Donato Environmental Services
ABN: 68083 254 015
Mobile: 0417 819 196
Int'l mobile: +61 417 819 196
Email: ddonato@rbe.net.au
Phone: +61 8 8842 1181
Fax +61 8 8842 1186

Influences of hypersaline tailings on wildlife cyanide toxicosis: Granny Smith Gold Mine

Report to:
Barrick Granny Smith Gold Mine
20 December 2010

FINAL REPORT

Carbon Planet
Donato Environmental Services is
Carbon Managed.

DES
DONATO
ENVIRONMENTAL SERVICES

Disclaimer

This report has been prepared and produced by Donato Environmental Services (ABN 68083 254 015) in good faith. However, Donato Environmental Services accepts no liability (including liability of negligence) and takes no responsibility for any loss that a user of this report or any third party may suffer or incur as a result of reliance or use, as stated or inferred in this report, and in particular for:

- any errors, misinterpretations or omissions in the report;
- any inaccuracy in the information and data on which this report is based or contained in this report; and
- any interpretations, recommendations or opinions stated in, or which may be inferred from, this report.

Citation

Smith G.B., Donato, D.B., and Madden-Hallett, D., 2010, Influences of hypersaline tailings on wildlife cyanide toxicosis, Granny Smith Gold Mine, Draft Report, September, Donato Environmental Services, Darwin.

Distribution

Receivers	Copies	Date Issued	Issued by
Frances Mills, Leon Hill, Arlene Rofe	Draft (electronic)	15 Sept 2010	DES
Frances Mills, Leon Hill, Arlene Rofe	Second draft (electronic)	18 November 2010	DES
Peer reviews, Owen Nichols	Second draft (electronic)	18 November 2010	BGS
Frances Mills, Leon Hill, Arlene Rofe	Final (electronic)	20 December 2010	DES

Preface

This preface is to provide peer reviewers with the context and ramifications of this report in terms of the International Cyanide Management Code (Code) and Code compliance at Barrick Granny Smith Gold Mine (BGS). Three issues are discussed in this preface: the relevance of recommendations derived from this work; the necessity of collecting site-specific data to test hypotheses; and the site data used in this study.

The effects of cyanide on fauna in tailings storage facilities (TSFs) are addressed primarily in Standard of Practice 4.4 of the Code. Code objectives, guidance on meeting the Code and auditing requirements are provided in additional documents [1-3]. A series of newsletters are also produced to inform the cyanide industry of new developments and provide clarification [4-7].

Recommendations

The Code stipulates that cyanide will generally not kill wildlife at a concentration of less than 50 mg/L WAD cyanide [1]. The Code provides a process for mining operations to prove and demonstrate compliance in excess of this numerical guideline. This peer-reviewed process involves collecting and analysing site-specific empirical data to establish a causal relationship between identified protective mechanisms and the lack of wildlife deaths (p. 33 [2]). This process of hypothesis development and subsequent findings and recommendations follows the Code compliance process at Sunrise Dam, Kanowna Belle and St Ives gold mines.

If any hypothesis describing a protective mechanism to an otherwise toxic solution is accepted then this is developed as a theory in the discussion of this report. Recommendations provided are to address limitations of the theory or dataset completeness and identify requirements for compliance with the Code. If accepted, the recommendations are binding and conditional for Code compliance.

> *While these necessary practices may be termed "recommendations," they are actually requirements for the operation's compliance with this Standard of Practice. Since the operation must implement the recommendations and their implementation will be evaluated by Code auditors during the certification process, they should be drafted so that, to the extent practical, they are clear and unambiguous in presentation, specific and quantifiable. The operation must be able to demonstrate that the recommendations have been implemented in order to maintain compliance with this Standard of Practice (p. 33 [2]).*

Hypotheses testing

The BGS Interim Report stated that to test the hypotheses proposed (and accepted at other mine sites following M398 and other work) the following conditions are required:

- wildlife is present and interacts with cyanide-bearing habitats;
- WAD cyanide at spigot discharge exceeds 50 mg/L; and
- tailings slurry and solution exceeds 50 000 TDS mg/L.

Causation was established with site-specific empirical data at the other hypersaline sites as the three conditions were continuously met. The WAD cyanide discharge concentration at BGS is variable, at times greater and less than 50 mg/L. This is expected to continue. The BGS Interim Report did not include data collected while the system was hypersaline and spigot discharge was greater than 50 mg/L. Consequently the hypotheses were not tested with site-specific data. Subsequently, spigot discharge has been above 50 mg/L and the system is hypersaline, and data collected under these conditions is included in this report. It has not been recommended and would not be compliant with the Code to deliberately increase the cyanide dosage rate to further test the hypotheses. Standard of Practice 4.2 states:

> *Introduce management and operating systems to minimise cyanide use, thereby limiting concentrations of cyanide in mill tailings (p. 3 [1]).*

The Implementation Guidance document goes on to state:

> *Limiting cyanide use to the greatest extent practicable has environmental and economic benefits because reducing the concentration of cyanide lowers the risk of potential seepage and harmful exposures to wildlife, and minimising the amount of cyanide that must be transported to the site lowers the potential of transport-related releases (p. 10 [8]).*

And the Auditor's Guidance document states:

> *Standard of Practice 4.2 applies solely to milling operations, the intent being to limit the use of cyanide to that optimal for economic recovery of gold so that the waste tailings material has as low a cyanide concentration as practical (p. 28 [2]).*

This predicament produces the ironic and counter-intuitive position that to meet Code compliance (by hypothesis testing with empirical data only) the operation must discharge above 50 mg/L WAD cyanide concentration during all seasons and under all conditions. This is currently not necessary to meet process gold-recovery targets. A process is not articulated in the Code where a site discharges WAD cyanide concentrations above and below 50 mg/L (with protective mechanisms) and gains compliance yet one exists for sites that solely discharge over 50 mg/L (with protective mechanisms).

To approach this issue this report provides site-specific data where WAD cyanide discharge concentrations are greater than 50 mg/L, however this report addresses causation and predicts risks while not continuously necessitating this requirement. This process is consistent with Standard of Practice 4.2 and does not necessitate or force the site to discharge above 50 mg/L WAD cyanide and hence continues to encourage a reduction in cyanide usage and meet the objectives of the Code.

Dataset

Wildlife cyanide toxicosis risk has been studied in a continuous and consistent manner at BGS since 2006, as part of the Sustainable Minerals Institute (SMI) (formerly Australian Centre for Mine and Environment Research (ACMER) P58), the Mining and Energy Research Institute of Western Australia (MERIWA) project M398 [9] and this work.

Data from all studies is considered and incorporated in this report. The data collection methodology has been improved since M398 and aims for continuous improvement.

Executive summary

Barrick Granny Smith Gold Mine (BGS) was one of the international mining operations involved in a study in 2006 under the auspices of the then Australian Centre for Mine Environment Research (ACMER) to investigate wildlife cyanide toxicosis risks associated with gold mine waste solutions. Subsequently, BGS was one of three mining operations that undertook a study of the effects of hypersalinity (greater than 50 000 mg/L total dissolved solids (TDS)) as a protective mechanism under the auspices of the Minerals and Energy Research Institute of Western Australia (MERIWA) as project 398 (M398). A salinity of 50 000 TDS is protective as wildlife cannot drink such saline water and avoids its ingestion during foraging activities. This current study builds upon and is a continuation of these previous studies. The M398 study was previously peer reviewed under the processes provided in the International Cyanide Management Code (Code) resulting in two sites (Kanowna Belle (BKB) and St Ives (GSI) gold mines) gaining full compliance due to acceptance of the hypothesised protective mechanisms. At the time BGS was documented as saline (14 000 to 21 000 mg/L TDS). A residual (theoretical) risk was therefore identified, even though no deaths were recorded during that study, as some wildlife species have been reported in the literature as able to drink solutions of up to 47 000 mg/L TDS (see Appendix 1).

BGS continued to monitor the tailings storage facility (TSF) as stipulated in the recommendations of the M398 study. To address the identified theoretical residual risk, a hypersaline wash circuit was introduced into the tailings system on 7 May 2010.

The primary avenue of exposure of wildlife to hypersaline cyanide-bearing solutions is ingestion while attempting to forage within the supernatant or successfully foraging on terrestrial invertebrates embedded in the supernatant and wet tailings. Ingestion rates of hypersaline solutions are reasoned to be less than that experienced on fresh tailings systems because wildlife purposely limits the amount of solution (and therefore salt) ingested to avoid ionic loading and dehydration (see Appendix 1). The elimination of drinking pathways and limited ingestion while foraging is therefore a significant exposure reduction relative to that expected at fresh tailings systems.

The authors have collected a number of different types of data to document wildlife ecology, resources availability for wildlife, exposure pathways to cyanide-bearing mine waste solutions and cyanide concentrations that wildlife was exposed to in different habitats.

Chemistry sampling was conducted in the mill circuit and on a spatial and temporal basis within the active tailings cell. Quality assurance and quality control of sampling analysis was conducted by utilising three NATA-registered laboratories.

A limited dataset is provided from a fresh water tailings system of similar cyanide concentration (Mt Todd Gold Mine) for comparison with the hypersaline tailings system at BGS.

Literature to further identify and validate hypotheses has been used and incorporated into theory development.

Under hypersaline conditions at the TSF (8 May to 21 August 2010) a total of 480 wildlife visitations were recorded by Donato Environmental Services (DES) at an average rate of 21.8 ± 19.0 visitations per day. This contrasts with an average of 31.4 ± 26.6 visitations per day on days DES observed the TSF during the saline period (34 days between 15 June 2006 and 7 May 2010). A total of 1 567 visitations to the TSF were recorded over both periods. On-site monitoring recorded 388 visitations over 70 days under hypersaline conditions (8 May 2010 onwards) and 4 093 over 1 023 days under saline conditions at the BGS TSF.

Red-capped Plovers were present on 100% of days DES observed the TSF and Welcome Swallows were present on 47% of days. Both species were regularly recorded by on-site staff monitoring over the four-year period.

Four cyanide-related wildlife deaths (all Red-capped Plovers) occurred on 1 May 2010 at the TSF when tailings discharge was brackish (< 10 000 mg/L TDS). This is consistent with the findings of M398 that wildlife exposure to cyanide-bearing habitats at greater than 50 mg/L WAD cyanide and less than 50 000 mg/L TDS provides a theoretical risk to wildlife.

Synchronised cyanide and wildlife interaction data collected by DES on the hypersaline system demonstrated a substantial level of wildlife exposure to habitats containing greater than 50 mg/L WAD cyanide with no impact.

Given the number of wildlife visitations to cyanide-bearing habitats recorded, literature predicts that significant numbers of wildlife deaths would have also been recorded. The lack of wildlife deaths at the hypersaline BGS TSF suggests that one or more mechanisms not present on fresh systems are acting as protective measures for wildlife.

A total of nine hypotheses were proposed to explain the lack of wildlife deaths. Eight were dismissed. The following hypothesis was accepted by this work:

Hypothesis 7: Hypersaline tailings solutions (nominally > 50 000 TDS) provide a natural barrier for wildlife exposure to contained WAD cyanide.

The necessity for wildlife to avoid salt ingestion or avoid salts once ingested has been discussed in the literature. Marine species can secrete salt through salt glands whereas terrestrial species (including ducks, waders and others) must avoid excessive salt intake to maintain osmotic balance within the body. Mechanisms for avoiding salt intake while foraging in hypersaline waters have been recognised and discussed in the literature and involve physiological and behavioural strategies. These processes of salt avoidance eliminate drinking as an exposure pathway and reduce inadvertent ingestion while foraging on terrestrial macroinvertebrates amongst tailings substrates.

Data collected during this and the M398 study provides support for this position.

This hypothesis is consistent with the effects on wildlife use (and inferred ingestion) of hypersaline water and is consistent with observed data. This hypothesis is supported for both drinking and foraging behaviour.

As with all research some limitations have been identified. Limitations are presented here in conceptual, generic terms and within the scope for compliance with the Code. These limitations identify gaps of knowledge or data. The subsequent recommendations are used to address these limitations to enable BGS to move toward Code compliance.

Recommendations have been developed in the context of the relevant standards of practice specified in the Code. Operating parameters have been determined using chemistry data from TSF samples collected between 8 May

2010 (when the TSF became hypersaline) and 21 August 2010 and analysed off-site by a NATA registered laboratory. Since no wildlife cyanosis deaths were recorded under hypersaline conditions, the recommendations address maintenance of the protective measures already in place, continued verification of the lack of wildlife deaths and modification of the current procedures where necessary to address any perceived limitations identified in this work.

Recommendation 1: Operating parameters.

A set of operating parameters for the BGS tailings system is required as wildlife does interact with the cyanide-bearing solutions and substrates. A toxicity threshold will exist but no such threshold for the hypersaline system was determined from this work. It is therefore considered that the hypersaline BGS TSF is benign to wildlife at the operating parameters measured.

The recommended operating parameters for cyanide (at spigot and supernatant) are given as a maximum discharge concentration (the 95th percentile) and an 80th percentile. The aim is to replicate the regime and the distribution of WAD concentrations that operated while hypersaline.

Recommended operating parameters are given in Table i. The operating parameter for salinity is given as a minimum of 50 000 mg/L TDS at spigot discharge into and within the TSF as this exceeds the maximum known salinity that wildlife is known to be capable of drinking.

Table i. Recommended target operating parameters for BGS

	Maximum WAD cyanide mg/L	WAD cyanide 80th percentile mg/L	TDS mg/L
Spigot	83.3	71.7	>50 000
Supernatant	40	N/A	>50 000

Recommendation 2: Write an articulated tailings management plan that incorporates relevant procedures to maintain compliance with these conditions.

Recommendation 3: Continue assessment of risk to wildlife.

Recommendation 4: Continue structured on-site monitoring regimes incorporating:

- daily salinity monitoring in the mill process circuit;
- daily cyanide and chemistry monitoring at the TSF;
- duplicate tailings samples to be taken from the spigot discharge;
- daily wildlife monitoring by trained staff;
- wildlife monitoring data management; and
- wildlife monitoring training.

Recommendation 5: Conduct regular assessments of on site laboratory practices to ensure continual improvement in accuracy of analysis.

Recommendation 6: Conduct an ongoing assessment or review of adherence to these conditions.

Recommendation 7: Minimise infrastructure in the vicinity of cyanide-bearing habitats.

Recommendation 8: Suppress and remove vegetation in and near cyanide-bearing water bodies.

The limitations of this work have been identified and addressed by the recommendations. There is no more than a minimal identified risk to wildlife if operating parameters are adhered to. Consequently the limitations of this work should not hinder Code compliance with Standard of Practice 4.4 of the Code. The recommendations are more descriptive and stringent than those of Sunrise Dam Gold Mine (SDGM), BKB and GSI, which reflects the increased knowledge gained. The recommendations are industry leading practice and exceed any other Code compliant operation with reference to Standard of Practice 4.4.

Contents

Appendices

Introduction

Standard of Practice 4.4 of the International Cyanide Management Code (Code) requires that operations implement measures to adequately protect wildlife, particularly birds, and livestock from adverse effects of cyanide process solutions [10].

It is stipulated in Standard of Practice 4.4 that operations should implement measures to limit the concentration in open impoundments to a maximum of 50 mg/L weak-acid dissociable (WAD) cyanide as this is the concentration widely viewed as being protective of most wildlife and livestock [11].This is derived for the protection of terrestrial vertibrates, which is also the focus of this project. This is derived from operations using relatively fresh water sources in their mill processing and depositing tailings via a peripheral-discharge tailings system. However the Code provides a process for mining operations to prove and demonstrate compliance in excess of this maximum WAD cyanide concentration.

> *(An) operation could demonstrate that a higher concentration of WAD cyanide in open water does not cause wildlife mortality due to site-specific reasons. For example, if there are no birds that drink from the beach of an impoundment in the area of an operation, then the 50 mg/L limit would not apply at the discharge point. Similarly, if the operation could demonstrate that a 50 mg/L concentration of WAD cyanide is not lethal to the specific types of birds and other wildlife that live and pass through the area, then some higher but still protective level would be appropriate. However, making these demonstrations to the auditor's satisfaction will not, and should not, be easy. Anecdotal evidence such as "we've never seen any bird mortality" is not sufficient, although any assertion that the 50 mg/L limit is unnecessary must be supported with comprehensive, daily inspection records demonstrating that there are no deaths. The operation must also present the scientific rationale for the lack of mortality at a cyanide concentration that would otherwise be toxic. This could be a study by an appropriately qualified person concluding, for example, that no wading or shore birds are known to be in the area, or that the local population of birds and wildlife are resistant to this cyanide concentration. In support of such a proposition, comprehensive daily inspection records demonstrating that there are no deaths must be presented in the form of a scientific study; any such study must be peer-reviewed and sufficiently rigorous that a causal relationship is established [10]. Like any competent scientific study, the results must be independently reproducible and predictive [10].*

Establishment of causation essentially requires identification of protective mechanisms (for example, habitat manipulation or natural degradation) that prevent solutions with typically toxic concentrations of cyanide from causing wildlife mortality [10]. Hypotheses must be supported by empirical data collected in a structured manner that withstands the scrutiny of peer review.

As a Code requirement, Donato Environmental Services (DES) must take an unbiased approach in considering the available information and data. Consequently, a number of hypotheses are presented in this report that explain the apparent discrepancy between WAD cyanide discharge levels and the few infrequent wildlife deaths.

Many gold mining operations in the Central Goldfields region of Western Australia utilise hypersaline water for gold ore processing, a practice understood to be essentially unique to this region.

Anecdotal information and evidence [9] suggests that wildlife interaction and ingestion of hypersaline solutions and tailings is less than that experienced at other tailings facilities. Furthermore, evidence suggests that some of these operations experience more rapid degradation of both free and WAD cyanide following deposition of plant tailings to a TSF than for fresh water systems [9]. It is thought that factors influencing this degradation may include chemical composition (i.e. dissolved salts), relatively low pH, and a hot and arid/semi-arid local climate.

If a hypothesis developed to describe these observations is shown by means of a comprehensive peer-reviewed study to be scientifically valid, it may be appropriate to establish a site-specific set of criteria for hypersaline tailings streams, dams and ponds, separate from those for fresh water tailings.

Classification of salinity levels

The definition of salinity of a solution is problematic in that the chemistry comprises a complex mixture of cations and anions, the ratios of which can change due to saturation limit effects as some insoluble compounds such as gypsum precipitate from higher-concentration solutions. In 1978, oceanographers redefined salinity in the Practical Salinity Scale (PSS) as the conductivity ratio of a seawater sample to a standard KCl solution [1]. Conductivity measurements can also be calibrated against simple TDS determinations for a specific site, hence, the convention adopted in this work is to report salinity levels in terms of TDS in mg/L.

Mantyla, 1987 [1] classified water as fresh at < 500 mg/L, brackish at < 30 000 mg/L and saline at < 50 000 mg/L. The Water Authority of Western Australia (WAWA) in their Goldfields Groundwater Area Management Plan of 1994 [2] classified potable water as < 2 000 mg/L TDS, brackish as < 14 000 mg/L and hypersaline as < 100 000 mg/L. However, the focus of this project is on protective mechanisms for wildlife and ingestability of saline solutions. Consequently salinity categories used for this project are related to abilities of wildlife to drink saline solutions. Literature review revealed that the Zebra Finch, a widespread Australian resident of semi-arid areas, is reportedly able to drink saline water of up to 47 000 mg/L TDS which determined the saline/hypersaline limit. The salinity levels adopted for this project are defined as:

- **fresh**: 0 to 2 000 mg/L TDS – palatable to all wildlife;
- **brackish**: 2 000 to 14 000 mg/L TDS – palatable to most (if not all) Australian terrestrial wildlife but not to some livestock;
- **saline**: 14 000 to 50 000 mg/L TDS – unpalatable to all livestock and some Australian wildlife but palatable to many terrestrial Australian wildlife; and
- **Hypersaline**: 50 000 to 300 000 mg/L TDS – unpalatable to all wildlife.

Influence of hypersalinity on exposure pathways for wildlife to cyanide-bearing solutions

Assessment of wildlife exposure and behaviour is required to understand the influences of hypersalinity on cyanosis risks on tailings systems. There are three ways that wildlife is exposed to cyanide in the tailings environment:

- epidermal absorption (absorption of aqueous cyanide through the skin);
- inhalation of cyanide gas; and
- ingestion (drinking of the supernatant and foraging in supernatant or on wet tailings) [12].

A review of the literature (see Appendix 1) found the following:

There has been no evidence of an epidermal absorption effect on wildlife at cyanide concentrations typically experienced at one site [13] or by the gold industry in general.

Cyanide gas exposure is not considered sufficient enough to cause cyanosis to wildlife at concentrations typically experienced in tailings dams throughout the industry (Sadler 1990).

Salinity strongly influences the palatability of drinking water for all vertebrate species. The maximum salinity an animal has been recorded drinking is 47 000 /L TDS (133% of sea water) for the Zebra Finch under laboratory conditions [14, 15]. This species is found on-site at BGS. No other bird has been recorded as being as saline tolerant.

Hypersalinity inhibits foraging behaviour for some species (Marchant and Higgins 1990, 1993). Many species can forage in hypersaline waters (Mahoney and Jehl 1985, [16] but seek to avoid salt ingestion to minimise physiological stress placed on the body through excess salt ingestion (Schmidt-nielson et al 1964, Skadhaudge 1982, Wingdingstad 1987, Gordus et al 2002, Hampton and Yamamoto 2002). Wildlife uses morphological and behavioural adaptations to avoid salt ingestion while foraging in hypersaline waters [17, 18]. Some inadvertent ingestion of solution while attempting to feed may occur but it is likely that amounts ingested will be very small as animals seek to avoid dehydration caused by hypersaline water.

Previous studies

Barrick Granny Smith Gold Mine (BGS) was one of the international mining operations involved in a study in 2006 (ACMER P58) under the auspices of the then Australian Centre for Mine Environment Research (ACMER) to investigate wildlife cyanide toxicosis risks associated with gold mine waste solutions and produce a site-specific report. The ACMER P58 study identified the apparent observational evidence of a lack of wildlife deaths at BGS and other hypersaline sites for the recorded cyanide concentrations.

Subsequently, BGS was one of three mining operations that undertook a study of the effects of hypersalinity as a protective mechanism for wildlife from an otherwise toxic solution. That study [9] was conducted under the auspices of the Minerals and Energy Research Institute of Western Australia (MERIWA) as project 398 (M398). The M398 study was peer reviewed under the processes provided in the Code resulting in two sites (Barrick Kanowna Belle (BKB) and Goldfields St Ives (GSI)) gaining compliance due to acceptance of hypothesised protective mechanisms.

These are as follows:

Hypothesis 7A: Hypersalinity (> 50 000 mg/L total dissolved solids (TDS)) provides a natural barrier for wildlife exposure to WAD cyanide contained in tailings solutions because at this salinity the solutions are outside the physiologically safe drinking range of wildlife and wildlife seeks to avoid its ingestion while foraging.

Hypothesis 7B: Salinity (> 14 000 mg/L TDS) provides a partial barrier for wildlife exposure to WAD cyanide contained in tailings solutions because at this salinity wildlife is either unable to drink solutions or preferentially drinks fresh water if it is available.

Hypothesis 8: WAD cyanide in hypersaline waters is lost at rates sufficient to have a substantial beneficial impact on the physical area of wildlife exposure to contained WAD cyanide (levels and profiles are to be determined on a site-specific basis).

Recommendations were provided in the context of the relevant standards of practice specified in the Code to address any perceived risks of wildlife cyanosis at BKB, GSI and BGS and identify requirements for compliance with the Code.

A set of operating parameters (recommendations) for each tailings system was provided as wildlife does interact with the cyanide-bearing solutions and substrates. A toxicity threshold will exist for every system but no such threshold was determined at any of the sites because no wildlife deaths were recorded during the project. It is therefore considered that these sites are benign to wildlife at the operating parameters experienced.

The operating parameters recommended for BKB and GSI by the M398 study for the discharge spigot are presented in Table 1. The recommended operating parameters for cyanide are given as a maximum discharge concentration plus a second 80th percentile value. The maximum discharge concentration (WAD cyanide) is the 95th percentile value for assays measured during the study. The 80th percentile is also given for WAD spigot discharge to represent a figure under which the site should aim to operate for 80% of days. The aim of this is to replicate the regime and the distribution of WAD concentrations that operated during the course of the project.

