune systems, can be affected by dewatering discharge, either by flooding, sub-surface movement of water into the dune zone or the deposition of wind blown salt onto the dunes (Foster 2004; Outback Ecology 2008b). Sites with rocky margins, or steep dunes, which are not common features of salt lakes of the Goldfields, display less impact from the discharge than low-lying areas (Outback Ecology 2007) .

Climate

Climate can influence the impact of dewatering discharge on inland salt lakes. Frequent and considerable rainfall events contribute to ameliorating the impacts of discharge by dissolving the salt crusts and redistributing constituents from the vicinity of the discharge outfall. Rainfall also aids in the dilution and movement of materials through the subsurface. This was the case at Lake Carey during a flood event in 2004, with sites that were previously impacted by dewatering discharge displaying characteristics similar to natural sites (Outback Ecology 2004).

Within these episodically-filled lakes, water is predominantly moved around the lake by the wind, a process known as seiching. Therefore the prevailing wind direction will influence the areas more likely to be affected by the discharge. Also as the water body dried out, it is likely that windblown salt may be distributed to the surrounding dunes.

Anthropogenic Structures

Man-made structures such as causeways, tailings storage facilities and exploration pads on the surface of salt lakes can contribute to the impact of dewatering discharge. Exploration on the lake bed is a common occurrence, leading to the construction of causeways, and the compaction and disturbance of sediments. Causeways effectively partition the lake and increasing local salt loadings, as well as potentially inhibiting flow and restricting the movement of biota (Timms 2005). Tailings storage facilities situated close to the lake can lead to leaching of constituents into the lake system (Finucane 2001). This contamination is believed to be exacerbated as a result of the greater flow of water from the discharge at this site than would occur in natural conditions.

Recovery of the lakes

Although the impacts of dewatering discharge can be considerable, there is potential for recovery from these impacts. Lakes within the Goldfields displaying signs of recovery include Kurrawang White Lake, Lake Miranda, Lake Austin, Banker Lake, Lake Koorkoordine, Southern Star Lake and parts of Lake Carey (Gregory 2007). However, with the exception of Lake Miranda, there is little information available on pre- discharge or baseline conditions. At Lake Miranda, water pH, as well as salinity, concentrations of nutrients, chlorophyll *a* and cyanide were all within baseline survey ranges (pre-discharge) by two years after discharge ceased. By contrast, concentrations of some metals remained elevated above baseline conditions, indicating some residual impacts from dewatering discharge (Finucane *et al.* 2003).

Outback Ecology has monitored 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 for all lakes, some common trends were observed, and recovery from discharge conditions is apparent. Salt loads and salt crusts have decreased over time, as have concentrations of certain metals. Although the biota present in the surface waters have not been monitored due to a lack of filling events, diatom productivity (i.e. a combination of diversity and abundance) in the BMCs has increased during the monitoring period, indicating recovery. This rate of recovery appears to be enhanced after large rainfall events (Outback Ecology 2006; 2007; 2008c). It should be noted however, the original condition of these lakes is unknown, and recovery is in relation to the conditions recorded from un-impacted sites during the discharge period.

MONITORING TO DETERMINE IMPACTS AND MONITOR RECOVERY

To adequately assess the impact and monitor the recovery of a salt lake from the impact of dewatering discharge it is imperative to start with a robust baseline data set. There is a lack of baseline data for many operations, and this issue is further complicated by the decrease in reliable rainfall. In the absence of surface water in these systems, other monitoring techniques have been utilized and are discussed below.

Baseline Data Collection

It is important to collect as much information as possible prior to the commencement of discharge operations for a number of reasons including;

1. To determine whether there are unique, rare or protected flora/fauna inhabiting the salt lake.

2. To establish the abiotic baseline conditions in relation to sediments and water quality of the lake, prior to any discharge, against which future data can be compared.
3. To aid in deriving objectives and targets for managing the lakes involved.

When collecting baseline data, the following should be considered;

1. Collection of data should occur over a number of seasons, both in the wet and dry phases of the hydrocycle to allow for an understanding of the productivity within the lake and the diversity of the biota.
2. Abiotic parameters that are likely to be of concern should be identified (chemical indicators), and included in the analyses of the water and sediment.
3. Sampling of both the zone of potential impact and comparable control sites is required, identify different habitats in the lake. Sites with similar geology and morphological characteristics should occur, as these parameters can have a profound affect on the chemical properties of the lakes.

It is advantageous to sample at a minimum the parameters listed in **Table 1**. While the productivity 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 of sediments. When choosing sample sites, consideration should be given to access during wet conditions.

Table 1 Potential components of a baseline monitoring program during both the dry and wet phases of the hydrocycle.

Ecosystem Component	*Stage of Hydrocycle*	
	Wet Phase	*Dry Phase*
Water Quality	✔	
Sediment Quality	✔	✔
Invertebrates		
Aquatic Invertebrates	✔	✔ *(hatching trial)*
Dormant Eggs	✔	✔
Algae/Macrophytes		
Phytoplankton	✔	
Benthic Microbial Community	✔	✔
Dormant Seeds/Oospores	✔	✔
Vegetation and Microbial Crusts	✔	✔
Avian Fauna	✔	✔

Operational Monitoring

It is not always possible to collect baseline data due to the long history of mining at some salt lake in the Goldfields. Therefore every effort should be made to find sites within the lake which have not been affected by dewatering discharge. If the entire lake is influenced by dewatering discharge, then proxy lakes may be utilized. However these lakes should be those within the same palaeodrainage system or with a similar geomorphology. Data collected during the operational monitoring program should be similar to that collected during the baseline studies.

Post Closure Monitoring

This type of monitoring is appropriate when discharge has ceased. Recovery of salt lakes can be monitored over time and monitoring should be completed to determine potential long term impacts. Changes expected in relation to recovery may include a reduction in salinity, size of salt crusts, major anions and cations, metals and nutrients. In addition, increases in the diversity of algae and invertebrates may indicate potential recovery of the system.

CONCLUSION

The impacts of dewatering discharge on the receiving environment are numerous and include changes to the water and sediment quality. These changes also influence aquatic biota and fringing vegetation. In addition, aeolian and fluvial erosion of shore lines and dunes can affect the integrity of the lake ecosystem. Factors such as discharge quality, quantity, local geology, climatic conditions, lake size, site morphology and topography and anthropogenic structures can all amplify the impacts of the dewatering discharge. Although these impacts can be significant in relation to the lake ecosystem, there is the capacity for recovery.

Recent publication of studies relating to the impact of dewatering discharge in the Goldfields region of Western Australia has led to increased knowledge in relation to the impacts of dewatering discharge in recent times. This has resulted in the tailoring of monitoring programs to adequately assess and monitor these impacts. In addition, there has been substantial efforts by mining companies to determine the impact of dewatering discharge on salt lakes which has contributed to the understanding of salt lake environments as a whole.

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