Table 1. Recommended operating parameters for GSI and BKB

	Maximum WAD cyanide mg/L	WAD cyanide 80th percentile mg/L (operate under on 80% of days)	TDS mg/L	Copper mg/L
GSI spigot	132	112	> 50 000	46
GSI supernatant	65	N/A	> 50 000	44
BKB spigot	92	78	> 50 000	50
BKB supernatant	40	N/A	> 50 000	50

A series of additional conditional recommendations were provided for each site. These were to address limitations associated with current knowledge and included wildlife and chemistry monitoring.

The apparent lack of wildlife deaths at BGS during the M398 study even with WAD cyanide concentrations above 50 mg/L at discharge was suggested to be due to protective mechanisms. These protective mechanisms were theorised to be provided by cyanide degradation, lack of drinking of tailings solutions and small dosage of tailings and cyanide ingested by birds foraging within the TSF (possibly due to salinity avoidance). However tailings solutions are theoretically palatable to some wildlife at salinities measured during M398. While protective mechanisms were inferred during the M398 study, a theoretical risk was found to exist.

Current study

This current study builds upon and is a continuation of the previous studies.

Chemistry parameters critical for evaluating the risk to wildlife at BGS are the same as for other hypersaline sites, as follows:

- WAD cyanide at the spigot and in the supernatant;

- salinity at spigot and supernatant;
- soluble copper at spigot and supernatant; and
- pH value.

While not all are operating parameters to which the site must adhere, they can all influence the risk to cyanide through either affecting ingestion rates for wildlife foraging or drinking (salinity), determine the hazard (cyanide) or determine the resilience of the hazard (pH and copper) in the TSF. Consequently the monitoring of these parameters is necessary at frequencies pertinent to each of the parameters.

BGS continued to monitor the tailings system as stipulated in the recommendations of M398 study. To address this theoretical risk, a hypersaline wash circuit was introduced into the tailings system (after the tailings thickener) on 7 May 2010. WAD cyanide concentrations at discharge have found to be below 50 mg/L WAD cyanide for the majority of the time for at least the last two years but at times it is above 50 mg/L. The supernatant has been measured at below 50 mg/L WAD cyanide in all but a few samples.

This current work focuses on wildlife and cyanide data collected by DES from April to August 2010 but also considers the data collected during the ACMER P58 and M398 studies. Combined, these studies involved:

- surveying available literature to define hypersalinity;
- developing a hypersaline cyanide hypothesis covering the proposal that hypersaline operations experience more rapid cyanide losses and lower ecotoxicological impacts than operations with freshwater conditions;
- reviewing available technical, ecotoxicological, TSF ecology literature and plant historical data to define, if appropriate, likely scientific bases for the hypotheses;
- determining cyanide speciation and water quality profiles for the final tank, tailings box, spigot, delta, beach, supernatant, decant pond, process water, tailings habitat, substrate and other related data;
- documenting and quantifying wildlife exposure and ingestion;
- inferring dosage rates according to habitats, cyanide concentration and speciation;
- documenting, describing and quantifying bat usage patterns over discrete habitats in hypersaline tailings systems and comparing interactions with nearby fresh and naturally saline lake habitats;
- documenting wildlife usage, habitat interaction and substrate ingestion (or interaction);
- considering macroinvertebrate diversity, abundance and life forms within tailings substrates to document inadvertent dosage rates; and
- establishing daily on-site routine monitoring (wildlife exposure, cyanide and climate) ultimately to be conducted by on-site personnel in a manner consistent with requirements of the Code.

The methodologies used since 2006 for on-site monitoring have remained the same, while continuous improvements were incorporated into the DES-collected data. Some of the improvements have been implemented since the M398 study.

Hypotheses to be tested

As BGS is now a hypersaline tailings system, all the hypotheses as previously accepted under M398 are tested in this report again.

To explain the observations of the only four cyanide-related wildlife deaths at BGS TSF under saline conditions and none under hypersaline conditions, the following hypotheses are proposed:

1. Wildlife deaths occurred but the monitoring regime failed to record the presence of all carcasses.
2. Wildlife did not die in situ but flew away and died elsewhere.
3. Wildlife deaths did not occur during the monitoring period due to seasonal or other environmental influences resulting in at-risk species not being present during the monitoring period.
4. Wildlife deaths do not occur due to the physical attributes of the TSFs resulting in no wildlife interaction with the hazard.
5. Wildlife deaths do not occur because at-risk species are not found in the region or on site.
6. Wildlife deaths are below detectable levels or non-existent due to a lack of aquatic food within the TSFs resulting in little or no wildlife ingestion of cyanide-bearing solutions (the hazard).
7. Hypersaline process waters (nominally TDS > 50 000 mg/L) provide a natural barrier to wildlife exposure to contained WAD cyanide.
8. WAD cyanide in hypersaline waters is lost at rates sufficient to have a substantial impact on the area of wildlife exposure to contained WAD cyanide (levels and profiles to be determined on a site-specific basis).
9. Hypersaline tailings solutions have sufficient buffer capacity to inhibit free cyanide liberation on ingestion.

Site description

Natural environment

BGS is located 950 km northeast of Perth and 23 km south of Laverton in the Coolgardie bio-geographic region of Australia and within the Archaean Greenstone belt. Outcrop in the area is sparse and the region is dominated by extensive ephemeral salt lake systems. Most of the tenure is covered by tertiary to recent deposits of laterite, colluvium and alluvium.

The general climate of the BGS region is described as semi-arid, receiving erratic rainfall, and in a moderate to severe drought risk zone [19, 20]. Long-term climate data has been collected from the Australian Bureau of Meteorology weather station located at Laverton. The average annual rainfall is 220.9 mm, most of which falls during the period January to June. Temperatures range from a mean daily maximum of 35.8°C in January to 17.8°C in July.

Vegetation in the broader Eastern Goldfields region is dominated by mulga woodlands (Acacia aneura) over mixed understory shrubs including species of eremophila, maireana, atriplex and senna. Ground cover comprises a suite of grasses and daisies, typically species of eragrostis, eriachne, triodia and sclerolaena [21-24].

Granny Smith process plant tailings storage facility

In 2006, production from BGS totalled approximately 295 000 oz of gold. Proven and probable mineral reserves as of 31 December 2006 were estimated at 690 000 oz of gold.

The bulk of the ore supply currently comes from the Wallaby underground deposit project, situated on the shore of Lake Carey, 11 km southwest of the existing BGS mine. The Wallaby deposit occurs below aeolian sand dunes and tertiary lake clays and sands. Wallaby underground ore will be blended with the existing run-of-mine stockpiles to sustain full milling capacity. Toll ore referred to as Crescent Ore is sourced from another mining operation. Each ore is treated separately as campaigns.

The BGS processing plant has an annual throughput capacity of 3 Mt pa. It consists of a two-stage fresh ore crushing circuit including closed-circuit screening and a single-stage oxide ore crushing circuit, followed by a semi-autogenous grinding mill in closed circuit with a cone crusher, a ball mill, an agitation leaching and carbon-in-pulp circuit, tailings retreatment plant, a gold recovery plant with elution, carbon reactivation and a tailings thickener.

Recycling tailings thickener overflow back to the circuit enables re-use of the water. The waste from the thickener underflow is then pumped to the TSF. The TSF cells are operated such that deposition into each cell does not exceed two months' duration. The TSF is a three-cell operation with a combined active surface area of 270 ha. The primary water recovery from the TSF is through the decant towers. The towers have pumpback installations, returning water back to the process ponds.

The TSF is a three-celled paddock system with peripheral discharge and a supernatant pool of variable size formed in the centre of each paddock cell. Central-gravity decants are used to collect and remove supernatant water for re-use in the milling circuit. Paddock cells are discharged into for varying lengths of time and are used on a rotational basis. TSF cells 1 and 2 are older, being the original cells since commissioning of the mine, and are approximately 40 m above the surrounding landscape. Cell 3 is approximately five to six years old and currently lower-walled than cells 1 and 2 (see Figure 1). All tailings cells provide similar structural features considered as habitats for wildlife, broadly consisting of open water, beaches, dry tailings and wet tailings. A concept of the tailings discharge zone (TDZ) is used throughout this report to assess primary risk to wildlife. The TDZ is defined as the area between active (or very recently active) discharging spigots and the supernatant including the tailings plume, where the tailings entering the supernatant is still concentrated. The TDZ includes spigot pools, wet (fresh) tailings, flowing tailings stream, wet tailings beaches, clear pools and plume habitats.

A number of on-site non-cyanide-bearing water bodies are also present and the location of these is shown in Figures 1 and 2.

Surrounding the tailings facility on three sides is a saline key that intercepts lateral and subterrain water movement from the tailings cells. This key is referred to as the trench.

The haul road lakes are 2 kms from the tailings cell and are borrow pits for haul road construction. These borrow pits often contain water but would dry out in times of drought.

There are other open pits and voids that contain water, the hypersaline Goanna, Granny Smith and Keringal pits; the brackish Winditch Pit and the fresh Phoenix and Jubilee pits.

Figure 1. Aerial photograph of the mine site (August 2010) showing TSF cells and adjacent pits

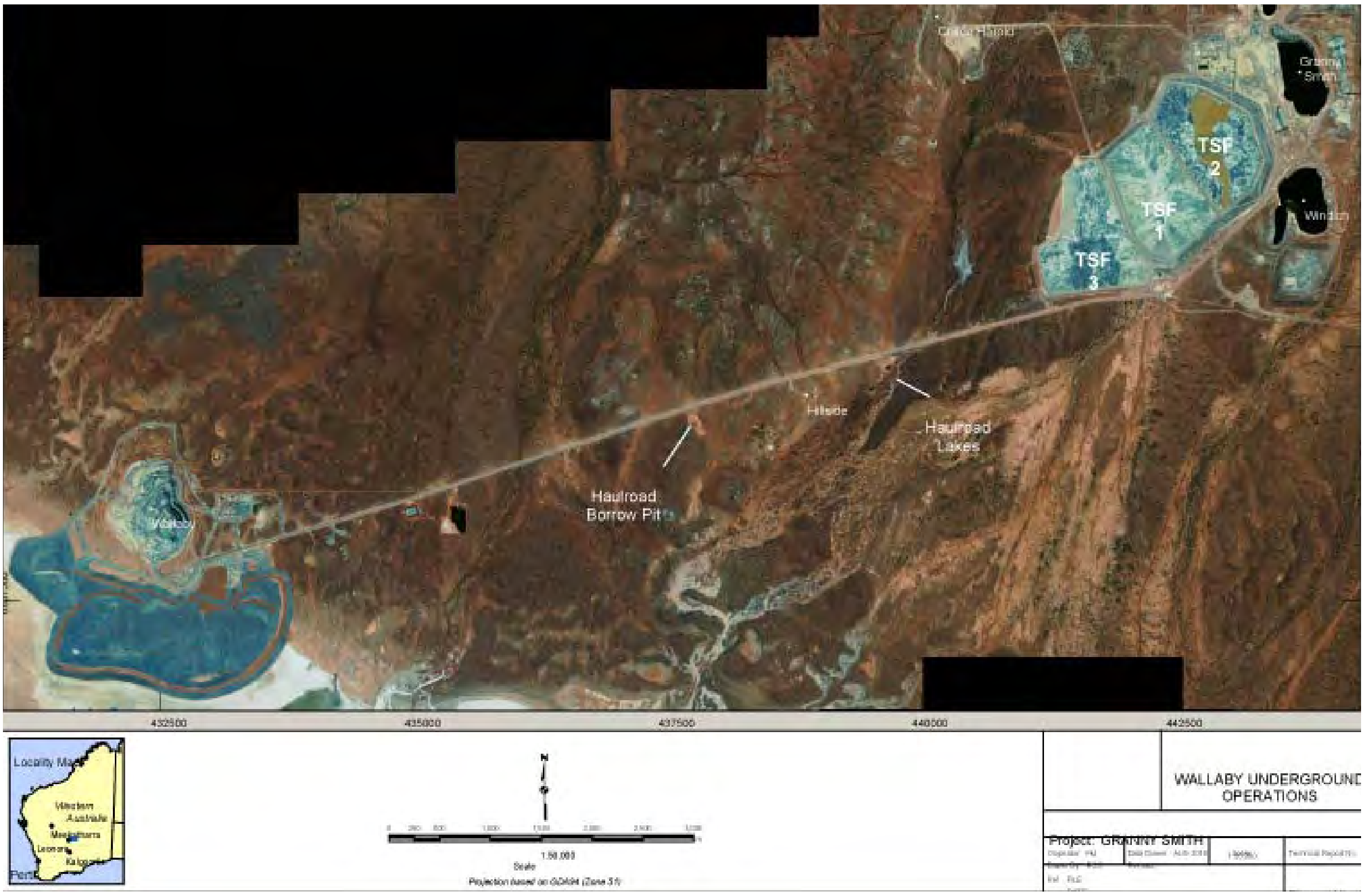


Figure 2. Aerial photograph of the mine, TSF, haul road and wallaby areas (August 2010).

Chemistry sampling and analysis methodology

Systematic on-site monitoring and study of the BGS TSF commenced in June 2006, with the ACMER P58 study and continued in 2007 and 2008 with the M398 study. The monitoring recommendations of M398 were implemented and have been ongoing through 2009 and 2010.

DES conducted intensive chemistry monitoring in May 2006 (ACMER P58), August 2007, January and May 2008 (M398) and April, May, June, July and August 2010 (this current work).

Routine on-site chemistry monitoring

On-site chemistry monitoring of the TSF in a manner consistent with current monitoring commenced in 2006 when BGS became participants in the ACMER P58 study, with regular chemistry samples taken from 17 April 2007. At the time BGS staff were advised on where to sample in the tailings system for WAD cyanide, pH, salinity and copper. The sample sites are the discharge spigot and the supernatant solution at the decant pump station of each active TSF cell.

The on-site dataset for this report considers data collected between 17 April 2007 and 18 August 2010. This routine monitoring is ongoing. Samples were analysed on site. A regular program of splitting spigot samples for duplicate ALS analysis was conducted from 16 February 2009 to 21 January 2010. Samples were split for two-way and three-way analysis at on-site, ALS and CCWA laboratories at other times. The number of samples taken and analysed by on-site, ALS and CCWA laboratories is given in Table 2.

Table 2. Number of samples analysed for each chemistry parameter by on-site, ALS and CCWA laboratories from on-site monitoring for saline and hypersaline conditions at the TSF between 17 April 2007 and 18 August 2010. Samples taken by DES are not included.

	Spigot				Decant			
Laboratory	WAD cyanide	pH	TDS	Copper	WAD cyanide	pH	TDS	Copper
Saline (17 April 2007 to 7 May 2010)								
On site	372	279	325	296	384	0	0	340
ALS	50	52	52	50	0	0	0	
CCWA	55	2	23		0	0	0	
Hypersaline (8 May to 18 August 2010)								
On site	76	72	74	78	84	70	62	60
ALS	2	2	2		2	2	2	
CCWA	2	2	2		2	2	2	

Additional chemistry sampling (mostly pH and free cyanide) regularly occurs at various points in the mill for process purposes. Cyanide is also measured automatically at leach tank 0 and free cyanide is measured every four hours in leach tank 0 and CIP tank 6 (Figure 3). BGS is commissioning an automated WAD cyanide analyser to be located in the mill, which will be installed, in coming months. This will automatically control cyanide addition to leach tank 0. An automated salinity analyser has also been commissioned and will be installed just before the tailings hopper (Figure 3) to measure salinity of the final tailings exiting the mill and control addition of hypersaline water to meet the objective of tailings discharge at above 50 000 mg/L TDS. This will also be installed in coming months.

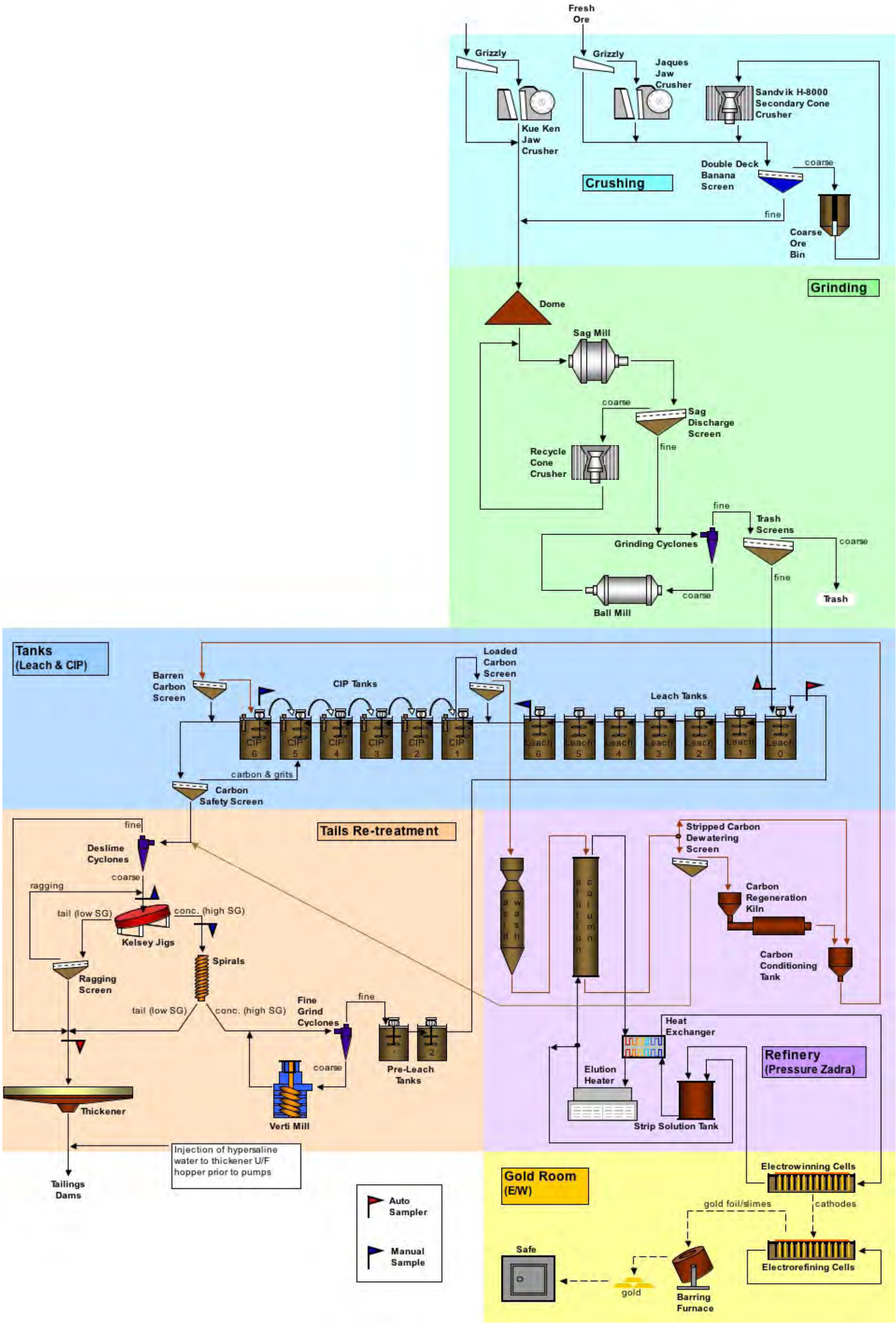


Figure 3. Mill flow sheet showing automated (red flags) and manual (blue flags) chemistry sampling points

Intensive chemistry sampling and analysis methodology (DES)

Intensive sampling by DES was conducted primarily during the M398 study and the current project however some more limited sampling (of spigots, the supernatant and time trials) was also conducted during ACMER P58.

The chemistry methodology consisted of:

- mill process plant sampling (including sample points in the mill not routinely sampled) to capture plant chemistry conditions at the time of TSF sampling;
- regular spigot and supernatant samples in the morning and late afternoon and periodically throughout the day for comparison with routine sampling analysis and wildlife observations;
- alternative water body sampling of water quality;

- spatial sampling of the TDZ primarily through spigot-to-supernatant surveys using spigots set up to discharge next to or close to the pier/causeway ('lucky spigots') and sampled with extended poles from the embankment;
- spatial and depth sampling of the supernatant using a radio-controlled boat (RCB) to determine if it is well mixed or stratified;
- time trials over one day for spigot discharge tailings where spigot sampling is conducted throughout the day (hourly to three-hourly) to determine discharge concentration variability;
- cyanide degradation test work, where cyanide degradation is measured for spigot and supernatant filtrate solutions over 48 hours under laboratory conditions;
- cyanide speciation calculation on selected samples;
- HCN gas volatilisation; and
- four special projects conducted during the M398 project:
    - Special project 1 (SP1) – determining bio-available WAD cyanide in wet and dry tailings (including unconsolidated wet tailings) by testing for leachable cyanide from dry and wet TSF surfaces;
    - Special Project 2 (SP2) – preferred sample preservation of saline and hypersaline cyanide solutions for transport to service laboratories;
    - Special Project 3 (SP3) – assessment of potential avian dose response to cyanide in hypersaline solutions; and
    - Special Project 4 (SP4) – assessment of site flame AAS analysis of copper in hypersaline solutions as a reliable plant and discharge management tool.

The number of samples taken for each site visit and the laboratory they were analysed at is given in Table 3. Methodologies employed in the current project are described in Appendix 2. All chemistry sampling was conducted in a Code-compliant manner and was consistent over all projects.

Table 3. Summary of samples taken for each site visit including total number of samples taken, the number of samples analysed by on-site, ALS and CCWA laboratories and number of samples by sampling activity. Samples may serve two or more purposes and therefore be counted in more than one category.

			Analysis				Sample Type												
Project	Sampling month	Ore Campaign	On- site	ALS	CCWA	Total number of samples taken	Plant/ Process	Spigot	Supernatant	Lucky spigot	Spigot pool	Plume (M398)	Dry or Wet Tailings	Alt water bodies	Spatial Super	Time Trials	Special projects (M398)	Two/Three way spilts	QA and QC
P58	May-06	Wallaby			41	41	6	16	16					3		26			3
M398	Aug-07	Wallaby			50	50	11	10	19	5		6				6			4
	Jan-08	Wallaby			64	65	17	10	16	11	2	1	2	4	9		8		5
	May-08	Wallaby			32	32	15	1	10			2		2					9
Current Project	Apr-May 10	Crescent	9			9		4	1				2	2					
	May-10	Crescent	22	27		35		12	14	6			2			17		22	
	Jun-10	Wallaby		37		37		22	7	6	1					17			7
	Jul-10	Crescent	18	38	13	41		20		8	5			1	8	12		14	
	Aug-10	Crescent	14	24	13	25	4	14	3		3		1		3			14	

Wildlife survey and analysis methodology

Data presented in this report is sourced from on-site monitoring results (BGS) and data collected over a number of site visits carried out by DES. All data is considered in its entirety with no omissions. The methods are described in Appendix 3 and cover on-site wildlife monitoring and intensive DES monitoring of the TSF and alternative water bodies used in this and previous studies (P58 and M398).

Routine on-site monitoring regime by trained mine staff

On-site wildlife monitoring of tailings dams

Within the TSF, only the operating cells and the surrounding ground water interception trench (seepage trench) were monitored regularly (i.e. the cells that were being discharged into) however non-active cells were also surveyed from time to time.

On-site personnel conducted on-site monitoring at the BGS TSF on a total of 1 023 days (71.8%) between 16 June 2006 and 7 May 2010, when the TSF was saline. The TSF was monitored on 70 days (68.0%) between 8 May and 18 August 2010 as a hypersaline system. The methodology used by on-site monitoring is described in Appendix 3.

Intensive diurnal wildlife monitoring (DES)

Particular attention was given to wildlife use of the TDZ as this is the area where WAD cyanide concentrations are highest. A TDZ is defined as the area between active (or very recently active) discharging spigots and the supernatant including the tailings plume, where the tailings entering the supernatant is still concentrated. The TDZ includes spigot pools, wet (fresh) tailings, flowing tailings stream, wet tailings beaches, clear pools and plume habitats. Habitats within the TDZ are categorised into finer resolution than for the rest of the TSF to gain a greater understanding of the risk presented to wildlife from TDZ habitats. Data analyses have been carried out for the TDZ and the rest of the TSF separately or combined where appropriate to gain a greater understanding of risks to wildlife.

The TDZ moved to different parts of the TSF on a rotational basis for operational reasons.

Monitoring was also conducted at a number of alternative water bodies, primarily at Goanna Pit (hypersaline), Winditch Pit (brackish), the haul road lakes (fresh) and the dewatering trench surrounding the TSF (saline to hypersaline) although other on-site water bodies were also visited. Alternative water bodies surveyed during this and previous projects are listed and broadly categorised in Appendix 3. Data collection methodologies employed at alternative water bodies are the same as those used at the TSF.

Wildlife presence, abundance, habitat use and behaviour was recorded, including carcass presence detection trials of carcass replicates. The intensive diurnal wildlife surveys were conducted at the TSF over a total of 56 days since 2006 (Table 4). Of these, 34 monitoring days were conducted on the TSF as a saline system (< 20 000 ppm TDS) and 22 monitoring days during this project as a hypersaline system (Table 4). Alternative water bodies were observed on a varying number of days (see Appendix 3).

Table 4. Number of days monitored and number of surveys performed for the TSF during this and previous projects

Site visit dates	Study	Season	Days observed	20-minute surveys	Habitat and behaviour surveys	1-minute/ interaction surveys	Balloon test conducted
Saline system			34	119	406	122	3
18-22/05/2006	ACMER P58	Autumn	5		57		
11-14/9/2006	ACMER P58	Spring	4		28		
18-19/08/2007	MERIWA M398	Winter	2		3		
18-28/01/2008	MERIWA M398	Summer	11	62	90	49	X
25-27/04/2008	MERIWA M398	Autumn	3	13	25	12	X
25-28/05/2008	MERIWA M398	Autumn	4	12	9	9	X
29/4 – 3/5/2010	Current project	Autumn	5	32	194	52	
Hypersaline system			22	113	306	271	2
11-14/05/2010	Current project	Autumn	4	21	37	35	
2-7/06/2010	Current project	Winter	6	26	32	20	?
21-26/07/2010	Current project	Winter	6	36	146	154	X
16-21/08/2010	Current project	Winter	6	30	91	62	X
Total			56	232	712	393	5

A number of different types of data was collected to document wildlife ecology and exposure pathways to mine waste solutions. The wildlife data collection can be categorised as follows:

- intensive diurnal observations of birds and terrestrial mammals recording presence, abundance, habitat use and behavior including carcass presence and abundance through:
  - daily total compilations;
  - 20-minute intensive surveys;
  - wildlife behaviour and habitat use surveys; and
  - interaction surveys of wildlife using cyanide-bearing habitats including foraging rates of individuals over a one-minute period (where appropriate).
- carcass replication detection trials;
- diurnal and nocturnal acoustic recordings of wildlife (excluding bats);
- infrared camera trap observations;
- nocturnal recordings for bats;
- aquatic macroinvertebrate (dip net) sampling; and
- aerial and terrestrial macroinvertebrates (malaise trap and pan trap) sampling.

Methods used are described in Appendix 3. Habitat and behaviour data categories used by DES for all methods are defined in Table 5 and are broadly similar to those used for on-site monitoring with a few additions.

Table 5. Behaviour and habitat data categories used for intensive diurnal wildlife monitoring by DES

Data category	Definition
Foraging	Searching for food, irrelevant of observation of food source consumed or success of feeding action
Resting	Not engaged in any activity or engaged in comfort activities such as preening
Locomotion	Moving from one location to another
Nesting	Used for Red-capped Plovers observed sitting on a nest within the TSF
Drinking	Only for observations where wildlife was actually observed drinking
Bathing	Wildlife engaged in active bathing behaviour in the supernatant
Patrolling	Hunting/searching behaviour typical of raptors and corvids
Supernatant	Open water
Flowing stream	Stream of tailings flowing in a channel from the spigot to the supernatant
Beach/dry tailings	The interface between supernatant and adjacent dry tailings
Beach/wet tailings	The interface between supernatant and adjacent wet tailings
Dry tailings/wet tailings interface	The interface between dry tailings and adjacent wet tailings
Dry tailings	Dry consolidated tailings
Wet tailings	Wet unconsolidated tailings
Infrastructure	Any infrastructure present in the survey area such as pipes, decant towers, causeways, etc.
Aerial	Only for wildlife flying over the water bodies
Aerial over supernatant	Used for flying birds foraging or patrolling very low over the supernatant (< 1 m) with an obvious interest or interaction with the supernatant
Aerial over wet tailings	Used for flying birds foraging or patrolling very low over wet tailings (< 1 m) with an obvious interest or interaction with the wet tailings
Aerial over dry tailings	Used for flying birds foraging or patrolling very low over dry tailings (< 1 m) with an obvious interest or interaction with the dry tailings

Chemistry results – routine in house

The on-site chemistry dataset considered for this report is between 17 April 2007 and 18 August 2010. A total of 489 spigot samples and 468 supernatant samples are included in the analysis for this period. As typical with most operations, BGS experienced regular and unscheduled mill shutdowns, process disruptions and changes, which greatly influenced chemical parameters at times, especially cyanide concentrations at spigot discharge. As a consequence, when considering the WAD cyanide spigot concentrations for BGS, those values below 10 were removed from the analysis. Raw on-site data is used for the following analysis. Error in the data is demonstrated by comparison with ALS data in the QA and QC section for cyanide in particular, however the error is variable and dependant on many factors. Consequently it is not possible to apply a uniform adjustment factor here for the whole range of cyanide data.

Chemistry data

A summary of BGS on-site cyanide analyses is presented in Table 6 for the saline and hypersaline conditions in the TSF. Average cyanide concentrations, as measured on-site, were similar for the saline and hypersaline periods (Table 6) although considerable variability is evident (Figure 4). Spigot sampling during the saline period recorded a maximum of 150 mg/L WAD cyanide and 71.2% of readings were above 50 mg/L. A maximum of 90 mg/L WAD cyanide was recorded in spigot samples during the hypersaline conditions with 78.9% of reading being over 50 mg/L. The mean WAD cyanide concentration in the supernatant was slightly higher in the saline period. The maximum reading was substantially higher in the saline period and 21 readings (5.5%) were above 50 mg/L in this period. Of importance is that the supernatant WAD cyanide concentration is substantially less than that at spigot discharge, and below 50 mg/L in all determinations as a hypersaline system. This illustrates consistent degradation of cyanides within the TSF.

The variability in the discharge concentrations of WAD cyanide at BGS (figures 5 and 6) is similar to that experienced elsewhere such as Sunrise Dam Gold Mine (SDGM) [25]. This variability is partly due to analysis error (see QA and QC section) but also due to numerous process plant metallurgical parameters, ore body characteristics, changes in ore body variable cyanide dosage rates and environmental factors.

Confidence in the accuracy of this dataset is not high (see QA and QC section) and the on-site laboratory dataset was not used to determine operating parameters (see recommendations).

Table 6. Summary of WAD cyanide analysis (mg/L) from on-site sampling conducted when the TSF was saline and hypersaline

	N=	Average (± S.D)	Max (min)	Samples/days (%) over 50 mg/L
Saline (9 January 2008 to 7 May 2010)				
Supernatant	384	19.7 ± 15.5	73.8	21 (5.5%)
Spigot	372	60.8 ± 22.5	150	265 (71.2%)
Hypersaline (8 May to 18 August 2010)				
Supernatant	84	15.0 ± 7.9	29.5	0
Spigot	76	61.6 ± 13.8	90	60 (78.9%)

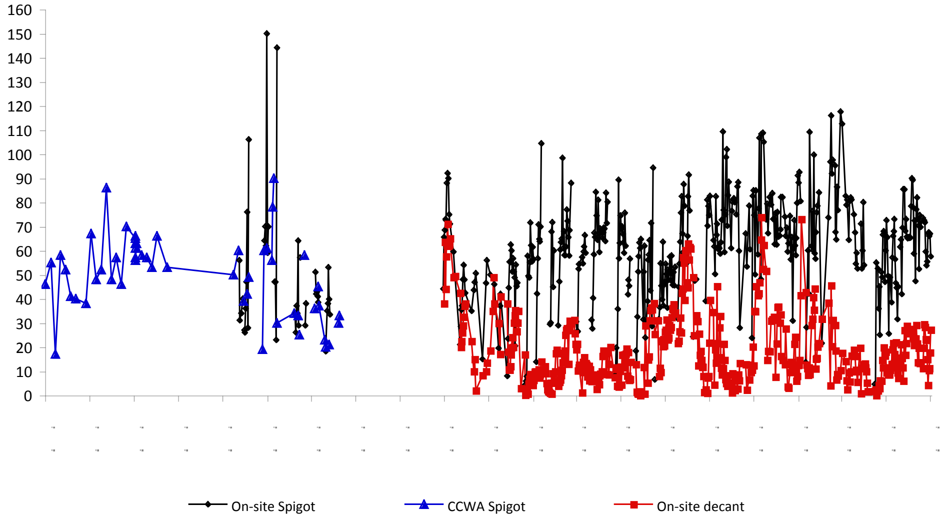


Figure 4. CCWA analysed BGS WAD cyanide concentrations (mg/L) at spigot discharge (n = 61 and 448) and in the supernatant (n = 468) between 17 April 2007 and 18 August 2010

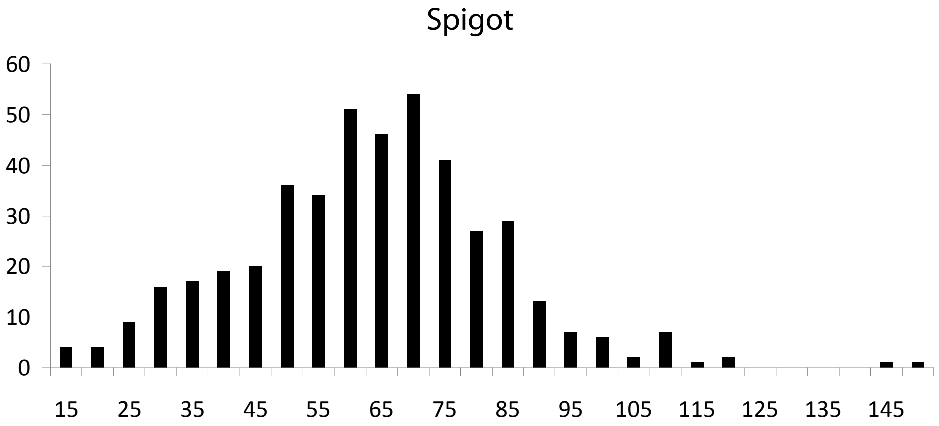


Figure 5. BGS distribution of WAD cyanide at spigot discharge (n = 448) in number of samples (y-axis) for each bin range of 5 mg/L WAD cyanide (x-axis)

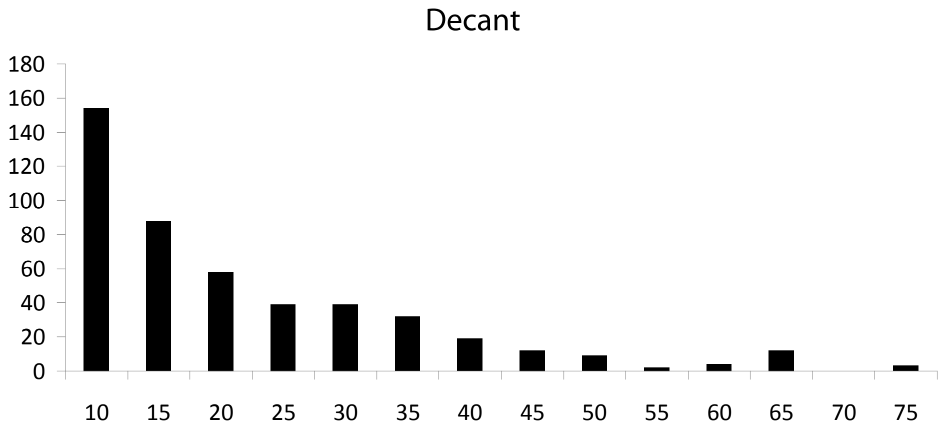


Figure 6. BGS distribution of WAD cyanide at supernatant (n = 468) in number of samples (y-axis) for each bin range of 5 mg/L WAD cyanide (x-axis)

Salinity (TDS) from on-site data at the spigot and in the supernatant is illustrated in Figure 7. It is obvious when the hypersaline tailings wash circuit was introduced (7 May 2010) and average salinity concentrations for the saline and hypersaline periods reflect this (Table 7) although variability is evident (Figure 7 and Table 7). Since early June 2010 salinity concentrations have generally stabilised at between 50 000 and 65 000 TDS at both spigot discharge and in the supernatant (Figure 10) although 22 (29.7%) of spigot samples were recorded at below 50 000 TDS.

The pH mean at spigot was 9.1 ± 0.8 when the TSF was saline but dropped to 8.8 at the spigot and in the supernatant once it was hypersaline (Table 7). These values are typical for a saline tailings system.

Mean copper concentrations at BGS were 18.4 ± 12.7 mg/L at the spigot and 11.8 ± 8.8 mg/L in the supernatant. There is great variability in the copper concentrations at different times illustrating that the copper levels differ considerably in the different ore bodies.

Table 7. Summary of pH, salinity (TDS) and copper analysis from on-site sampling conducted when the TSF was saline and hypersaline

	pH		TDS (mg/L)		Copper (mg/L)	
	n =	Av	n =	Av	n =	Av
Saline (9 January 2008 to 7 May 2010)						
Supernatant	0	-	0	-	340	12.1 ± 9.4
Spigot	279	9.1 ± 0.8	326	14 490 ± 3 901	296	20.5 ± 13.2
Hypersaline (8 May to 18 August 2010)						
Supernatant	70	8.8 ± 0.7	62	68 261 ± 19 936	60	10.0 ± 3.7
Spigot	72	8.8 ± 0.6	74	61 086 ± 18 097	78	10.4 ± 5.0

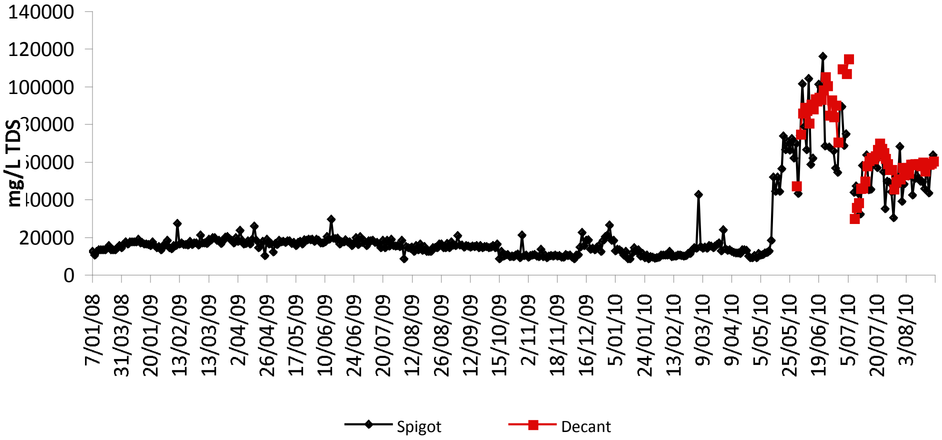


Figure 7. Salinity (TDS) at spigot discharge (n = 400) and in the supernatant (n = 62) between 7 January 2008 and 18 August 2010

Chemistry results – DES-collected data

Only the most pertinent chemistry results are presented here and in a summarised form. The full presentation of results and analysis can be found in Appendix 2.

Spigot and supernatant (including spatial and time trials)

Averages for spigot discharge and supernatant chemistry data are given for samples collected by DES under saline and hypersaline conditions at the TSF in tables 8 and 9. All results are from analyses conducted by ALS. All cyanide and salinity analysis results are provided in Appendix 4.

WAD cyanide averaged just over 50 mg/L at the spigot during samples taken under hypersaline conditions (Table 8) with a recorded maximum of 90.5 mg/L. Free cyanide averaged just below 50 mg/L but had a maximum of 93.1, which indicates a level of analytical error as free cyanide is a subset of WAD cyanide. Average supernatant cyanide concentrations were substantially lower than at the spigot (Table 8). WAD cyanide in the supernatant was well below 50 mg/L in all samples.

Compared to hypersaline conditions, under saline conditions WAD cyanide was lower at the spigot but higher within the supernatant (but still under 50 mg/L) (Table 9).

Variability in cyanides at the spigot and in the supernatant is indicated by the standard deviations but also in Figure 8, which shows variability between site visit averages. This variability at the spigot is consistent with on-site data from a more complete dataset and is likely to be due to many factors within the mill. Cyanide concentrations in the supernatant can be influenced by many factors other than just spigot discharge concentrations such as supernatant size, the pattern of TSF cell activity, environmental conditions and rainfall events.

Table 8. Summary of chemistry data from DES sampling under hypersaline conditions at the BGS TSF between 8 May and 21 August 2010. Cyanide and TDS are in mg/L.

	WAD cyanide	Free cyanide	Total cyanide	pH	TDS	Copper
Supernatant						
n =	22	22	22	14	14	22
Average (± SD)	10.5 ± 6.0	9.7 ± 5.7	19.5 ± 12.4	8.7 ± 0.1	61 464 ± 14 406	3.9 ± 1.8
Maximum (minimum)	21.3	18.3	41.1		(33 200)	
Spigot						
n =	79	79	79	46	46	75
Average (± SD)	53.4 ± 19.5	48.6 ± 20.2	65.3 ± 23.8	9.2 ± 0.1	61 595 ± 11 540	4.4 ± 4.5
Maximum (minimum)	90.5	93.1	111	9.5	(35 600)	20.7

Table 9. Summary of chemistry data from DES sampling under saline conditions at the BGS TSF between June 2006 and 7 May 2010. Cyanide and TDS are in mg/L.

	WAD cyanide	Free cyanide	Total cyanide	pH	TDS	Copper
Supernatant						
n =	41	25	24	25	27	25
Average (± SD)	24.9 ± 7.6	9.4 ± 3.3	52.4 ± 23.7	8.0 ± 0.3	20 518 ± 2 578	15.0 ± 5.1
Maximum	37	15	110	8.6	33 000	22
Spigot						
n =	37	21	22	22	17	21
Average (± SD)	40.9 ± 13.9	30.6 ± 12.8	94.0 ± 19.3	9.1 ± 0.5	14 656 ± 1 215	8.3 ± 3.1
Maximum	66	49	130	10.1	17 000	14

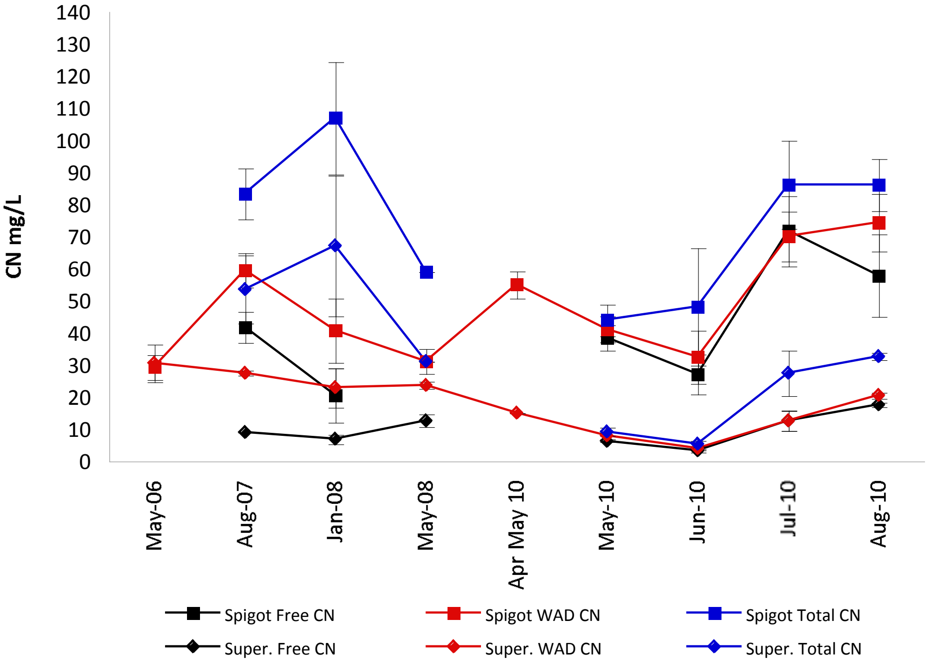


Figure 8. Averages for free, WAD and total cyanide (mg/L) at the supernatant and spigot from samples taken by DES during each site visit between May 2006 and August 2010

Average salinity (TDS) at spigot was approximately 61 000 mg/L TDS under hypersaline conditions (Table 8) but was variable with seven spigot samples (15.2%) under 50 000 mg/L. The average salinity of the supernatant was similar under hypersaline conditions (Table 8) and three samples (21.4%) returned a value of less than 50 000 mg/L TDS. Lower TDS in the supernatant at times is due to rainfall events. Variability of salinity averages is illustrated for each site visit in Figure 9. Consistent with on-site data, salinity was generally between 10 000 and 25 000 TDS at both the spigot and in the supernatant before the hypersaline circuit was introduced, which is clearly seen in the data (Figure 9). The averages for August 2010 were lower than for June and July however the spigot discharge still averaged over 50 000 TDS although the supernatant was less than this (Figure 9).

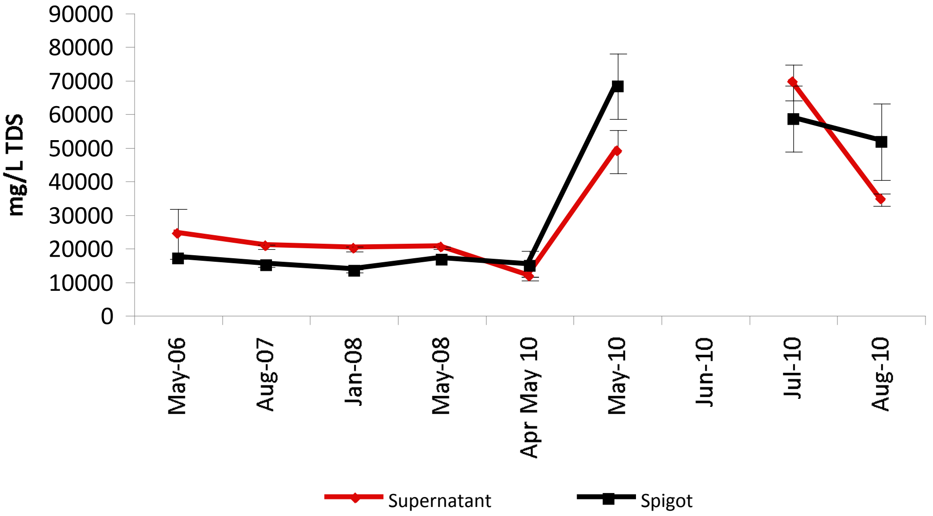


Figure 9. Average concentrations of salinity (mg/L TDS) at the spigot and supernatant from samples taken by DES during each site visit between May 2006 and August 2010

Averages measured for pH during DES sampling were higher in the hypersaline datasets at both the spigot and supernatant compared to the saline datasets (tables 8 and 9). This is expected for the spigot sampling as a higher pH is required to keep cyanide stable in hypersaline solutions. The reasons for a substantially higher pH of the supernatant under hypersaline conditions is not immediately evident.

Copper concentration averages measured during DES sampling were below 10 mg/L at the spigot and in the supernatant under hypersaline conditions. Average copper concentrations were higher in the saline dataset.

Hourly spigot time trials were conducted by DES on most site visits to assess variability on a temporal scale. Some variability in WAD cyanide discharge concentrations at the spigot is evident on all days they were conducted (Figure 10). Within a 12-hour period cyanide concentration can vary as much as 15 mg/L (30%) as evident in sampling on 12 May 2010. Of note is that the variability is not random but sequential, with the previous sample influencing the subsequent sample concentration.

Such variability can be caused by many factors in the mill circuit and is likely to reflect actual variability at spigot discharge as well as some level of analytical error.

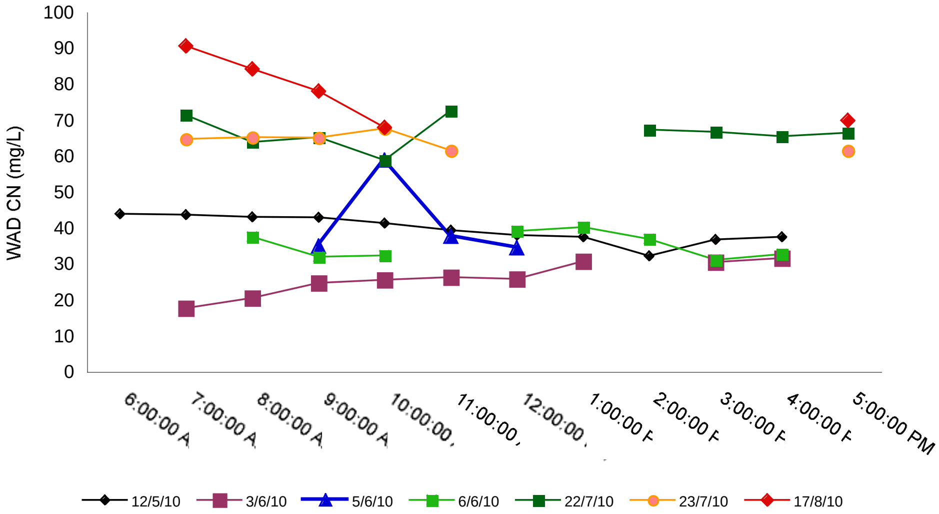


Figure 10. WAD cyanide concentration at the spigot according to time within each sample day for seven days between May and August 2010

Temporal sampling of a spigot pool was also conducted over a 10-hour period on 23 July 2010 soon after the spigot was turned off to document cyanide degradation. No cyanide degradation was evident after the first hour of sampling however the samples taken at 9:00 and 10:00 showed substantial degradation (25% and 36%, respectively). When the next sample was taken at 17:00, 85% of the WAD cyanide had been lost. WAD and free cyanide concentrations were very similar and tracked each other over the ten-hour period indicating that most of the WAD cyanide was composed of free cyanide. Interestingly the pH for the first four samples was between 9.1 and 9.3, hence cyanide loss over the first three hours was not pH related. The pH of the 17:00 sample was 7.8.

Spatial sampling of the supernatant with a remote-controlled boat in January 2008 found that the supernatant was well mixed, with no hot spots of elevated concentrations of cyanides. Supernatant samples were also taken at various points around the decant finger on 22 and 23 July 2010 however results showed some variability in WAD cyanide concentrations but little variation in pH. Some of this variation may have been due to analytical error. A well mixed solution is expected due to regular winds and a shallow depth of the supernatant.

Spatial sampling of the tailings discharge zone

Lucky spigot is the terminology used when a spigot immediately adjacent to a decant wall is turned on and the tailings stream flows parallel to the wall within sampling pole distance to the supernatant. Lucky spigot sampling was conducted under saline and hypersaline conditions.

Lucky spigots conducted on hypersaline tailings from May to July 2010 showed mixed results in terms of WAD cyanide degradation (Figure 11). Sampling conducted on four days showed some limited degradation before tailings reached the supernatant. In the profile from 24 July 2010 at 7:00 no cyanide degradation was observed at all within the plume (Figure 11). Similar pH was measured throughout the plume for all of these profiles at between 9 and 9.2, which is at the threshold for pH stabilisation and may account for the variable results.

Results from saline lucky spigots conducted in M398 were not consistent with one another. The lucky spigot conducted on 19 August 2007 showed little cyanide degradation throughout the profile (Figure 12). This is due to pH (9.4 to 9.6) stabilisation, being above the stability threshold of pH 9.1. The supernatant was 8.1. In contrast, sampling conducted on 24 January 2008 showed definite cyanide degradation (Figure 13) at pH levels of between 9.2 at the spigot and 8.8 in the plume. The supernatant was again measured at pH 8.1 and had much lower cyanide concentrations. The copper levels measured in both profiles were low and indicate that copper was not a primary reason for WAD cyanide resilience throughout both lucky spigot profiles (figures 12 and 13). Environmental conditions influence cyanide degradation rates. This may account for greater degradation during the summer (January 2008) sampling exercise.

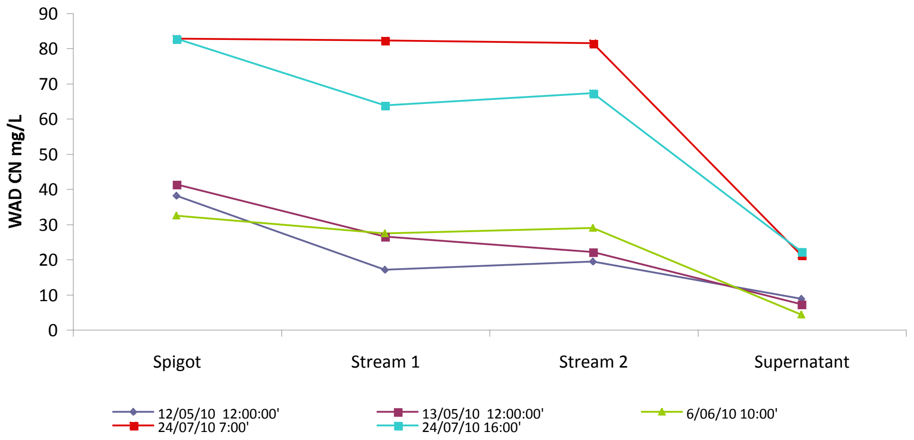


Figure 11. WAD cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile at BGS on five occasions (four days) under hypersaline conditions from May to July 2010. Locations for in-stream samples (stream 1 and 2) vary between lucky spigots depending on access.

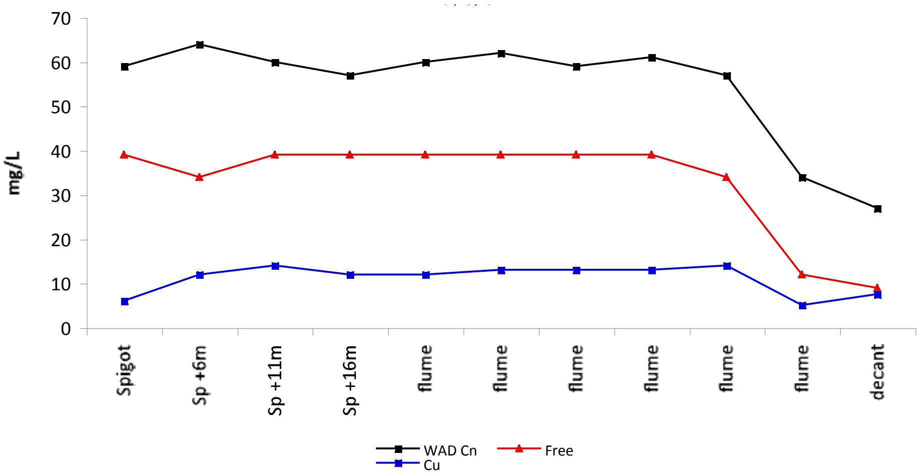


Figure 12. Cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile under saline conditions at BGS on 19 August 2007 during the M398 project

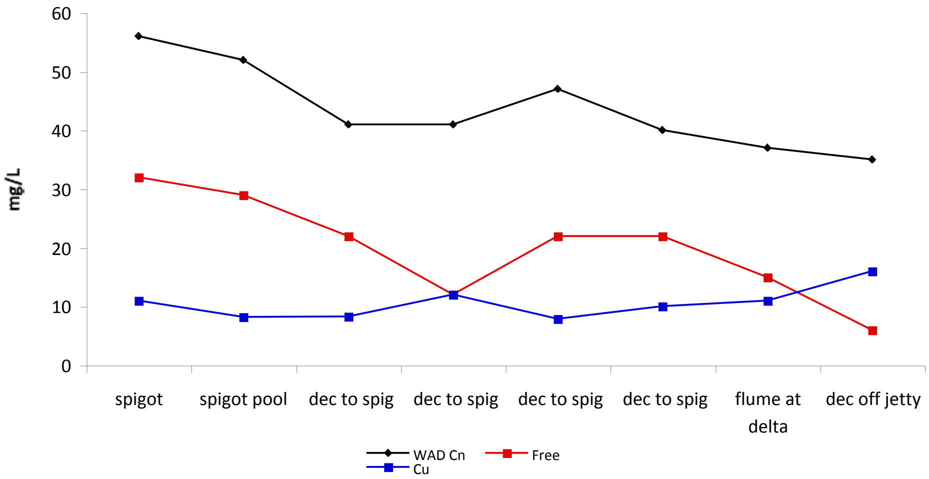


Figure 13. Cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile under saline conditions at BGS on 24 January 2008 during the M398 project

Cyanide speciation and metals

Metallo-cyanide speciation of some samples by ion chromatography (IC) was conducted during January 2008. All metallo-cyanide complexes were found to be in very low concentrations with the exception of copper and iron 2+ cyanides, which were between 8 and 17 mg/L for copper cyanide and 4 and 31 mg/L for iron cyanide. Analysis of metals (by ALS) for spigot and supernatant samples taken on 22 July 2010 were consistent with this with all metals again in low concentrations except for copper (approximately 4 mg/L) and iron (between 5.8 and 7.1 mg/L). Copper cyanides are included in WAD cyanide analysis. Iron cyanides are strong acid dissociable (SAD) and hence not considered toxic to wildlife and not included in WAD cyanide analysis.

Laboratory cyanide degradation test work

Degradation test work conducted for WAD cyanide in tailings solutions in July 2010 demonstrated that WAD cyanide degradation at the spigot was rapid at first with 77% being lost over the first four hours (Figure 14).The degradation then slowed considerably but did continue over the next 44 hours to the end of the trial.

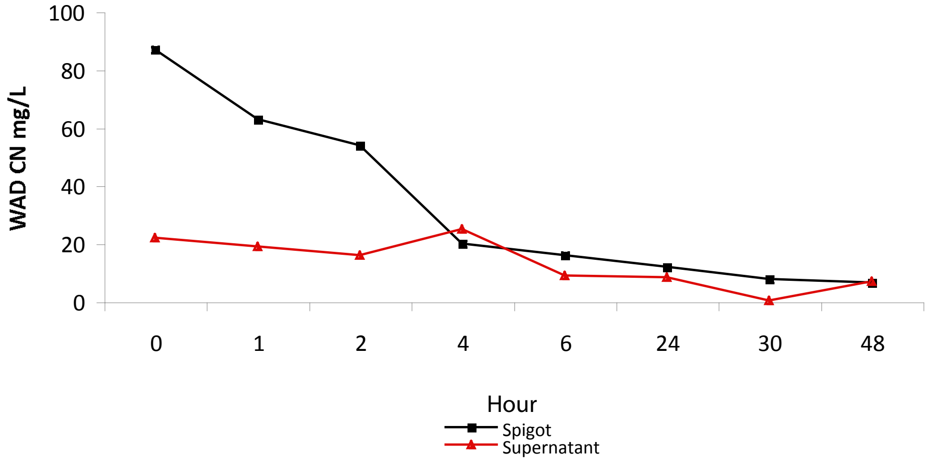


Figure 14. Cyanide degradation test chart of time versus cyanide concentration in mg/L for spigot and supernatant samples tested

Quality assurance and quality control of chemistry data

Comparison of on-site and ALS chemistry analysis

The on-site picric acid WAD cyanide analysis results are compared with NATA registered ALS laboratory Discrete Analyser instrument method (Figure 15). Duplicate spigot samples from 16 February 2009 to 21 January 2010 were used in comparative analysis. The on-site laboratory picric acid method provided results higher than the ALS results. The mean value for the on-site laboratory was 61.2 mg/L compared to the ALS assay of 42.9 mg/L (n = 46). The mean difference is 18.3 ± 6.1 (95% C.I), this represents an overestimation of 30% ± 9.9%. The correlation between the two laboratories for WAD cyanide analysis is close ($R^2 = 0.54$) is significant (R = 0.73, n > 30, R's critical value = 0.478 for two-tailed p > 0.01). Of interest is that the strong correlation represents a consistent over-estimation by the on-site laboratory of approximately 30% for the period of these samples which may relate to over-aggressive acidic digestion of samples.

This relationship does not hold up for comparisons of ALS and on-site data collected in May, July and August 2010 under hypersaline conditions (Table 10, Figure 16). In May 2010 on-site WAD cyanide analyses averaged 47.5% ± 21.9% higher than ALS results but ranged between 18.9% and 112.4% difference. In July 2010 on-site analysis was very close to that of ALS results (Figure 16) with only 1.3% ± 6.9% difference on average (Table 10). This is understood to be due to additional quality assurance (QA) and quality control (QC) measures employed in the laboratory for this time period (such as making of new standards, etc). In August 2010 the average difference between on-site and ALS results was 15.9% ± 8.0% but this time with on-site results being lower (Table 10). Since January 2010 there has been no obvious relationship between on-site and ALS results for WAD cyanide analysis.

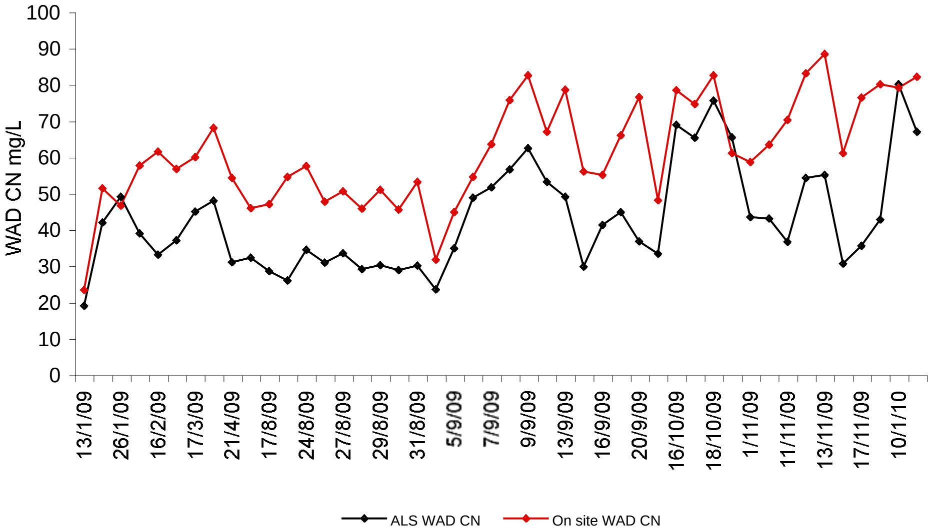


Figure 15. ALS and on-site laboratory WAD cyanide analysis between 13 January 2009 and 24 January 2010

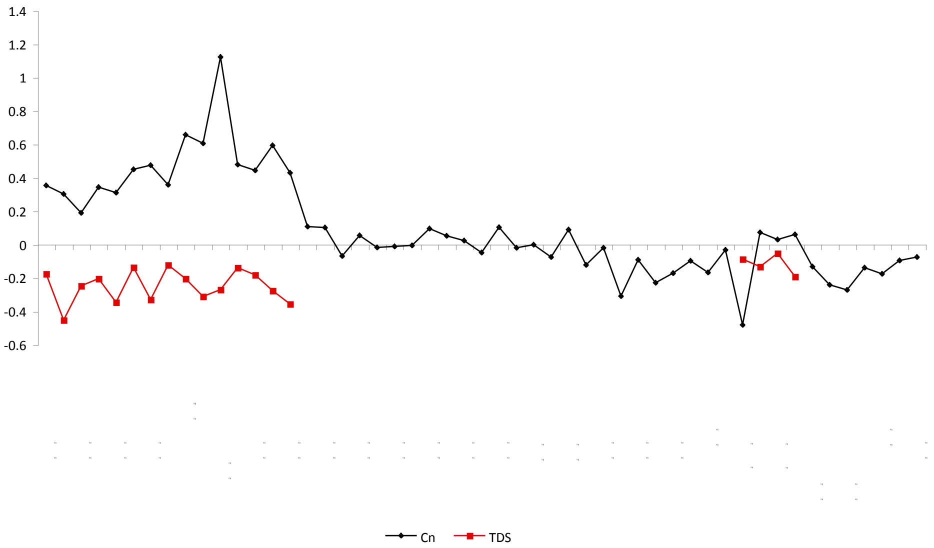


Figure 16. Proportional difference of on-site WAD cyanide and TDS analysis from ALS analysis for samples taken in May, July and August 2010

Table 10. Average per cent variance of on-site WAD cyanide analysis from ALS analysis for three site visits. Positive averages indicate higher analysis values and negative averages indicate lower analysis values. The number of samples compared, standard deviation, minimum variation and maximum variation are also shown for each site visit.

	No. of samples compared	Average	Standard deviation	Minimum	Maximum
May-10	15	47.5%	21.9%	18.9%	112.4%
Jul-10	18	1.3%	6.9%	-0.1%	-12.1%
Aug-10	14	-15.9%	8.0%	-3.2%	30.8%

Samples were split between ALS and on-site laboratories and analysed for salinity (TDS) in May and August 2010 (Figure 16). ALS analysis results were consistently higher than on-site results (Figure 16) by between 5% and 45% with an average of 22% ± 10.4% difference.

Comparison of off-site laboratory results

QA and QC for DES chemistry sampling consisted of two and three-way splits of chemistry samples for analysis on site, at ALS and CCWA laboratories in Perth. QA and QC testing commissioned by BGS included three-way splits of spigot and supernatant sampling on 4 and 9 August 2010.

The percentage difference of CCWA and on-site results from ALS results is presented in Figure 17. Interestingly CCWA and ALS WAD cyanide results differed by more than 10% in ten samples and in three samples the difference was 50 to 60%. For 12 results they were within 10% of the ALS result (Figure 17). CCWA analysis for TDS was very close to ALS results, generally within 5% (Figure 17) although one CCWA TDS result differed from ALS by 12%.

One spigot sample (10:30, spigot 12 taken on 18/8/10) was split and both samples were sent to CCWA for analysis. Results of 65 and 73 mg/L WAD cyanide were returned, an error of about 11 to 12%.

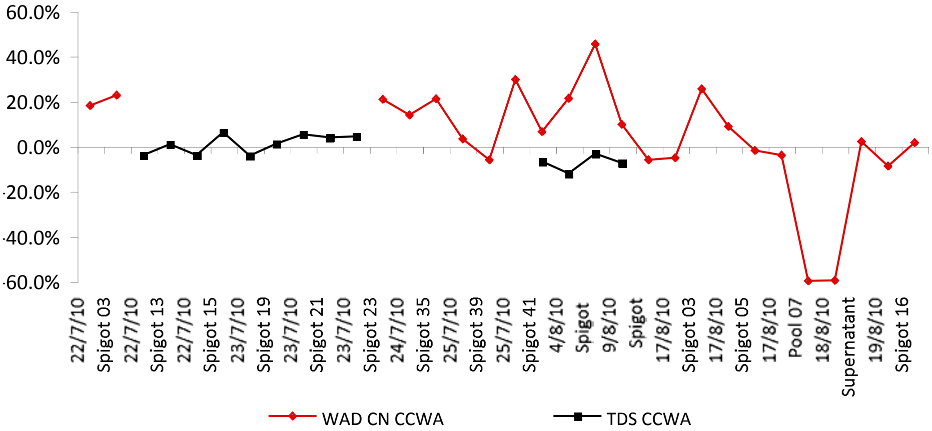


Figure 17. Per cent difference of CCWA results from ALS results for WAD cyanide and TDS in samples taken during July and August 2010

QA and QC testing was conducted during M398 for the off-site laboratory (CCWA) through comparison with National Measurements Institute (NMI) laboratory. The WAD cyanide results of both laboratories were usually within 10% but occasionally there were discrepancies (see Appendix 2).

Summary of chemistry results

WAD cyanide concentrations at the spigot were a mean of 60.8 with 95% of samples being between 21.3 and 100.5 mg/L.

WAD cyanide concentrations at the spigot appear to be higher on average during Crescent Ore campaigns (compared to Wallaby Ore campaigns).

WAD cyanide is mostly composed of free cyanide at the spigot.

The accuracy of on-site chemistry analysis fluctuates substantially and off-site laboratory results do not always agree with each other.

Cyanide loss within the TDZ is variable. Cyanides are pH-stabilised between the spigot and the supernatant with little cyanide loss evident in lucky spigots.

The supernatant is generally well below 50 mg/L WAD cyanide and pH is correspondingly well below 9.1.

Salinity concentrations are mostly well within the hypersaline range but variable at the spigot with 15.1% of readings below 50 000 mg/L TDS.

The supernatant is generally well mixed.

The supernatant is hypersaline. Variability in results is likely to be a mix of analytical error and rainfall events as the supernatant salinity cannot vary significantly on a day to day basis unless due to significant rainfall influx.

Copper and iron are the only metals (and metallo-cyanide complexes) in concentrations of typically greater than 1 mg/L.

Copper concentrations are considered low (mostly less than 10mg/L) and not a significant stabiliser of WAD cyanide in the tailings and supernatant.

On-site observations

On-site wildlife data is primarily assessed at the guild level due to difficulties of species identification, except for some frequently recorded and easily identified species. A total of 5 191 visitations to the TSF representing eight guilds were recorded during 1 093 surveys between 15 June 2006 and 18 August 2010. Of these records 4 803 visitations were recorded before 8 May 2010 under saline TSF conditions (14 000 to 50 000 mg/L TDS) at a rate of 4.7 ± 7.2 wildlife per survey. A further 388 visitations were recorded under hypersaline conditions (8 May 2010 onwards) at a rate of 5.5 ± 3.7 wildlife per survey.

The majority of these (85.5% of overall records) were of a single species, Red-capped Plover (a wader), which was recorded at an average of 4.0 and 4.9 birds per survey for saline and hypersaline conditions, respectively. Less species were recorded under hypersaline conditions, which most likely reflect the comparatively shorter observation period. The two terrestrial mammal species observed were kangaroo and dingo. The TSF is unfenced.

No wildlife was observed during 339 (31.0%) observation sessions and the maximum number of animals observed during a session was 58.

Guild composition reflects the dominance of waders in on-site wildlife records, which made up 89.4% of records (Figure 18). Four other guilds contributed greater than 1% of records: ducks, raptors and corvids, aerial feeders (such as swallows) and bush birds (Figure 18).

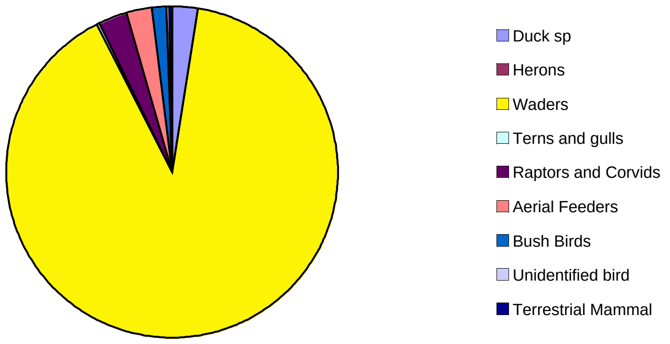


Figure 18. Guild composition of on-site wildlife records at the TSF for the complete dataset between June 2006 and 18 August 2010 (n = 5 191 records, 1 093 surveys)

A seasonal effect is evident in the total number of records per day with an obvious pattern of higher visitations during late summer and autumn (January to May) and fewer visitations in winter and spring for all four years (Figure 19). This pattern almost wholly reflects the seasonal visitations of the commonly recorded Red-capped Plovers.

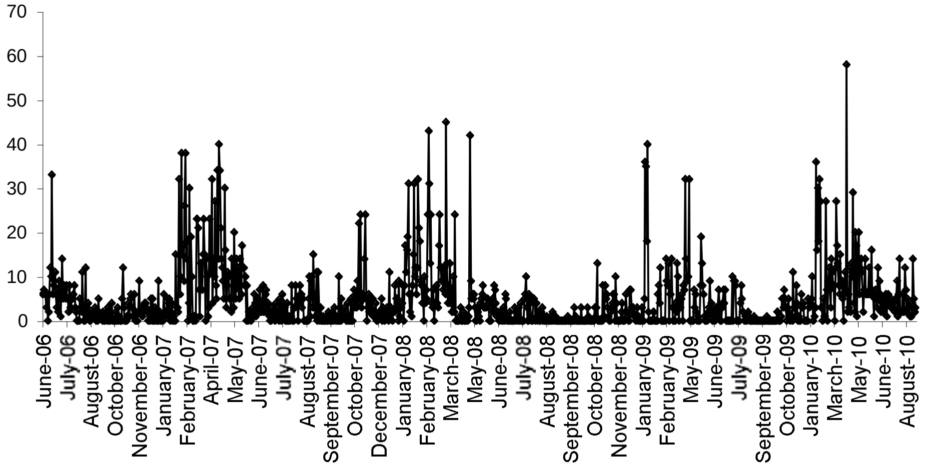


Figure 19. Daily visitation totals recorded by on-site monitoring at the TSF between 15 June 2006 and 18 August 2010 (n = 5 191 records, 1 093 surveys)

On-site monitoring of the seepage trench recorded seven guilds between 13 May 2008 and 18 August 2010 at a rate of 5.4 ± 4.1 wildlife per survey. The reported visitation rates and the species recorded were similar for the TSF. The guild composition at the seepage trench is still dominated by waders (Figure 20) although other guilds make up larger proportions than for the TSF (Figure 18).

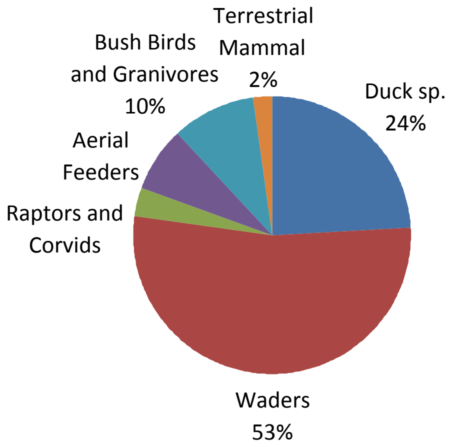


Figure 20. Guild composition of on-site wildlife records at the seepage trench between 13 May 2008 and 18 August 2010 (n = 2 572 records, 480 surveys)

DES observations

DES described wildlife visitations to the TSF as the number of individual animals visiting the TSF over a 24-hour period.

Under hypersaline conditions at the TSF (8 May to 21 August 2010) a total of 480 wildlife visitations were recorded by DES at an average rate of 21.8 ± 19.0 visitations per day for the 22 observation days (Table 11). This contrasts with an average of 31.4 ± 26.6 visitations per day on days DES observed the TSF during the saline period (34 days between 15 June 2006 and 7 May 2010). A total of 1 567 visitations to the TSF were recorded over both periods.

A maximum of 125 wildlife was recorded at the TSF during a single day (1 May 2010) and the minimum was two. Records consisted of eight guilds (Figure 21) and 18 species (see Appendix 3). Consistent with on-site observations two species, Red-capped Plover (a wader) and Welcome Swallow (an aerial species) dominated observations (Figure 21). Only one species of migratory wader was recorded by DES, Red-necked Stint, for which one was recorded on 25 April 2008 and ten on 26 April 2008. Mammal species other than bats were limited to a single record of a kangaroo. Species and guild composition of DES observations is broadly consistent with those of on-site observations with differences likely to be due to intensity and length of observation sessions on a given day, observer skill and the number of days observations were conducted. Guild composition recorded is consistent with that previously recorded elsewhere and reflects the habitat provision and availability of resources within and adjacent to the TSF. Most of the guilds are cosmopolitan, being found across Australia.

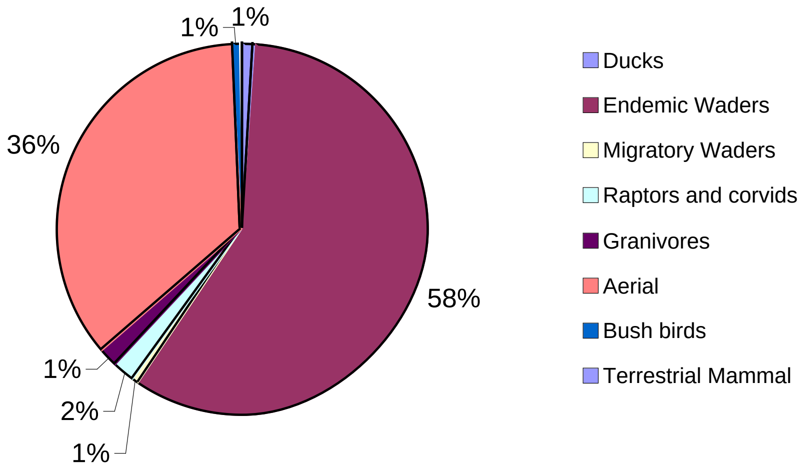


Figure 21. Guild composition of wildlife observations at the active cell of the TSF recorded by DES as determined from daily totals recorded between 18 June 2006 and 21 August 2010

Comparing wildlife visitation rates between saline and hypersaline conditions, it is evident that for Red-capped Plover and for all species combined the visitation rates were higher under saline conditions (Table 11). In contrast, recording rates for Welcome Swallow were higher in the hypersaline dataset. However, this is due to a seasonal distortion since all of the survey work for the hypersaline TSF was conducted in autumn and winter (Table 4), whereas for the saline conditions surveys occurred in summer when visitation rates for Red-capped Plover were substantially higher (Table 11). When visitation rates are viewed on a seasonal basis it looks as if visitation rates are highest in summer for Red-capped Plover and in winter for Welcome Swallow (Table 11). This is consistent with on-site data. Red-capped Plovers may be taking advantage of higher winged macroinvertebrate activity in summer, which is the only source of food on the TSF for this species. The reverse pattern for Welcome Swallow is likely to be due to regular seasonal movements (north in autumn and south in spring, Higgins et al 2007). It appears that the largest determinant of visitation rates to the TSF is seasonal rather than tailings salinity although the dataset under hypersaline conditions is short.

Table 11. Summary of visitation rates as determined by day totals and 20-minute surveys at the TSF active cell conducted between 18 June 2006 and 21 August 2010

				All species		Red-capped Plover		Welcome Swallow	
	Season	Number of days TSF observed	Number of 20-minute surveys	Average per day	Average number of records per 20-minute survey	Average per day	Average number of records per 20-minute survey	Average per day	Average number of records per 20-minute survey
All surveys		56	232	28.0 ±25.2	16.0 ± 17.2	16.6 ± 17.4	12.5 ± 14.7	9.5 ± 15.8	3.3 ± 9.4
Saline		34	119	31.4 ± 26.6	23.1 ± 19.2	21.8 ± 18.9	19.9 ± 17.2	7.0 ± 14.5	2.8 ± 9.2
Hyper-saline		22	113	21.8 ± 19.0	8.5 ± 10.6	7.8 ± 4.3	4.6 ± 3.4	13.3 ± 17.3	3.8 ± 9.6
Jan-08	Summer	11	62	42.3 ± 14.3	24.3 ± 17.2	40.5 ± 12.9	24.2 ± 17.2	0.8 ± 2.4	0.0
Apr-May 08/10	Autumn	21	78	33.8 ± 33.7	19.1 ± 20.5	15.8 ±17.3	13.0 ± 14.4	15.3 ± 20.5	5.6 ± 13.2
June-Aug 10	Winter	20	92	17.4 ± 14.6	7.7 ± 8.3	6.7 ± 3.0	4.1 ± 2.6	10.0 ± 13.3	3.5 ± 8.1
Sep-06	Spring	4	0	11.3 ± 10.1		7.2 ±3.5		4.4 ± 4.8	

Other known seasonal wildlife patterns, such as the international migration of waders, will dictate the movements of wildlife but these species have not been commonly recorded at the TSF. Movements of wildlife according to other environmental factors that are not seasonal in nature, or operate on a greater-than-12-months time frame, are expected in this arid environment.

Foraging rates

Monitoring of foraging actions for individuals over a one-minute period was conducted for four species at the TSF (Table 12). Pecking rates averaged 25.0 ± 17.5 for Red-capped Plover during 242 one-minute counts and 6.5 ± 3.5 for Welcome Swallow over 58 counts (Table 12). The foraging rate for Red-necked Stint was substantially higher although only two counts were conducted (Table 12). The differences most likely reflect the different foraging mechanisms and behaviours. It is notable that foraging rates did not vary much for either Red-capped Plover or Welcome Swallow between the saline and hypersaline datasets (Table 12). All three of the above species were observed pecking at prey on the surface of TSF substrates, especially wet habitats in which invertebrates become entrained.

The foraging rate for Welcome Swallow was a reflection of consistent and successful foraging behaviour, which was observed mostly in early mornings and mainly in autumn and winter. In contrast, Red-capped Plover was present all year round and often foraged throughout most daylight hours but often stopped for two to three hours in the middle of the day.

Table 12. Peck rates recorded during one-minute foraging action counts for species foraging within TSF habitats (n = 305)

	All data		Saline		Hypersaline	
	No. of 1 min Surveys	Average no. of pecks (± s.d.)	No. of 1 min Surveys	Average no. of pecks (± s.d.)	No. of 1 min Surveys	Average no. of pecks (± s.d.)
Australian Shelduck	3	5.7 ± 2.5	2	5.5 ± 3.5	1	6
Red-capped Plover	242	25.0 ± 17.5	104	24.5 ± 19.3	138	25.4 ± 16.0
Red-necked Stint	2	80.5 ± 2.1	2	80.5 ± 2.1		
Welcome Swallow	58	6.5 ± 3.5	16	6.1 ± 3.8	42	6.6 ± 3.4

The Australian Shelduck was observed attempting to feed on two occasions. On one occasion it stopped foraging after one one-minute count and on the other occasion after two one-minute counts. On both occasions foraging was likely to be, and appeared to be, unsuccessful as it quickly stopped foraging and left the system soon after. This species feeds on aquatic plants and aquatic invertebrates, neither of which are present in the supernatant.

Wildlife interaction with cyanide-bearing habitats

Habitat use for the TSF as a whole is presented in Appendix 3. The only risk to wildlife from cyanide within the TSF is from cyanide-bearing habitats and interaction with these is considered here. Dry tailings habitats contain very low concentrations of WAD cyanide and are not considered cyanide-bearing. The supernatant has been well below 50 mg/L WAD cyanide at least since May 2006. Habitat interaction records for supernatant habitats (supernatant, dry tailings beach and aerial over supernatant) are considered separately to the TDZ due to the substantially lower risk they present to wildlife compared to TDZ habitats. Wildlife interactions observed with cyanide-bearing habitats during habitat and behaviour surveys are presented in Table 13 according to TDZ habitats and supernatant habitats.

A total of 6 088 records of wildlife using cyanide-bearing habitats were obtained, representing 87.4% of habitat and behaviour records, and of these 4 140 records (59.4% of all records) were with TDZ habitats. Not all of these records were of oral interaction with the cyanide-bearing habitats. Oral interaction is the only identified cyanide exposure pathway of wildlife (see Appendix 1). Other avenues for lethal doses of cyanide necessitate the presence of very high levels of free cyanide. A total of 3 141 foraging records were obtained from TDZ habitats during habitat and behaviour counts and are assessed to have involved actual or potential oral interaction with TDZ habitats (Table 13). The potential for wildlife to receive a cyanide dose exists in each of these interactions. It was however repeatedly noted that not all foraging interactions involve actual contact with TSF habitats as invertebrates often appear to be alive and take to flight as the birds strike, resulting in prey being taken just above the surface. It is also noteworthy that all records of wildlife in the TDZ are due to the presence of food.

The majority of TDZ foraging records (2 098) were of Red-capped Plover, however 1 037 TDZ foraging records for Welcome Swallow were also obtained. In addition, 199 and 57 one-minute foraging surveys of Red-capped Plover and Welcome Swallow, respectively, were conducted. The majority of these records were of Welcome Swallows and Red-capped Plovers taking small invertebrates from the surface of TSF habitats. They preferentially use wet habitats, as the invertebrates adhere to the surface.

Only three species have been observed by DES interacting with cyanide-bearing habitats within the TDZ, Red-capped Plover, Red-necked Stint and Welcome Swallow. In the case of Red-necked Stint, ten birds were observed on 26 April 2008 primarily interacting with dry tailings beaches and supernatant, but some interactions with wet tailings beaches were also observed with no effect. For Red-capped Plover, interactions with TDZ habitats occur all year to some degree. For Welcome Swallow, interactions with TDZ habitats occur primarily in winter although may possibly occur in summer. All species interact orally with TDZ habitats by pecking, however it appears that Red-capped Plover at times puts its bill further into the tailings and has been observed with tailings stuck to the bill.

Table 13. The number of habitat and behaviour observations recorded for cyanide-bearing habitats at the active cell of the TSF during habitat and behaviour surveys between 15 June 2006 and 21 August 2010 (n = 6 088)

	TDZ					Supernatant			
	Flowing stream	Dry tailings/wet tailings interface	Wet tailings	Beach/wet tailings	Aerial over wet tailings	Supernatant	Aerial over supernatant	Beach/dry tailings	Total
All data	74	1 172	290	1 626	978	175	215	1 558	6 088
Foraging	20	920	290	933	978	92	215	961	4 409
Drinking	1								1
Resting		252		679		77		561	1 569
Locomotion				14		4		36	54
Bathing	53					2			55
Saline	70	996	110	1 473	328	173	143	1 152	4 445
Foraging	17	762	110	810	328	92	143	621	2 883
Drinking	1								1
Resting		234		650		77		512	1 473
Locomotion				13		4		19	36
Bathing	52								52
Hyper-saline	4	176	180	153	650	2	72	406	1 643
Foraging	3	158	180	123	650		72	340	1 526
Drinking									0
Resting		18		29				49	96
Locomotion				1				17	18
Bathing	1					2			3
Nesting									
Drinking									
Bathing									

A Red-capped Plover nest containing two eggs was observed in May 2010, located underneath a tailings pipe along the decant causeway. In subsequent July 2010 surveys, two adults and two immatures foraged in close proximity to each other, presumably as a family unit, in the vicinity of the nest.

The significance of a nest with eggs within the TSF demonstrates long-term presence of some individuals within the system. It is likely that these individuals foraged within the system on a daily basis. The presence of the nest and likely survival of the young strongly indicates that the TSF did not cause harm to these individuals over an extended period.

Balloon (carcass replication) detection

A total of 58 balloons were set on six occasions with 36 (62%) balloons being detected by on-site staff and 55 (95%) detected by DES (Table 14). In five out of six trials, on-site staff detected balloons on the next scheduled wildlife monitoring observation session (either the same day or the following morning) but in one trial no balloons were detected. On-site staff was not informed of the balloons and how many would be set.

Detectability of balloons depended on a number of factors. Where balloons came to rest close to the decant wall or on flat areas of wet tailings, they were generally easy to observe with binoculars. Where they came to rest along beaches or in supernatant or wet tailings at a distance greater than 150 m from the closest observation points, they were difficult to observe other than with a high-powered telescope. Some balloons were not seen again once placed in the TSF. Whether they burst or came to rest out of sight is unknown. It is clear that monitoring without good field binoculars and training probably does not detect the presence of balloons (or carcasses), except those that are obvious.

Table 14. Summary of balloon trial results including DES and on-site staff detection rates

	No. of balloons set	Location of placement	Location of balloons once at rest	No. (%) observed by consultants	No. (%) observed by on-site monitoring	Comments
M398						
20/1/2008	10	All in supernatant	Supernatant close to decant finger	10 (100%)	10 (100%)	Balloons easy to see when looked for.
26/4/2008	9	All in supernatant	Supernatant close to decant finger	9 (100%)	9 (100%)	Balloons easy to see when looked for.
25/5/2008	10	All in supernatant	Supernatant close to decant finger	10 (100%)	10 (100%)	Balloons easy to see when looked for.
Current study						
1/6/2010	9	In flowing stream	Wet tailings	9 (100%)	1	
25/7/2010	8	2 supernatant, 6 in flowing tailings stream	2 in supernatant close to decant finger, 6 on wet tailings, 300+ meters from decant finger.	7 (87.5%)	0	Some balloons on wet tailings quite easy to see, others difficult.
18/8/2010	12	4 supernatant, 8 in flowing tailings stream	2 in supernatant on far beach from decant finger, 8 on wet tailings, 300+ meters from decant finger, 2 not seen again after placement.	10 (83.3%)	6 (50%)	Very windy conditions on day of placement, 2 grey balloons in supernatant not seen again, the other 2 were very difficult to see and could only be seen under very still conditions. Balloons on wet tailings obvious and easily seen.

Insectivorous bat activity

Little is known of bat behaviour, presence and associated cyanide risks on tailings systems. The M398 study is the only published literature regarding bat activity on tailings systems. An avoidance of hypersaline TSFs was previously reported [9] (see Table 14, p.45, M398 volume 2) and this has been found again with further surveying at BGS.

A total of 93 bat passes (all species combined) at 0.73 ± 0.19 calls/hour were recorded from above the BGS TFS (128 hours recording) (Table 24, Appendix 3). Tadrida australis (42%) and Mormopterus spp (24%) dominated the recorded calls.

Bat calls could be differentiated into navigation calls and foraging 'buzz' calls, which can indicate feeding, drinking or social behaviour [26]. Table 25 (Appendix 3) illustrates buzz calls as a proportion of total number of calls. The ratio of buzz-to-cruise calls at non-saline water bodies (0.21, combined average at the BKB turkey nest and GSI turkey nest) is higher than that recorded at hypersaline supernatants (0.07 calls/hour) ($p < 0.001$) (Table 25). This indicates that the level of feeding, drinking and social contact is less at hypersaline TSFs water sources compared to fresh water sources. This concurs with terrestrial and aquatic macroinvertebrate sampling, suggesting that more food resources exist at fresh water bodies compared to hypersaline water bodies. It illustrates an avoidance of hypersaline and saline water bodies.

Ecological summary of the TSF and mine lease

The BGS TSF can be described as ecologically and physically simple, once saline and now hypersaline, devoid of complex habitats, devoid of vegetation and containing no aquatic macroinvertebrates and minimal terrestrial macroinvertebrate food resources for wildlife. The tailings system can subsequently be described as low wildlife visitation and interaction system, although interaction with cyanide-bearing habitats exists.

A summary ecological description of the TSF is as follows:

- wildlife recognised as at-risk are present;
- supernatant solutions are essentially devoid of live aquatic macroinvertebrates;
- terrestrial macroinvertebrates of varying class sizes are present on the TSFs and provide a limited food resource for wildlife;
- the presence of wildlife is influenced by habitat and food provisions;
- the abundance of food resources (terrestrial macroinvertebrates) is influenced by temperature, rainfall and vegetative conditions of the surrounding environment;
- hypersalinity inhibits wildlife drinking although some species can, under extreme conditions, tolerate some of the lower salinities previously recorded at the BGS TSF;
- hypersalinity influences the species that visit the TSFs; and
- vertebrate wildlife, primarily birds and bats, inhabit or interact with tailings solutions to a far lesser extent than they do at nearby fresh water bodies.

The mine lease has large areas of extant vegetation and numerous sources of drinking water for wildlife. A variety of habitat types, both terrestrial and aquatic, exist that provide resources for resident, nomadic and migratory species of wildlife. Wildlife numbers and visitation patterns to the lease are strongly influenced by environmental conditions and general nomadic behaviour of wildlife in an arid environment.

A summary ecological description of pertinent features relating to the TSF and pits is:

- The seepage trench and TSF are separated by only the TSF wall (100 m wide and 40 m elevation) however the species composition differs.
- Seasonality is evident with Welcome Swallows more abundant in winter, and Red-capped Plovers more abundant in summer and autumn.
- It appears that the largest determinant of visitation rates to the TSF is seasonal, rather than tailings salinity, and this is consistent with the ecology of the dominant species. Red-capped Plover commonly uses saline and hypersaline habitats, and Welcome Swallow has little interaction with terrestrial substrates regardless of salinity.
- Visitation rates and species diversity at alternative water bodies are likely to be influenced by a combination of water palatability, extent of vegetation present, physical features, shape of the water body and water depth.
- A number of ducks, waders and aerial species appear to be resident on the mine lease and utilise the various alternative water bodies. Other individuals and species come and go depending on various environmental factors.
- Drinking regularly occurs at the brackish Winditch Pit by a variety of wildlife including, ducks, granivores, swallows, bush birds and kangaroos. Drinking was observed at the fresh Phoenix and Jubilee pits to a lesser extent, mostly due to fewer visitations.
- Vegetation is present to varying degrees within the pits surveyed with Winditch and Phoenix pits having the greatest extent of vegetation and the greatest access to the vegetation, which is reflected in the visitation rates of mammals and bush birds. The remaining pits had very little vegetation within the pit, hence the bush bird and mammal records at Goanna and Jubilee pits were from the rim of the pit.
- While recording rates for aerial species vary considerably, timing greatly influences this as aerial species in arid Australia are often in flocks and visit pits a number of times throughout the day for short periods.

Wildlife deaths

Since wildlife monitoring began at BGS, on-site staff have recorded nine wildlife deaths, and DES discovered four additional deaths in May 2010 (Table 15). Seven of these deaths were terrestrial mammals (Table 15) that got bogged in wet tailings and drowned or died of exhaustion and were unrelated to cyanide.

Two of the wildlife deaths were Red-capped Plover chicks recorded in the ground water interception trench on the outside perimeter of the TSF. They were estimated at one to three days old and the carcasses were located within 5 m of each other outside the eastern wall of the TSF. Picric Acid WAD cyanide analysis of samples taken from the seepage trench adjacent to where the carcasses were located gave results of < 4 mg/L WAD cyanide. These carcasses were located at least 50 m below the rock-armoured wall of the TSF, which consists of loose rubble. Access to the cyanide-bearing tailings is not conceivable. Historical data for the seepage trench ranges from 0.01 to 0.6 mg/L WAD cyanide. There was evidence of other waders and ducks (footprints) in the immediate area and a juvenile and four adult Black-fronted Dotterels and an Australian Shelduck were sighted feeding in the same location when carcasses were discovered. The cause of death is not known but unlikely to be from cyanide.

The remaining four wildlife deaths were adult and immature Red-capped Plovers discovered in the active cell on 1 May 2010 by DES. Intensive observations were conducted between 06:10 and 07:47 on this day and carcasses were not observed and not deemed to be present. During this period up to 56 Red-capped Plovers were recorded actively feeding on beach/dry tailings and beach/wet tailings. At times, individual birds were within 10 m of spigots and were observed foraging in wet tailings. No wildlife deaths were recorded between 06:10 and 07:47, but upon recommencement of observations at 12:25 one carcass was detected within 20 m of the decant finger. A second carcass was then easily detected by DES using binoculars and these two carcasses appeared obvious. Further observations using the telescope revealed two more carcasses, however they were not easily identified and required a change of locations within the TSF for confirmation. All carcasses were located on or close to wet tailings within the TDZ (see photo essay). The carcasses all appeared very fresh and clean with no tailings on the plumage and no signs of struggling in the tailings, suggesting a quick death. Shortly after the discovery of the carcasses (at 12:40) 22 Red-capped Plovers were observed actively foraging on or adjacent to wet tailings within the TDZ with no apparent affect.

No carcasses were recorded by on-site staff however they may not have been present as their observations were completed by 09:00 that day.

No carcasses were retrieved. The deaths were attributed to cyanosis because of the in-situ location of carcasses on wet tailings; obvious rapid on-set of death; and multiple deaths of a species actively feeding in cyanide-bearing substrates.

Table 15. Wildlife deaths recorded within the TSF and adjacent seepage trenches at BGS during on-site monitoring

	Location	Species	Number
17 August 2006	TSF	Rabbit	1
14 November 2006	TSF	Kangaroo	1
27 May 2007	TSF	Kangaroo	1
24June 2007	TSF	Kangaroo	1
27June 2007	TSF	Kangaroos	3
31 August 2007	Ground water interception trench	Red-capped Plover juveniles	2
1 May 2010	TSF	Red-capped Plovers	4

Chemistry data preceding and at the time of the Red-capped Plover deaths on 1 May 2010

To understand the reasons for the Red-capped Plover deaths, chemistry data was scrutinised both from within the TSF (decant and discharge) and from within the mill. The chemistry data available for the spigot discharge is the most pertinent to the cyanide concentrations within TSF habitats however only one sample a day is taken. Monitoring of free cyanide and pH is conducted at various points in the mill on a regular basis, for example every four hours for the final tailings exiting CIP tank 6 (see Figure 3 for mill process flow sheet). Cyanide addition ratios (kg cyanide to tonnes of ore) are also measured by an automated system roughly every 1.5 minutes. The data available from the mill is therefore a much finer resolution however the relationship with cyanide concentration in TSF habitats is more tenuous. The ore residence time from leach tank 0 to tailings discharge is approximately 24 hours.

The daily spigot discharge concentration as analysed by the on-site laboratory was relatively high at the time of the Red-capped Plover deaths (1 May 2010) (Figure 22). The tailings discharge salinity level at the time was approximately 8 000 mg/L TDS, well within the drinking range for a number of species such as ducks, granivorous birds and bush birds (see literature review; no data is available for Red-capped Plover) (Figure 22). Salinity at this concentration is below the recommended operating parameter derived in M398 for BGS. Circumstances at the time of the incident do not appear to present a critical risk level or threshold when the dataset of WAD cyanide and salinity concentrations at discharge for 2010 is considered (Figure 22). However a single sample per day does not capture the variability in WAD cyanide at the spigot.

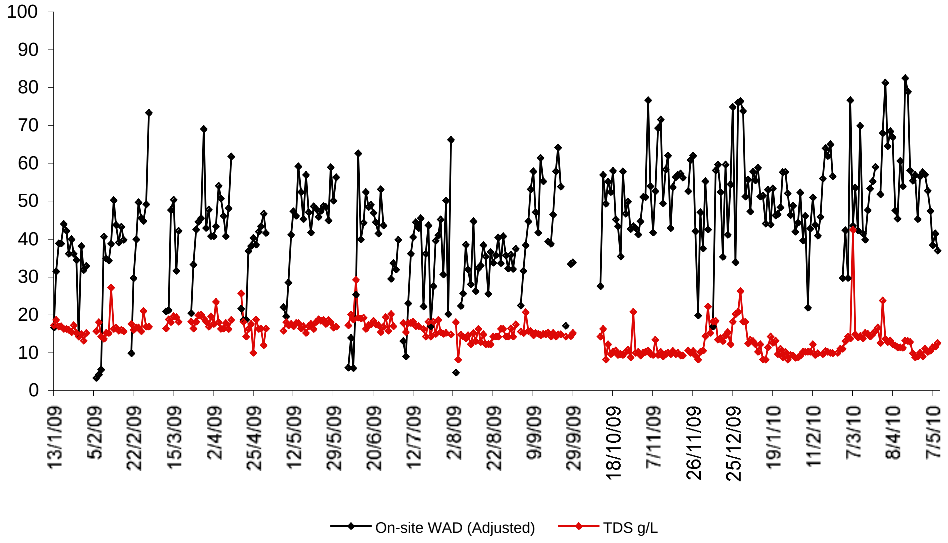


Figure 22. Adjusted WAD cyanide concentrations (mg/L) at spigot discharge measured by on-site monitoring (x 0.7 to adjust for reported 30% over reading) and salinity (g/L TDS) as measured by on-site monitoring at the spigot between 1 January 2010 and 9 May 2010

The free cyanide readings from the final tailings (exiting CIP tank 6) are more frequent and around 30 April show comparatively high values (Figure 23) with an average of 152 and a maximum reading of 170 for the six readings prior to the discovery of the incident (12:00). While these concentrations are higher (Figure 24) the maximum had been reached or exceeded on 34 days since 4 December 2009. The variability in cyanide concentration is also substantially reduced by the time the tailings reaches the spigot. Consequently while it is evident that cyanide levels at spigot discharge were high at the time of the incident this data is not definitive.

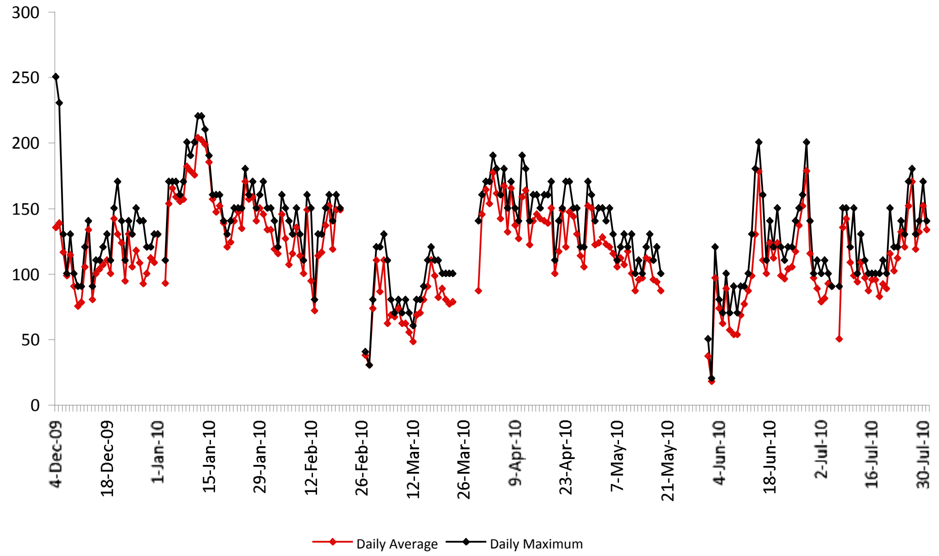


Figure 23. Average (from six four-hourly samples) and maximum free cyanide concentrations (mg/L) in tailings exiting CIP tank 6 ('final tailings') between 4 December 2009 and 14 May 2010

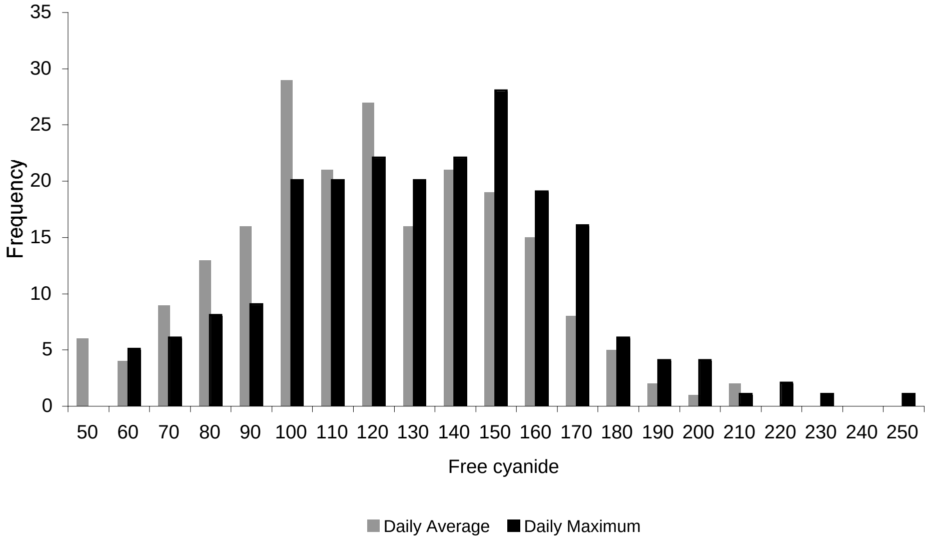


Figure 24. Distribution of average (from six four-hourly samples) and maximum free cyanide concentrations (mg/L) in tailings exiting CIP tank 6 ('final tailings') between 4 December 2009 and 14 May 2010

At the time of the incident the cyanide additions were measured automatically but actually controlled manually due to an equipment malfunction. This is not normally the case, with cyanide addition controlled automatically. Manual control of cyanide addition is less precise and consequently the dose oscillated above and below the target rate of 0.24 kg per tonne of ore (Figure 25). It can be seen from Figure 25 that cyanide additions were at times above 0.5 kg per tonne (200% of the target) and reached as high as 0.85 kg per tonne, 3.5 times the target level. These levels were only sustained for minutes at a time but there were a series of them. While the variability of these would be expected to be reduced by mill processes and tank residence times it is likely that pulses of high free cyanide concentrations continued through the entire mill circuit. It is therefore plausible that free cyanide spikes occurred at the spigot for short periods of time throughout the incident period. These spikes would have been missed by daily spigot monitoring and by four-hourly CIP tank 6 monitoring.

This is consistent with the location of the carcasses, which were immediately downstream from active spigots. It is the author's impression that Red-capped Plover carcasses located on wet tailings is a sign of free cyanide toxicity rather than metallo-cyanide toxicity. Aqueous free cyanide could have been liberated to a gaseous state readily on contact with saliva in the plover's bill. Metallo-cyanide complexes probably require considerable volume of gastric juices (in the gizzard) to liberate gaseous cyanide.

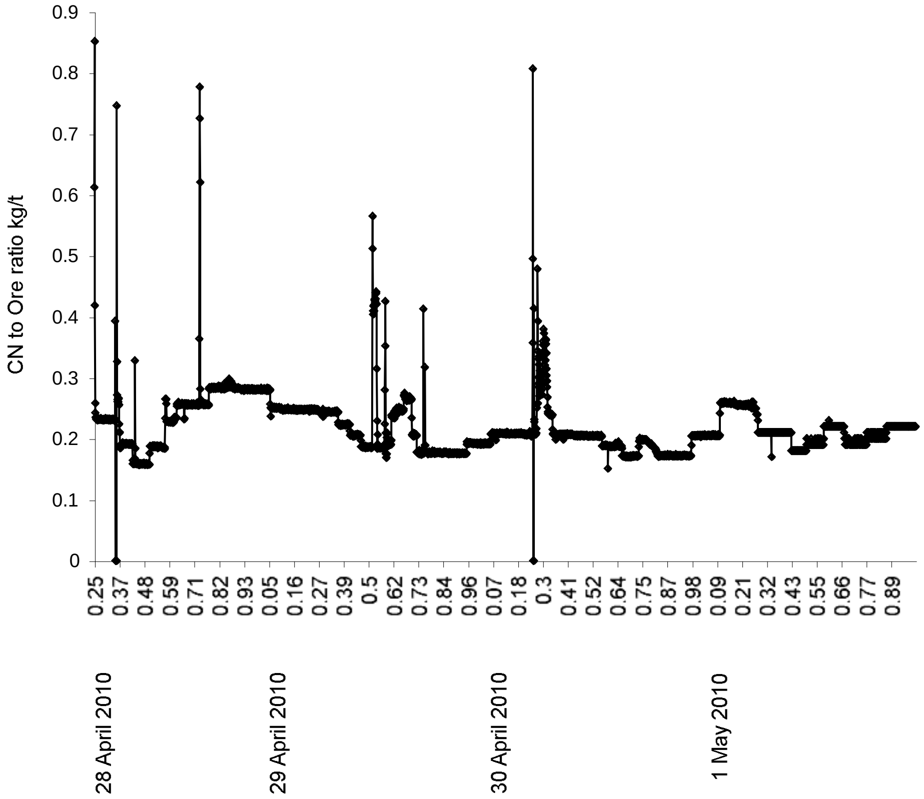


Figure 25. Ratios for free cyanide added to leach tank 0 for each tonne of ore (kg/tonne) between 6:00 28 April 2010 and 6:00 3 May 2010. Readings are taken automatically approximately every 1.5 minutes and the target ratio was 0.24 kg/tonne throughout this period

Concurrent wildlife and cyanide data (over 50 mg/L WAD)

This section synchronises DES intensive wildlife observation data with WAD cyanide sampling and analysis. The data presented here is of wildlife interaction with the TDZ at known spigot discharge concentrations of above 50 mg/L WAD cyanide and salinity concentrations above 50 000 mg/L TDS. The synchronisation of data collection and analyses was not conducted in M398 or previous studies.

During ten days in July and August 2010 DES conducted wildlife observations with concurrent hourly (or three- to four-hourly) cyanide sampling. Cyanide discharge was found to be above 50 mg/L WAD on all days and in all samples taken. A summary of wildlife observations is presented in Table 16. Cyanide data and concurrent observed wildlife interactions with TDZ habitats are presented in Table 17 on an hourly basis for the two species observed. The full dataset used to compile these tables (with some notes) is contained in Appendix 3.

Table 16. Summary of wildlife observation data from observations conducted on ten days in July and August 2010 while spigot discharge was above 50 mg/L WAD and the TSF was hypersaline. All wildlife interactions considered are with TDZ habitats

	Red-capped Plover	Welcome Swallow	Both species combined
No. of one-hour observation blocks when wildlife interaction observed with TDZ habitats and spigot discharge was above 50 mg/L	27	23	36
Total number of wildlife observations (wildlife visitations for each observation hour, all hours combined)	60	283	343
Average number of wildlife present per observation hour	0.9 ± 1.4	4.4 ± 8.6	5.3 ± 9.0
Number of one-minute foraging surveys conducted	59	43	102
Average number of pecks per minute in TDZ habitats	23.8 ± 11.2	6.5 ± 3.4	16.5 ± 12.3

Table 17. Wildlife interaction with wet tailings in the TDZ at the BGS TSF, with concurrent WAD cyanide concentrations and TDS at spigot discharge. Spigot samples were taken on the hour at the beginning of the survey hour. It is indicated where pecking with wet tailings was observed and pecking rates are given where recorded (with number of 1-minute foraging surveys)

				Red-capped Plover			Welcome Swallow		
	Obs. hour (start time)	WAD CN (mg/L) at Spigot (ALS)	TDS (mg/L) at spigot (ALS)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)
Total no of wildlife				60			283		
22/7/10	6:00			5	x				
22/7/10	7:00	71.3	48 100	1	x	12.5 (2)	10	x	5.9 (7)
22/7/10	8:00	63.8	47 100				15	x	6.3 (3)
22/7/10	9:00	65.2		1	x	42 (1)	1	x	
22/7/10	10:00	58.7	68 200						
22/7/10	11:00	72.5							
22/7/10	16:00	65.4	66 700	3	x	8 (1)			
22/7/10	17:00	66.4	63 400						
23/7/10	6:00			3	x		37	x	
23/7/10	7:00	64.7	68 700	1	x	26.7 (6)	1	x	
23/7/10	8:00	65.1	64 600	1	x	49 (2)	24	x	7 (4)
23/7/10	9:00	65	68 800	1	x	13 (7)	1	x	7 (1)
23/7/10	10:00	67.6	62 600	1	x	23.2 (6)			
23/7/10	11:00	61.4	62 200						

continued

				Red-capped Plover			Welcome Swallow		
	Obs. hour (start time)	WAD CN (mg/L) at Spigot (ALS)	TDS (mg/L) at spigot (ALS)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)
23/7/10	15:00			3	x				
23/7/10	16:00			1	x				
23/7/10	17:00	61.5	70 600						
24/7/10	6:00						12	x	
24/7/10	7:00	82.7	58 000				5	x	8.7 (3)
24/7/10	8:00						27	x	3.5 (2)
24/7/10	9:00								
24/7/10	10:00								
24/7/10	11:00	71.2	57 000						
24/7/10	16:00	82.6	54 800						
25/7/10	6:00			1	x				
25/7/10	7:00	88.2		3	x	27 (1)	1	x	4.75 (4)
25/7/10	8:00			1	x	23 (1)	13	x	6 (6)
25/7/10	9:00			2	x		3	x	14.5 (2)
25/7/10	10:00								
25/7/10	11:00	74.1	36 200						
25/7/10	16:00			2	x				
25/7/10	17:00	72.4	39 000	1	x				
26/7/10	6:00						19	x	4.25 (4)
26/7/10	7:00	80.3	56 000	1	x		4	x	7.5 (2)
26/7/10	8:00			8	x		5	x	
26/7/10	9:00								
26/7/10	10:00								
26/7/10	11:00	77.2	54 300						
17/8/10	6:00								
17/8/10	7:00	90.5					20	x	8.5 (2)
17/8/10	8:00	84.1		3	x	22 (1)	4	x	
17/8/10	9:00	77.9		4	x	24.6 (5)			
17/8/10	10:00	67.8							
17/8/10	17:00	69.8							
18/8/10	6:00						9	x	6 (1)
18/8/10	7:00	79.4		3	x	18 (1)	22	x	
18/8/10	8:00						20	x	
18/8/10	9:00			4	x	17.7 (3)	28	x	10 (1)
18/8/10	10:00	72.8		2	x	15 (1)			
18/8/10	17:00	72.3	64 000						
19/8/10	6:00								

continued

				Red-capped Plover			Welcome Swallow		
	Obs. hour (start time)	WAD CN (mg/L) at Spigot (ALS)	TDS (mg/L) at spigot (ALS)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)	No.	Oral int. (Pecks) with wet tailings observed	Peck rate av. (no of counts)
19/8/10	7:00	70.4	55 800						
19/8/10	8:00								
19/8/10	9:00								
19/8/10	10:00	71.2	48 800						
20/8/10	6:00								
20/8/10	7:00	86.5	66 200						
20/8/10	8:00								
20/8/10	9:00			2	x	31.75 (4)			
20/8/10	10:00	83.2	51 500	1	x	24.7 (3)			
21/8/10	6:00								
21/8/10	7:00	59.3	40 200						
21/8/10	8:00								
21/8/10	9:00			1	x	28.1 (14)			
21/8/10	10:00	64.7	35 600				2	x	2 (1)

The spigot discharge WAD cyanide concentrations during the ten days, as analysed at the ALS laboratory, ranged between 59.3 and 90.5 mg/L and averaged 72.2 ± 8.6. A total of 35 samples were taken during this period. Salinity of tailings at the spigot was measured for 25 samples and was mostly above 50 000 TDS however in five samples (20%) it was below this.

It is clear from Tables 16 and 17 that during the ten observation days a substantial amount of interaction with TDZ habitats occurred and there was no mortality detected by DES. DES deliberately scanned the entire active cell each morning and throughout the day using a high quality telescope and binoculars. Confidence was high that the lack of wildlife deaths was accurate. Balloon detection tests carried out on both site visits were consistent with this through demonstration of high detection rates.

Red-capped Plovers and Welcome Swallows were observed using TDZ habitats and both were regularly observed interacting orally (through pecking) with wet tailings. In 36 one-hour blocks one or both of these species were observed interacting orally with wet tailings habitats (Table 16). An average of 5.3 ± 9.0 wildlife was present and observed interacting with wet tailings per hour.

During the 102 one-minute foraging surveys, Red-capped Plovers made an average of 23.8 ± 11.2 pecks and Welcome Swallows averaged 6.5 ± 3.4 pecks (Table 16). Not all pecks resulted in actual contact with wet tailings as prey at times take flight just before being struck however it appeared (although was not quantified) that many, if not most pecks do result in bill interaction with wet tailings (and other substrates). The percentage of strikes touching the wet tailings is likely to be higher for this habitat compared to other TSF habitats due to the viscosity of the tailings and prey being entrained. On a number of occasions Red-capped Plovers were observed with tailings stuck to their bill.

Wet tailings appeared to take a few minutes to reach the supernatant where it was flowing quickly in channelled streams. Where wet tailings flows in sheets, it takes longer to reach the supernatant (approximately 30 minutes or longer). Consequently, wet tailings within the TDZ are a variety of ages with variable cyanide loss. It was clear that on many occasions Red-capped Plovers and Welcome Swallows were orally interacting with wet tailings in the immediate vicinity of spigots.

In addition to the direct observation considered above, there is a substantial dataset of observed wildlife presence in the BGS TSF on days when spigot discharge has been measured at greater than 50 mg/L WAD cyanide. In addition there is similar data from GSI and BKB collected during the M398 project. While this data does not demonstrate wildlife orally interacting with wet tailings in most instances, the behaviour of at-risk species in the TSF environment is now well documented and such data is worthy of consideration. This includes monitoring data collected by DES and on-site staff and is considered here on a day-by-day basis.

The dataset used for this section includes chemistry and wildlife data collected at BGS between 17 April 2007 and 18 August 2010 and analysed on-site or off-site at either the CCWA or ALS laboratories in Perth. The QA and QC assessment of cyanide data analysed on-site demonstrated variability in the error of readings, consequently raw data is used. ALS and CCWA readings are also given and are considered more accurate however all days where cyanide was measured at over 50mg/L are presented. While on some of these days WAD cyanide concentrations may have been below 50 mg/L the majority are likely to have been over this threshold. Much of this data therefore represents wildlife presence within the TSF on days when spigot discharge was above 50 mg/L WAD cyanide.

Data from a total of 97 days is considered in Table 18. A total of 573 daily on-site visitations and 619 daily on-site visitations were recorded on these days, the great majority of which are Red-capped Plover and Welcome Swallow visitations (Table 18). These visitations were of birds observed on wet tailings and supernatant or swallows flying over these habitats. Interaction with TDZ habitats was therefore either observed on these days or very likely, given the known behaviour of these at-risk species, in the TSF environment. Up to 124 Red-capped Plover and Welcome Swallow visitations were recorded by DES on 1 May 2010 and clearly much interaction with TDZ habitats occurred on many days.

Table 18. Cyanide and wildlife observation data for BGS on days when WAD cyanide at discharge was measured at greater than 50 mg/L by either on-site or off-site laboratory analysis.

	WAD cyanide (mg/L)		TDS ppk		On-site wildlife records										DES						
Date	BGS on-site laboratory (non-adjusted)	ALS/CCWA	BGS/ALS/CCWA	On-site total	Duck	Habitat	RCP	Habitat	Other wader	Habitat	Silver Gull	Habitat	Swallow	Habitat	DES total	Duck	Habitat	RCP	Habitat	Swallow	Habitat
				572	21		503		28		4		16		619	6		371		242	
25/4/07		55		23	3	BWT	20	BWT													
8/5/07		58		3			3	BWT													
15/5/07		52		5			5	BWT													
19/6/07		67		2			2	BWT													
7/8/07		70		8			8	BWT													
18/8/07		64		4			4	BWT							9			9	DT/B		
19/8/07		66		8			8	BWT							11			11	DT/B		
21/8/07		63		5			5	BWT													
4/9/07		57		3			3	BWT													
18/9/07		66		1			1	BWT													
1/1/08		50	12.0	3			3	BWT													
8/1/08		60	12.0	3			3	BWT													
20/1/08	76	42	13.0	6			6	BWT							36			36	BWT, BDT		
22/1/08	106	49	15.0	6			6	BWT							36			36	BWT, BDT,S		
23/1/08		56													40			40	BWT, BDT,S		
24/1/08		56													56			56	BWT, BDT,S		
12/2/08		60	13.0	7			7	BWT													
14/2/08	70			11			11	BWT													
16/2/08	150	61		31			31	BWT													
18/2/08	70			24			24	BWT													
26/2/08		90	14.0	4			4	BWT													
13/2/09	72		16.0	6			6	BWT													
28/2/09	104		16.6	9			9	BWT													
15/3/09	72		19.4	6			6	BWT													
5/4/09	72		16.2	5			5	BWT													
10/4/09	88		25.4	5			5	BWT													
14/5/09	84		16.2	2			2	BWT													
28/5/09	84		16.4	6			6	BWT													
17/6/09	75		17.0	1			1	BWT													
16/10/09	78	69	10.7	5			5	BWT													
26/10/09	82		10.0	3			3	BWT													

continued

	WAD cyanide (mg/L)		TDS ppk		On-site wildlife records										DES						
Date	BGS on-site laboratory (non-adjusted)	ALS/CCWA	BGS/ALS/CCWA	On-site total	Duck	Habitat	RCP	Habitat	Other wader	Habitat	Silver Gull	Habitat	Swallow	Habitat	DES total	Duck	Habitat	RCP	Habitat	Swallow	Habitat
6/11/09	77		9.2	11			11	S													
8/11/09	75		9.2	3			3	S													
9/11/09	99		10.0	1			1	S													
10/11/09	102		8.8	8					8	S											
17/11/09	76	36	9.3	1			1	BWT													
20/12/09	85		14.4	5			5	BWT													
24/12/09	77		12.0	4			4	BWT													
31/12/09	105		18.0	4			4	BWT													
3/1/10	73		12.2	4			4	BWT													
10/1/10	79	80	11.4	3			3	BWT													
13/1/10	73		8.0	2			2	BWT													
16/1/10	76		14.0	16			16	BWT													
29/1/10	74		9.2	31			31	WT													
11/2/10	73		9.2	1			1	BWT													
16/2/10	91		10.0	9			9	BWT													
17/2/10	88		9.8	12			12	BWT													
18/2/10	93		9.6	7			7	BWT													
14/3/10	76		14.8	17			17	BWT													
15/3/10	79		15.6	13			13	BWT													
30/3/10	74		12.4	8			8	BWT													
3/4/10	116		13.4	6									6	BDT							
4/4/10	92		12.6	11	7	WT					4	WT									
5/4/10	98		13.0	7	7	WT															
11/4/10	86		11.2	2			2	BWT													
23/4/10	83		12.6	2					2	BWT											
24/4/10	79		9.6	13			13	BWT													
25/4/10	81		8.6	10			10	BWT													
28/4/10	81		9.8	4			4	BWT													
1/5/10	81		10.8	20			20	BWT							124	2	S	75	WT, BWT, BDT,S	47	WT, FS, S
5/5/10	68		10.4	1			1	BWT													
14/5/10	71		44.0	2	2	BWT									25			17	WT, BWT, BDT,S	8	WT
17/5/10	80		51.4	5	2	BWT			3	BWT											
5/6/10		59		5			5	BWT							4			4	WT, BWT, BDT		
13/6/10	67		66.0	2			2	BWT													

continued

	WAD cyanide (mg/L)		TDS ppk		On-site wildlife records										DES						
Date	BGS on-site laboratory (non-adjusted)	ALS/CCWA	BGS/ALS/CCWA	On-site total	Duck	Habitat	RCP	Habitat	Other wader	Habitat	Silver Gull	Habitat	Swallow	Habitat	DES total	Duck	Habitat	RCP	Habitat	Swallow	Habitat
15/6/10	68		58.4	2			2	BWT													
18/6/10	73		91.0	6			6	BWT													
27/6/10	66			3			3	BWT													
28/6/10	68		65.5	4			4	BWT													
29/6/10	73		56.4	4			4	BWT													
11/7/10	85		31.9	1			1	BWT													
15/7/10	73		63.4	6									6	A							
18/7/10	65		59.4	14			14	BWT													
19/7/10	66		60.1	2			2	BWT													
20/7/10	65		56.6	2			2	BWT													
21/7/10	65		62.9	2			2	BWT							4			4	WT, BWT, BDT		
22/7/10	78	73	64.6	6			6	BWT							29			7	WT, BWT, BDT	22	WT, S
23/7/10	90	68	54.4	2			2	BWT							45			8	WT, BWT, BDT	37	
24/7/10	89	83	34.7												22	2		6	WT, BWT, BDT	14	WT, S
25/7/10	78	88	49.2												37	2		7	WT, BWT, BDT	28	WT, S
26/7/10	59	80	48.6												28			9	WT, BWT, BDT	19	WT, S
29/7/10	77		51.4	12			12	BWT													
2/8/10	52		48.0	7					7	BWT											
3/8/10	75		56.2	2					2	BWT											
4/8/10	70	79	52.2	5					5	BWT											
7/8/10	73		56.9	3			3	BWT													
8/8/10	72		42.1	3			3	BWT													
9/8/10	72	68	50.6	2			1	BWT	1	BWT											
12/8/10	54		49.2	4									4	A							
13/8/10	55		49.1	1			1	BWT													
15/8/10	68		57.6	14			14	BWT													
16/8/10	66		43.2												48			14	WT, BWT, BDT	34	WT, S

continued

	WAD cyanide (mg/L)		TDS ppk		On-site wildlife records										DES						
Date	BGS on-site laboratory (non-adjusted)	ALS/CCWA	BGS/ALS/CCWA	On-site total	Duck	Habitat	RCP	Habitat	Other wader	Habitat	Silver Gull	Habitat	Swallow	Habitat	DES total	Duck	Habitat	RCP	Habitat	Swallow	Habitat
17/8/10	67	91	58.1	5			5	BWT							35			4	WT, BWT, BDT	31	WT, S
18/8/10	58	79	63.4												7			7	WT, BWT, BDT		
19/8/10		71		2			2	BWT							8			8	WT, BWT, BDT		
20/8/10		87		3			3	BWT							7			7	WT, BWT, BDT		
21/8/10		65													8			6	WT, BWT, BDT	2	WT, S

Similar wildlife and cyanide data can be presented for the two other sites involved in the M398 project (GSI and BKB), which have since gained Code compliance.

There were 39 days at BKB on which cyanide discharge was measured at above 50 mg/L WAD and at-risk wildlife was observed in the TSF (Table 19). Over this period, a total of 126 wildlife visitations were recorded by on-site monitoring, and 78 wildlife visitations were recorded by DES. Red-capped Plovers and swallows made up the bulk of records for BGS, however ducks, Black Swan, a tern species, another wader species and crows were also observed using wet tailings and the supernatant. Red-capped Plovers and Welcome Swallows were observed by DES to behave in the same way at the BKB TSF as they do at the BGS TSF, which is consistent with other tailings dams where they have been observed. Hence the risk to these species using TSF habitats at BGS is primarily determined by cyanide concentrations within the habitats used. Wildlife exposure to TDZ habitats on many of these days was either observed or expected. The maximum WAD cyanide concentration at discharge was 110 mg/L and the average for these days was 73.7 ± 16.8.

Table 19. Cyanide and wildlife observation data for BKB on days when WAD cyanide at discharge was measured at greater than 50 mg/L by either on-site or off-site laboratory analysis

	Cyanide analysis			On-site wildlife observations													DES wildlife observations				
	On-site WAD	CCWA WAD	CCWA free	On-site total	Ducks/swans	Habitat	Tern sp.	Habitat	Red-capped Plover	Habitat	Wader sp.	Habitat	Swallow/martin sp.	Habitat	Crow	Habitat	DES total	Red-capped Plover	Habitat	Swallow sp.	Habitat
				126	36		2		52		8		27		2		78	32		46	
18/5/06		52															20			20	DTB
26/6/07	86			17	15	S							2	A							
27/6/07	101			3							3	BWT									
29/6/07	70			1							1	BWT									
10/7/07	69			1																	
11/7/07	87			2									2	BWT							
12/7/07	96			13									11	BWT	2	BWT					
13/7/07	93			1							1	BWT									
8/8/07	94			1									1	A							
9/8/07	68			21	16	S			3	BWT			2	A							
17/12/07	66			1					1	W											
21/1/08	56			2			2	BWT													
7/2/08	53			3									1	A			4	4	DT		
12/2/08	52			1					1	W											
17/2/08	55			3					3	BWT											
18/2/08		110	64	8					7	B/DT	1	B/DT					3	3	DTB		
19/2/08		110	55														9	2	WT	7	A
13/3/08	62			2					2	WT											
31/3/08	67			2					2	A											
2/4/08	74			1					1	A											
4/4/08	97			2					2	A											
5/4/08	73			3					3	B/DT											
9/4/08	75			5	5	S															
12/4/08	54			2					2	BWT											
15/4/08	52			1					1	A											
18/4/08	82			6					6	B/DT											
19/4/08	73			2					1	BWT											
22/4/08	80																6	6	WTB		
23/4/08	62			2					2	B/DT							7	3	WTB, DTB	4	A
4/5/08	72			2							2	W									
5/5/08	84			2									2	A							
9/5/08	78			1									1	A							
10/5/08	73			1					1	B/DT											
16/5/08	50			5									5	A							

continued

	Cyanide analysis			On-site wildlife observations												DES wildlife observations				
	On-site WAD	CCWA WAD	CCWA free	On-site total	Ducks/swans	Habitat	Tern sp.	Habitat	Red-capped Plover	Habitat	Wader sp.	Habitat	Swallow/martin sp.	Habitat	Crow	Habitat	DES total	Red-capped Plover	Habitat	Swallow sp.	Habitat
18/5/08	62			2					2	A											
19/5/08	54			2					2	B/DT											
29/5/08	65	90	63	5					5	A							21	10	WTB	11	A
30/5/08	72																4	2	DTB	2	A
31/5/08									5	B/DT							4	2	WTB	2	A

The situation at GSI differed from the other two sites in that the supernatant was above 50 mg/L WAD cyanide for periods of time. At GSI wildlife was observed on 66 days between 18 January 2007 and 2 June 2008 when spigot discharge was measured at above 50 mg/L WAD cyanide or when the supernatant was reasonably expected to be above 50 mg/L WAD cyanide from sampling on adjacent days. The maximum discharge concentrations measured by on-site monitoring was 190 mg/L WAD at an average of 99 ± 26.0 mg/L WAD for these days. The supernatant was measured at above 50 mg/L WAD on 16 days by on-site monitoring. It must have been above that on many more days as it cannot vary substantially on a daily basis and would take many days or weeks to get below this level again once above it. This is the case even if spigot discharge concentrations drop below 50 mg/L, due to the large volume of water.

On these days 187 and 41 wildlife visitations were recorded by on-site staff and DES, respectively, the majority of which were swallows (Table 20). Ducks, swans and waders were also observed and, while little interaction with wet tailings was observed, interaction with a supernatant above 50mg/L WAD was observed on a number of days. No deaths were recorded. The lack of deaths indicates that no drinking occurred (but is not expected as TDS is greater than 50 000 mg/L) as a supernatant of greater than 50 mg/L WAD cyanide is known to be toxic to wildlife.

It is of interest that a substantially larger dataset is available for retrospective synchronisation at BGS than for the other two sites. This is partially because BGS has higher numbers of visitations compared to BKB and GSI.

Table 20. Cyanide and wildlife observation data for GSI on days when WAD cyanide at discharge was measured at greater than 50 mg/L by either on-site or off-site laboratory analysis

	Cyanide analysis (mg/L)			On-site wildlife obs									DES wildlife observations										
	On-site spigot WAD CN	CCWA spigot WAD CN	On-site super. WAD CN	On-site total	Ducks/swans	Habitat	Stilt/avocet	Habitat	Red-capped Plover	Habitat	Swallow sp.	Habitat	DES total	Duck sp.	Habitat	Black-winged Stilt	Habitat	Red-capped Plover	Habitat	Red-necked Stint	Habitat	Swallow sp.	Habitat
Total				187	13		16		6		152		41	2		6		10		1		22	
18/1/07	130		42	1							1	S											
1/2/07	120		73	6	6	S																	
6/2/07	190																						
8/2/07		160																					
9/2/07													6			6	S						
10/2/07													1					1	BWT				
15/2/07			95	2					2	DT/ WT													
21/2/07			55	2					2	BDT													
8/3/07	110			1					1	BWT													
7/5/07	120		75	2							2	A											
27/6/07	86			2							2	A											
10/7/07	75			2	2	S																	
17/7/07	84			4	2	S					2	S											
23/7/07	81			3							3	A											
26/7/07	76			9							9	A											
2/8/07	93			2							2	A											
20/8/07	82			2							2	DT											
22/8/07		59											2	2	S								
30/8/07	89			1							1	A											
4/9/07	50			2							2	A											
24/9/07	69			1							1	A											
11/10/07	68			3							3	A											
7/1/08	100		51	1							1	A											
8/1/08	130		50	2							2	A											
9/1/08	110			2							2	A											
10/1/08			52																				
14/1/08	94		52																				
29/1/08	51			9			9	BWT															
30/1/08	56		93																				
7/2/08	88			10							10	A											
12/2/08	120	74		2							2	A											
13/2/08	110			1							1	A											
15/2/08	81			2							2	A	1									1	A

continued

	Cyanide analysis (mg/L)			On-site wildlife obs									DES wildlife observations										
	On-site spigot WAD CN	CCWA spigot WAD CN	On-site super. WAD CN	On-site total	Ducks/swans	Habitat	Stilt/avocet	Habitat	Red-capped Plover	Habitat	Swallow sp.	Habitat	DES total	Duck sp.	Habitat	Black-winged Stilt	Habitat	Red-capped Plover	Habitat	Red-necked Stint	Habitat	Swallow sp.	Habitat
17/2/08													9					8	WT, S	1	S		
18/2/08	94			2							2	A											
19/2/08	110			6							6	WT											
20/2/08	100			2							2	WT											
22/2/08	130			10							10	I											
27/2/08	140			7			7	S															
28/2/08	110			6							6	A											
29/2/08	120			7							7	A											
5/3/08	110			5							5	A											
6/3/08	140		53																				
26/3/08	90			3							3	A											
10/4/08	97			2							2	WT											
14/4/08	97			2							2	A											
15/4/08	84			1							1	A											
16/4/08	89			2							2	A											
28/4/08	79			9							9	A	4									4	A
29/4/08													10									10	A
30/4/08	76			2							2	A											
4/5/08	79			2							2	A											
5/5/08	75			1					1	BWT													
6/5/08	67			2							2	A											
7/5/08	110			2							2	A											
8/5/08	120			2							2	A											
11/5/08				3	3	S																	
12/5/08	130		64	1							1	A											
13/5/08	120		61	1							1	A											
15/5/08	120		77	1							1	A											
16/5/08	120		53	6							6	A											
20/5/08	93		50	5							5	A											
21/5/08	79			3							3	A											
29/5/08	130		97	18							18	WT											
1/6/08		78											6									6	BWT
2/6/08		79											2					1	WT			1	

Discussion

The authors have collected a number of different types of wildlife data to document wildlife ecology, resource availability for wildlife, exposure pathways to cyanide-bearing mine waste solutions and cyanide concentrations that wildlife was exposed to in different habitats.

Chemistry sampling was conducted in the mill circuit and on a spatial and temporal basis within the tailings cells. QA and QC of sampling analysis was conducted by utilising three NATA-registered laboratories.

Comparative data from Mt Todd Gold Mine (MTGM) is provided by examination of a non-saline tailings system of similar cyanide concentration.

Literature to further identify and validate hypotheses has been used and incorporated into theory development.

Species bias, guild composition and habitat use

Guild composition reflects the primary habitats present within the TSF: airspace over the TSF, tailings and supernatant. Diurnal wildlife visitations to BGS are strongly biased to two species: Red-capped Plover (endemic waders) and Welcome Swallow. This bias is deemed to be real rather than due to influences of the monitoring regime, seasonality or timing of observations. Swallows are common throughout the surrounding environment and were observed at most water bodies surveyed, hence, it is not surprising that they were regularly recorded over the BGS TSF. As with Red-capped Plover, winged insects provide a consistent food source to this species.

The lack of recorded migratory waders at the TSF reflects low numbers in the region, the TSF being an inappropriate habitat and possibly misidentification by on-site mine staff. Only two species of migratory waders have been recorded on-site at BGS, including at alternative water bodies, Red-necked Stint and Wood Sandpiper. Red-necked Stint is the only migratory wader to be recorded at the TSF, on two consecutive days in April 2008 and has been seen once at the haul road lakes. Wood Sandpiper has been recorded regularly during summer in numbers of between one and ten individuals at the seepage trench along the outer wall of the TSF. This species has never reliably been recorded within the TSF cells and is not expected to be, due to its association with vegetated wetlands [27]. The conditions in arid areas of Australia are unpredictable and an influx of waterbirds and migratory waders could occur in response to certain conditions.

The comparative lack of ducks and other waterbirds is primarily influenced by the absence of aquatic food, hypersalinity and physical features of the TSF cells. Previous ornithological studies of hypersaline waters have found that species diversity is lower than on fresh waters but bird abundance can be very high, if food abundance is high [28].

The small numbers of bush birds, granivores and terrestrial mammals is a reflection of the lack of vegetation, rock-armour outer walls and hypersalinity within the TSF. Most records of these bird guilds are of those flying overhead. One exception is the Richards Pipit, a bare ground specialist, which regularly uses the TSF walls for foraging.

Nocturnal wildlife activity

Insectivorous bats were recorded in the airspace above all water bodies surveyed including the TSF cells. The bat recording devices cannot be used to directly extrapolate bat abundances due to repeat recording of the same individual. Bat activity however can be demonstrated.

Differences in bat pass rates between hypersaline TSFs and freshwater control sites are likely to be related to many physical and environmental factors such as presence of food, proximity to vegetation, palatability of freshwater and physical features. However bat activity results indicate that bats mostly avoid hypersaline TSFs and water bodies, with substantially lower recording rates (see Appendix 3).

The buzz-to-cruise calls ratio at non-saline water bodies is higher than that recorded at hypersaline supernatants of BKB, GSI and BGS. This indicates that the level of feeding, drinking and social contact is less at hypersaline TSFs compared to freshwater sources. This concurs with terrestrial macroinvertebrate sampling, suggesting that more food resources exist at freshwater bodies compared to hypersaline water bodies. The reduced buzz-to-cruise call ratio can be attributed in part to a lack of drinking from the hypersaline supernatant or gleaning insects from tailings surfaces.

Songmeter surveys were conducted for a limited time at night at the TSF and recordings of Red-capped Plovers were detected. No night birds such as owls or nightjars were recorded at the TSF. Only one night bird (an owlet-nightjar) was recorded at the haul road lake.

Daily morning observations are scheduled within three hours of sunrise to detect if an impact occurs at night. No indication of this occurring was detected.

Seasonality of wildlife visitations

The rhythm of Australia’s seasons can be difficult to predict [29], increasing in difficulty with greater distance from the equator [30, 31] and from oceans [30]. While seasonality exists in Australia its influence on natural systems is often overshadowed by extreme weather events such as cyclones, flooding, severe storms, droughts and bushfires [32, 33]. Complex and unpredictable cycles such as El Niño events produce a high degree of inter-annual variability in rainfall.

Australia’s western and central inland has low average rainfall and yet it is highly erratic with heavy rain and strong winds accompanying ex-cyclones in some years [31, 33]. Such a series of events have been observed at BGS, for example, in late 2003, early 2004, which resulted in the most recent flooding event of nearby Lake Carey.

The variability and uniqueness of Australia’s climate does not allow simple seasonal monitoring on a four-season-annual basis. For example, truly seasonal patterns of wildlife presence are often not measurable in one or two years in many areas of Australia and require much longer time frames, probably of the order of 25 years. While some seasonality is evident in wildlife visitations to BGS it is not clear whether patterns observed are primarily influenced by current short-term environmental conditions. It is also unknown what seasonal patterns may exist for the BGS area that have been missed during survey efforts. To address this variability monitoring recommendations have been provided previously as ongoing for the life of mine at BKB, GSI and SDGM [9, 25].

A similar daily ongoing monitoring regime is provided here for BGS.

Wildlife cyanide exposure at the tailings storage facilities

Birds regularly interact with cyanide-bearing habitats (wet tailings and supernatant) by removing terrestrial macroinvertebrates from the surface of the substrates. It is unlikely that macroinvertebrates completely submerged in opaque wet tailings are taken, as all the species that successfully forage in the TSF are sight hunters. Bats may also interact with tailings and or supernatant in a similar way but due to their rarity over TSFs and the many difficulties in observing this behaviour it is not possible to confirm this. The lack of buzz calls would indicate minimal or possibly no interaction.

Welcome Swallows have been observed occasionally pecking invertebrates from the surface of the supernatant but this habitat is not toxic to wildlife at the measured cyanide concentrations. The only species of migratory wader recorded, Red-necked Stint, was foraging in a pecking manner similar to Red-capped Plover, which had also been reported at the Kalgoorlie Consolidated Gold Mine TSF [12]. While this species does forage by probing (or piping) into muddy habitats in a natural setting this was not observed at the BGS tailings system. This species is assessed to have a similar risk profile to Red-capped Plover and Welcome Swallow on the rare occasions it utilises TSF habitats. Other migratory waders that primarily forage by probing have not been recorded at the TSF or in the area.

Results from Special Project 1 and sampling in August 2010 indicated that very little cyanide is bioavailable from solid wet tailings and dry tailings. The supernatant is essentially below 50 mg/L. The prime at-risk habitat is therefore tailings solutions in the TDZ.

Exposure to cyanide by foraging birds in the TDZ is limited by hypersalinity and the opaque, turbid nature of tailings, which render it unpalatable and unattractive as a foraging medium (apart from visible prey sitting on the surface). Exposure to cyanide within the TDZ does occur by inadvertent ingestion (swallowing) of tailings that adheres to prey. This implies that a toxicity threshold exists.

Wildlife that does ingest some hypersaline tailings solutions is clearly not receiving lethal doses of cyanide at the identified WAD cyanide concentration recorded at the spigot. This was verified repeatedly through observations and cyanide testing over ten days in July and August 2010.

The death of four Red-capped Plovers on a day when a maximum of 75 individuals were present, and 56 were observed foraging, provides an insight into mechanisms of wildlife cyanide toxicosis. Salinity concentrations at the time did not inhibit ingestion or drinking of tailings and a toxicity threshold was clearly breached. However cyanide concentrations were not high enough to cause the death of most Red-capped Plovers that were foraging. This is probably influenced by a number of factors such as individual habitat use; individual foraging rates; spatial variability in presence of food; and variable cyanide degradation throughout the TDZ.

This species feeds by deliberately seeking individual prey with accurate peck actions. The prey item is removed from the cyanide-bearing substrate, briefly manipulated in the mandibles and swallowed; some cyanide-bearing substrate may be inadvertently consumed. If solutions are not hypersaline then the species may not seek to reduce ingestion of tailings, though may drink the solutions, thereby ingesting greater volumes.

Comparative freshwater site wildlife survey – Mt Todd Gold Mine

For the purpose of comparison with an assumed freshwater tailings system during the M398 study, a visit in February 2008 to the Barrick Darlot Gold Mine (BD) site was included. On investigation, process waters at BD were found to be saline (>15 000 mg/L TDS). No freshwater tailings system was therefore available as a comparative study however access was given to a limited dataset from MTGM.

MTGM was one of seven gold mining operations that partook in a study of wildlife use patterns at gold mining tailings facilities in the Northern Territory [34]. Selected and specific data from that case study was made publicly available (M398) for inclusion here to provide a direct comparison with a fresh tailings systems discharging at concentrations similar to BGS (Figure 26).

MTGM is situated in the Top End of the Northern Territory and is described as a single-celled peripheral discharge system [34]. The mine site is no longer operational. The salinity was anecdotally recorded below 1 500 mg/L TDS.

WAD cyanide concentrations at spigot discharge and in the supernatant are provided in Figure 26. Mine staff trained by DES collected wildlife observational data in a manner consistent with routine data collection at BGS. The dry season wildlife observations between June and September 1997 were not made available.

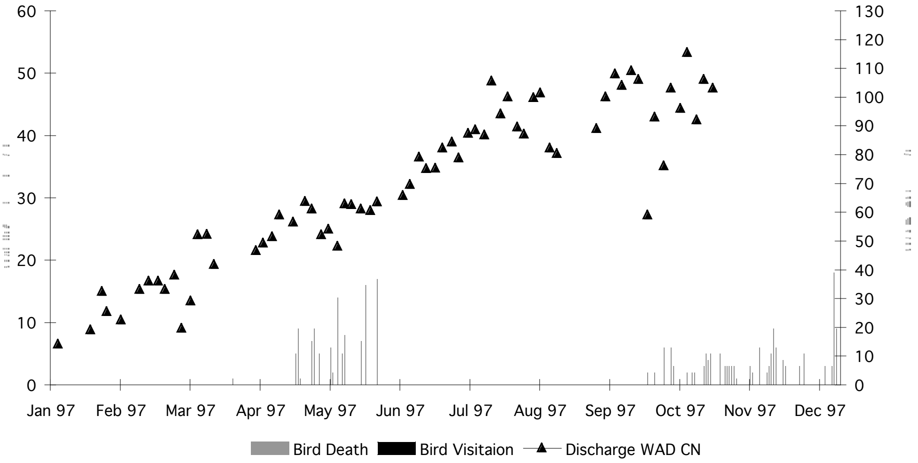


Figure 26. MTGM wildlife visitation, wildlife deaths (primary y-axis) and discharge WAD cyanide concentration (secondary y-axis)

Table 21. Descriptive comparison of WAD cyanide at discharge between the tailings systems of MTGM in 1997, BKB, and GSI in 2007-08 and BGS in 2009-10

	MTGM 1/1/97 – 31/12/97	BGS 13/1/2009 – 18/8/2010	BKB 20/6/2007 – 31/5/2008	GSI 6/3/2007 – 31/5/2008
Mean	71	52	47.3	95
Median	75	49	44	93.5
Standard deviation	28	23.4	22	22.8
Minimum	14	17	10	40
Maximum	120	150	101	150
Samples >50mg/l	48	42	68	113
Count	67	72	168	114
Recorded wildlife deaths	147	4	0	0
Wildlife visitations	2 343	1 774	1 055	824

Table 21 depicts the variability and spread of cyanide concentrations for each tailings system, at times being well above or below the 50 mg/L Code compliance threshold.

Wildlife deaths were recorded at MTGM almost immediately after the spigot WAD cyanide concentration exceeded 50 mg/L (Figure 26). The wildlife deaths then became regular. The data provided shows 147 recorded wildlife deaths at MTGM for the 12-month period from January to December 1997 (excluding the dry season, June to September). This contrasts strongly with what has been observed at BGS where wildlife presence and interaction has regularly been recorded on days of cyanide discharge at above 50 mg/L with no wildlife deaths on the hypersaline system.

This case also demonstrates that with training and field optics mine staff can detect wildlife deaths. The detection of carcasses as the accepted cyanide toxicity threshold was breached indicates that the monitoring regime was in all likelihood effective at detecting carcasses as soon as they appeared. While they are unlikely to have detected all carcasses, the monitoring regime is designed primarily to detect an impact and it appears to have done so. This strengthens the finding that the lack of a detected impact at the hypersaline TSF at BGS is real and not a critical error of the monitoring methodology.

Evidence of protective mechanisms

The cyanide management threshold (50 mg/L WAD cyanide) is based on laboratory results and observations of wildlife interactions and deaths on TSFs containing fresh water [34-37]. The validity of this threshold has been reinforced by a lack of recorded wildlife deaths for solutions of under 50 mg/L WAD cyanide and many published and unpublished records of deaths on solutions of over 50 mg/L WAD cyanide. Until the publishing of the SDGM Code compliance report and M398, there was no information on hypersaline systems. This in part reflects the rarity, around the world, of gold mines utilising saline and hypersaline water for processing.

The following points are now considered for exploring evidence of protective mechanisms at the BGS TSF:

- wildlife is present and interacts on a daily basis at the BGS TSF;
- wildlife interacts with cyanide-bearing habitats (wet tailings, supernatant and beaches) and this has been observed concurrent with WAD cyanide concentrations recorded above 50 mg/L at the spigot;
- there is variable natural degradation of cyanides within the TDZ;
- wildlife can feed close to discharging spigots;
- no wildlife deaths have been recorded on 70 monitoring days by on-site staff and 22 days by DES while it was hypersaline.

Over the period considered in this report when the TSF was hypersaline (7 May 2010 to 21 August 2010; 107 days in total) DES recorded 480 wildlife visitations on 22 observation days. Red-capped Plovers were present on 100% of these days and Welcome Swallows were present on 64%. In addition, on-site monitoring recorded 388 wildlife visitations over 70 days. Neither regime recorded wildlife deaths.

Synchronised cyanide sampling and wildlife interaction data collected by DES on the hypersaline system (Table 17) demonstrated wildlife exposure to habitats containing greater than 50 mg/L WAD cyanide with no impact. Wildlife was observed interacting with wet tailings under these conditions during 36 observation hours at an average of 5.3 wildlife present per hour. Substantial interaction was observed with wildlife foraging on wet tailings within the TDZ for 102 one-minute foraging counts performed and an average of 16.5 ± 12.3 pecks per minute. Some wildlife interactions with wet tailings were observed in this dataset within 50 m of the active spigot. This data is strongly supportive of at least one protective mechanism.

In addition to observations on the hypersaline TSF, four years of wildlife and chemistry data has been collected at BGS. DES monitored on 34 days when the TSF was saline, recording 1 037 wildlife visitations. Many one-minute surveys were conducted and interaction with cyanide-bearing habitats was observed on most days with up to 124 Red-capped Plover and Welcome Swallow present. On-site monitoring was conducted on 1 023 days while the BGS TSF was brackish or saline.

Only four wildlife deaths were recorded on the brackish/saline TSF despite 97 days when tailings discharge was measured at greater than 50 mg/L. It is also likely that it was above this threshold on many more occasions during this period and some wildlife deaths may have been missed. DES found no evidence of carcasses until 1 May 2010. DES spent extended time in the TSF (between four and ten hours per day), used high quality optical equipment including telescopes and has extensive experience at numerous TSFs both with and without wildlife deaths. Other indications that were looked for included: presence of old carcasses, feathers and body parts; patrolling of scavenging species looking for food; and sub-lethal affects on wildlife interacting with cyanide-bearing habitats. None of these signs were observed. This contrasts strongly with experiences at freshwater sites discharging at greater than 50 mg/L WAD cyanide (such as MTGM).

On-site monitoring is not designed to detect wildlife deaths under all circumstances due to the number of factors that influence detection rates of carcasses. The regime used however has a demonstrated ability to detect some (or most) carcasses and carcass replicates at BGS and other sites. The probability of regular wildlife deaths occurring and none being detected by on-site or DES monitoring is regarded by the authors as very small.

The occurrence of four wildlife deaths when tailings discharge was brackish (< 8 000 mg/L TDS) is consistent with the current understanding of cyanide toxicology in TSFs. It is also consistent with hypotheses proposed previously and in this report, that wildlife exposure to cyanide-bearing habitats at greater than 50 mg/L WAD cyanide and less than 50 000 mg/L TDS provides a risk to wildlife.

Given the number of wildlife visitations to cyanide-bearing habitats recorded, literature predicts that significant numbers of wildlife deaths would have been recorded. [10, 34, 35]. The lack of wildlife deaths at the hypersaline BGS TSF and the single recorded incidence of wildlife deaths on the brackish/saline TSF suggest that one or more mechanisms not present on fresh systems are acting as a protective measure for wildlife.

Risk prediction

Observations by experts in a structured manner as conducted by DES are required to determine risks to wildlife. On-site daily monitoring by mine staff is appropriate for identifying an impact and gaining a measure of wildlife visitations only. Expert observations on a daily basis to document risk to all species are not practicable.

The dataset collected at BGS under hypersaline conditions is seasonally skewed towards observations conducted between May and August 2010, however the ecology of the BGS tailings system is well understood. Species risk in various seasons can be predicted through experience and literature despite the limited dataset.

The following is a risk assessment conducted on a guild and species basis (where appropriate) to predict ongoing risks to wildlife (if any) at the hypersaline BGS TSF.

To predict wildlife cyanosis deaths, the following parameters must be understood:

- wildlife habitat provisions of the tailings system;
- wildlife behaviour and interaction with cyanide-bearing habitats; and
- cyanide concentrations in a spatial and temporal context.

Therefore, an understanding of species' feeding behaviour and habitat preference can be used to assess likely cyanide exposure and dosage.

The actual behaviour of at-risk species is not determined by seasonal factors at the TSF (although abundance is), therefore a risk approach can be used to assess risk even with a seasonally skewed dataset (under hypersaline conditions).

All findings of the risk matrix are only valid while the TSF is operating within the parameters measured during the study since it became hypersaline (8 May 2010). The dataset used to determine operating parameters is drawn only from chemistry samples taken by DES in May, June, July and August 2010 and analysed at the NATA-registered ALS laboratory. The spigot discharge concentration is above 50 mg/L WAD, while the supernatant is below 50 mg/L WAD cyanide. Excursions beyond parameters measured are not included in this assessment.

The impact assessment approach used here follows that of Standards Australia/ Standards New Zealand Environmental Risk Management – Principles and Process HB 203:2004 [38]. The approach takes into account the high degree of complexity of environmental systems and that decisions regarding impacts must often be made when there is still significant scientific uncertainty about potential outcomes. At the core of its approach is the concept of environmental risk management [38].

The measures of likelihood and consequence used (Tables 22 and 23) are as suggested in the standard.

Table 22. Qualitative measures of likelihood

Level	Descriptor	Description
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Could occur
D	Unlikely	Could occur but not expected
E	Rare	Occurs only in exceptional circumstances

Table 23. Qualitative measures of consequence

Level	Descriptor	Definition
1	Catastrophic	Severe environmental damage. Local species destruction and long recovery period likely. Extensive clean-up required. Impact on a regional scale. Regulatory: license to operate revoked or suspended. Forced site shutdown to closure.
2	Major	Serious environmental damage with major environmental impact. Requires large clean-up efforts. Extends beyond lease boundary. Regulatory: regulation breach, action by regulator likely. Penalties, e.g. fine or infringement notice issued. Possible or actual prosecution.
3	Moderate	Moderate and reversible environmental damage. Clean up possible by site personnel. Confined within lease boundary. Regulatory: technical compliance issue. Possible regulator action. Field notice issued. Exceed statutory limit.
4	Minor	Minor environmental damage restricted to lease and within previously disturbed area. Regulatory: minor technical breach. Internal standard exceeded. Explanation letter to regulator required.
5	Insignificant	No or very low environmental damage and impact confined to small area. Regulatory: no potential legal action. Standard or limit not exceeded.

A risk matrix is used as a tool to make decisions on risk management through the measure of risk using likelihood and consequence (Table 24). As outlined in the standard, measures of risk are defined as:

E = Extreme risk: immediate action required.

H = High risk: senior management attention needed.

M = Moderate risk: management responsibility must be specified.

L = Low risk: manage by routine procedures.

Table 24. Qualitative risk analysis matrix: level of risk

	Consequence				
Likelihood	5 – Insignificant	4 – Minor	3 – Moderate	2 – Major	1 – Catastrophic
A – Almost certain	M	H	H	E	E
B – Likely	M	M	H	H	E
C – Possible	L	M	M	H	H
D – Unlikely	L	L	M	M	H
E – Rare	L	L	L	M	M

Table 25 provides a description of the at-risk guilds and species that may be present at the BGS TSF. For simplicity, guilds are treated as a whole where likelihood of occurrence and potential habitat use and behaviour at the TSF is assessed to be similar for all species. Otherwise species are treated separately or grouped according to similar risk profiles. Only species and guilds reasonably expected to occur in the region are considered. Habitats and behaviours are as follows:

- B/DT – beach of tailings and dry tailings;
- B/WT – beach of tailings and wet tailings;
- SP – spigot pool;

- A – aerial space above the tailings system;
- SV – scavenging of carcasses;
- R – roosting; and
- F – feeding.

Table 25. At-risk guilds and species and their wildlife habitat use, behaviour, likelihood of interaction with the TSF, consequence and risk

Guilds	Species	Habitat (in order of preference)	Potential behaviour	Interaction mode	Likelihood	Consequence	Risk
Grebes	All	S	R, F	Pecking	E	5	L
Ducks	All	S	R, F	Filtering/ dabbling	B	5	M
		B/DT	R, F	Filtering/ dabbling	D	5	L
		B/WT	R, F	Filtering/ dabbling	D	5	L
Waterbirds	All (herons, egrets, spoonbills, moorhens, coots)	B/DT	R, F	Pecking	E	5	L
		B/WT	R, F	Pecking	E	5	L
Endemic waders	Hooded Plover, Black-fronted Dotterel and Red-kneed Dotterel	B/DT	R, F	Pecking	E	5	L
	Stilts and avocets	S	R, F	Filtering/ pecking	D	5	L
		B/DT	R, F	Filtering/ pecking	D	5	L
		B/WT	R, F	Pecking	E	5	L
	Banded Lapwing	B/DT	R, F	Pecking	E	5	L
	Red-capped Plover	WT, B/ WT	R, F	Pecking	A	5	M
		B/DT	R, F	Pecking	A	5	M
Migratory waders	Wood Sandpiper, Common Sandpiper, Sharp-tailed Sandpiper, Curlew Sandpiper and Common Greenshank	B/WT	R, F	Pipping/ pecking	E	5	L
		B/DT	R, F	Pipping/ pecking	E	5	L
		S	R, F	Pecking/ filtering	E	5	L
	Red-necked Stint	B/WT	R, F	Pecking	C	5	L
		B/DT	R, F	Pecking	C	5	L
Parrots and pigeons	All	SP	None	None	E	5	L

continued

Guilds	Species	Habitat (in order of preference)	Potential behaviour	Interaction mode	Likelihood	Consequence	Risk
Swallows and martins	Martins, woodswallows	S	F	None	E	5	L
		B/WT	F	Pecking	E	5	L
	Welcome Swallow	WT	F	Pecking	A	5	M
		S	F	Pecking	A	5	M
	White-backed Swallow	WT	F	Pecking	C	5	L
		S	F	Pecking	C	5	L
Passerines	All	SP	None	None	E	5	L
Raptors	All	B/DT	SV	None	E	5	L
	All	B/WT	SV	None	E	5	L
Insectivorous bats	All	S	F	Gleaning	E	5	L
		B/DT	F	Gleaning	E	5	L
		B/WT	F	Gleaning	E	5	L
Terrestrial mammals	Dingo	B/DT	SV	None	E	5	L
		SP	SV, D	None	E	5	L
	Kangaroo	SP	D	None	E	5	L
		WT	None	None	E	5	L

For each guild, habitats are listed in order of preferred use. This provides a descriptive comparative abundance measure of risk associated with each habitat.

The risk matrix has identified that Red-capped Plover and Welcome Swallow as at-risk, however these two species were observed and investigated as part of this work. Red-necked Stint presence was determined as occasional, however its mode of feeding as previously observed does not render this species at any risk greater than Red-capped Plover.

A brief description of the ecology of the guilds in the context of tailings dams is provided here.

Grebes look like small ducklings, with which they are sometimes confused, and inhabit open water bodies. They are regularly recorded on fresh water tailings dams [34] and one species (Hoary-headed Grebe) will use hypersaline waters. They have been recorded at on-site water bodies (including Winditch Pit) but are not expected at the TSF. They feed on aquatic macroinvertebrates and travel nocturnally.

The duck guild is rarely present at the TSF even though it is commonly recorded on the mine lease. This guild is primarily crepuscular and nocturnal, often feeding on beaches at this time. They feed on aquatic vegetations and aquatic and terrestrial plants.

The northern hemisphere migratory wader guild arrives in Australia from the end of August and remains until April. This guild is protected under international treaties and the EPBC Act. The presence of one species (Red-necked Stint) has been recorded in the BGS TSF and another (Wood Sandpiper) is regularly recorded at the seepage trench and yet has not been reliably recorded at the TSF. Other species have not been recorded on site but may occur. This guild primarily comprises of species that forage in a range of manners and many use more than one method according to habitat and food resource. While it is possible that some species may attempt to pipe (probe) into wet tailings, species that do this have not been recorded. Such behaviour would be expected to be short-lived as the waders quickly realise no food is present. Red-necked Stint has been observed pecking on terrestrial macroinvertebrates present on TSF surfaces in a similar manner to the Red-capped Plover. Other migratory species, should they occur, may forage in a similar manner. If such species occur on the TSF and engage in foraging they would have a similar risk as the Red-capped Plover.

The endemic wader guild is not migratory but nomadic within Australia, although Red-capped and Black-fronted Plovers appear to be resident in their respective habitats. The BGS TSF provides habitat provisions for Red-capped Plover as evidenced by its constant presence on most days and probably during the night, and its breeding behaviour on TSF cells. Its feeding behaviour is of pecking terrestrial macroinvertebrates from tailings substrates. On-site records of Black-fronted and Red-kneed Dotterels at the TSF are most likely erroneous and could relate to either Hooded Plover (a vulnerable species) or Red-capped Plover. No Hooded Plover records are known from Lake Carey but in Western Australia this species uses inland saline lakes predominantly in the south-west in winter (Marchant and Higgins 1993; Blakers et al 1988-aust bird atlas). It is considered as near-threatened in Western Australia and vulnerable in eastern Australia (Garnett and Crowley 2000).

The waterbird guild refers to crakes, egrets, herons and other birds that have a strong affinity to water for feeding, roosting or breeding. This guild inhabits a variety of habitats particularly if vegetation (dead or alive) is present. Many species of this guild are active nocturnally. Their presence is not expected nor been recorded at hypersaline tailings systems at BGS or elsewhere.

Parrots and pigeons are primarily granivorous and consequently are dependent on freshwater sources. They cannot drink from tailings solutions or from pooling at the outlet of spigots at hypersaline concentrations.

Martins, swallows and swifts feed on insects flying above water bodies and peck at those in tailings substrates. The Welcome Swallow interacts frequently with the substrate.

Passerines (typically bush birds) do not interact with hypersaline slurries or solutions. Their presence is limited to the airspace above the tailings and the dam walls.

Raptors are usually attracted to tailings dams for carcasses. Cyanide is not resilient, biomagnifying or accumulative in carcasses or the food chain, and is not a risk to scavengers unless drunk. They are intolerant of hypersaline conditions.

Hypotheses assessment

Few ecological studies of TSFs have been conducted and all were observation-based, where wildlife, cyanide and other parameters were observed and measured. No parameters have been or could be manipulated at operating sites with such large systems to resemble a controlled experiment. However, this does not eliminate establishing the likely protective mechanisms and therefore gaining Code compliance. A multi-faceted approach, as undertaken in this study, can be used to infer and establish beyond reasonable doubt the validity of hypotheses based on observations.

Hill's Criteria has been widely used to determine if causal associations exist, especially for observationally based studies, and can be used in this study in an ecological and toxicological context. Causal relationships are required to establish if the mechanisms proposed actually reduce wildlife exposure to the cyanide hazard. The rationale for extending the application of Hill's Criteria to other applications (apart from medical research for which it was developed) is supported by the US EPA as used in 'Toxic Substances' and 'Disease Registry: A Quick Guide to Evaluating Environmental Exposures' [39].

Hill's Criteria has been described as follows [39]:

1. Strength: increased prevalence of impact in the exposed population.
2. Consistency: independent replication of empirical findings.
3. Specificity: the association is limited to wildlife with specific exposures.
4. Temporality: the cause precedes the effect.
5. Biological gradient: there is a dose-duration-response curve.
6. Plausibility: the association is biologically plausible and consistent with scientific knowledge.
7. Coherence: the causal interpretation does not conflict with generally known facts of the natural history and biology of the impact.
8. Experiment: some preventive action or intervention prevents the association.
9. Analogy: to well characterised disease.

Not all criteria are applicable to each facet of analysis of this study.

To investigate the hypothesis presented in this report, Hill's Criteria is used to infer causation.

Hill's Criteria is used as a tool to enable determination of a causal relationship and validating of hypotheses as used for Code compliance of BKB, GSI and SDGM.

These hypotheses were first derived from the M398 study and are reassessed specifically to BGS as a hypersaline tailings system. To explain the lack of wildlife deaths under hypersaline conditions at the BGS TSF, the following hypotheses are proposed. Each is assessed for support on the basis of published literature and of data collected in this and previous studies.

Hypothesis 1: Wildlife deaths occurred but the monitoring regime failed to record the presence of any carcasses.

The on-site staff wildlife monitoring methodology employed has been utilised at a range of other gold mining operations in Australia and Africa. While this monitoring regime is not used to gain an accurate measure of the magnitude of any impact that can occur, it has been shown to be effective in detecting and documenting episodic and continuous cyanide-related mortality events. Data from a range of sites consistently shows that where the on-site methodologies are employed an impact has been detected when it occurred [34]. No evidence to the contrary is available. Wildlife impact data is not usually publicly available. The MTGM dataset has been made available via the M398 study and detected an impact as soon as the accepted toxicity threshold was breached. This dataset demonstrates the methodologies' ability to detect an impact even though some carcasses may have been missed.

DES recorded no evidence of carcass scavenging such as regular patrolling by corvids and raptorial birds, and or the presence of tracks of terrestrial scavengers such as dingo, fox, cat or feral dog. If regular wildlife deaths occur scavenging and patrolling for carcasses by some birds and mammals usually occurs and is easily detected. This is secondary evidence that wildlife deaths are or are not occurring.

Wildlife monitoring by on-site staff and DES did not detect any wildlife cyanide toxicosis effects or impacts on the hypersaline TSF. When a mortality event occurred (under saline conditions) DES detected it within minutes of arrival after the event and on-site monitoring would in all likelihood have observed at least one of the carcasses. Both on-site staff and DES wildlife monitoring was conducted within three hours of sunrise to maximise the probability of detecting wildlife deaths that may have occurred nocturnally.

The risk of an impact occurring and the on-site staff monitoring regime failing to detect any deaths is deemed by the authors to be very small.

This hypothesis is not supported.

Hypothesis 2: Wildlife did not die in situ but flew away and died elsewhere.

The literature demonstrates that cyanide is a quick-acting poison that rapidly incapacitates animals once ingested [37, 40]. It cannot be discounted that some wildlife may leave systems after ingesting cyanide and may die elsewhere, however all available data is inconsistent with this assertion. Where sites have been demonstrated to be having deaths due to cyanosis, some, if not all, carcasses have always been recorded in situ [34, 35]. Therefore if deaths were occurring literature expectations and experience dictate that carcasses would be recorded in situ.

This hypothesis is not supported.

Hypothesis 3: Wildlife deaths did not occur during the monitoring period due to seasonal or other environmental influences, resulting in at-risk species not being present during the monitoring period.

At BGS, 5 191 wildlife visitations to cyanide-bearing habitats were recorded by on-site staff monitoring. Wildlife observations covered all seasons at BGS however, not all environmental variations were covered because some climatic cycles occur over a much longer time frame (years and decades). Nevertheless, the number of visitations to cyanide-bearing habitats by guilds known to be at-risk demonstrates that this hypothesis is unsubstantiated. The BGS tailings system, like other hypersaline and saline systems studied [9] is ecologically simplistic and contains no aquatic fauna resources, no drinking resources and very limited habitat diversity. Consequently, these systems typically have low vertebrate wildlife diversity compared to other water bodies. Nevertheless, over time this tailings system has experienced visitations from a diverse range of waterbird species. Continual monitoring is warranted.

This hypothesis is not supported.

Hypothesis 4: Wildlife deaths do not occur due to the physical attributes of the TSF resulting in no wildlife interaction with the hazard.

Considerable visitation and interaction with cyanide-bearing substrates was recorded.

This hypothesis is not supported.

Hypothesis 5: Wildlife deaths do not occur because at-risk species are not found in the region or on any of the sites.

More than 4 300 wildlife visitations to the BGS TSF were of species considered as at risk.

This hypothesis is not supported.

Hypothesis 6: Wildlife deaths are below detectable levels or non-existent due to a lack of aquatic food within the TSFs resulting in little or no wildlife exposure to the hazard.

The presence (number and composition) of wildlife species visiting and interacting with tailings solutions is strongly influenced by lack of aquatic food provisions, which are limited by metal and cyanide concentrations. Very limited interaction occurs from wildlife that feeds on aquatic invertebrates.

Correlations between presence and abundance of food, and wildlife use of habitats has been demonstrated many times [41-43]. However, all TSF supernatants containing cyanide at typical industry levels (< 10 mg/L) will have no live aquatic biota within them as cyanide is acutely toxic to all aquatic biota at very low concentrations (1 mg/L) [37]. The lack of food within the supernatant does not differ from the situation within fresh TSFs where deaths have been recorded. This is therefore not the mechanism for reduced wildlife deaths on hypersaline TSFs compared to fresh TSFs.

This hypothesis is not supported.

Hypothesis 7: Hypersaline tailings solutions (nominally > 50 000 TDS) provide a natural barrier for wildlife exposure to contained WAD cyanide.

Finding: Lack of drinking due to hypersalinity. No wildlife species likely to be present at BGS can drink hypersaline tailings solutions of 50 000 mg/L TDS because of osmotic regulatory (water balance) requirements. Most wildlife species can only tolerate much lower salinities (see literature review Appendix 1). Wildlife drinking such saline water can lead to a range of symptoms related to dehydration such as weight loss, loss of condition and death [44-46]. The Zebra Finch is reportedly the most saline-tolerant species with a reported ability to drink 47 000 mg/L TDS. This was under laboratory conditions for a short period of time only and has not been reported in natural conditions. This species is likely to attempt to drink such saline water under extreme conditions only as a survival mechanism. Any other less saline water source would be preferable due to the metabolic costs and eventual death resulting from reliance on such drinking water. This phenomena was observed during this study with wildlife regularly observed drinking from fresh and brackish water bodies 1 to 2 km from the TSF but never from tailings solutions.

In contrast, drinking from freshwater TSF systems has regularly been observed at other sites [34].

Hill's Criteria: This finding is consistent with empirical data (Criterion 2) outlined in this work. It is also plausible (Criterion 6) and coherent (Criterion 7) with current biological knowledge and literature for all wildlife species known to occur in the area [27, 47, 48] as outlined in the literature review. The effects of negative water balance (dehydration) on wildlife ingesting water of salinities measured within the TSFs has been demonstrated by experiment (Criterion 8) for a number of species [44-46, 49, 50].

Finding: Limited ingestion of cyanide-bearing solutions while foraging due to hypersalinity. Foraging activity resulting in interaction with cyanide-bearing habitats was observed primarily by endemic waders and swallows but also ducks and migratory waders to a lesser extent. Such activity has been observed to lead to deaths on fresh and saline TSFs with similar cyanide concentrations [34]. The few species of wildlife that interacts or forages within the TSF limit ingestion of saline and hypersaline solutions to avoid ingestion of salt and dehydration. The dosage of cyanide-bearing solutions received by wildlife from interaction with hypersaline tailings solutions is therefore limited to small amounts of solution ingested inadvertently by birds pecking while seeking terrestrial macroinvertebrates from dry tailings, wet tailings and supernatant solutions. The dosage of cyanide received is insufficient to cause wildlife deaths at the salinity and cyanide concentrations recorded. This has been repeatedly demonstrated by concurrent wildlife observations and cyanide sampling.

Hill's Criteria: This is consistent (Criterion 2) with the empirical data of this work. It is also plausible (Criterion 6) and coherent (Criterion 7) with scientific knowledge. The rationale that wildlife limits ingestion of a hypersaline solution is logical and consistent with literature. A substantial body of literature is available on wildlife foraging on hypersaline waters both from North America (Mono Lake and the Salton Sea) and within Australia [17, 18, 42, 43, 51-55]. The effects of negative water balance (dehydration) on wildlife ingesting water of salinities measured within the TSFs has been demonstrated by experiment (Criterion 8) for a number of species [44-46, 49, 50].

The necessity for wildlife to avoid salt ingestion or avoid salts once ingested has been discussed in the literature [16, 56-58]. Marine species can secrete salt through salt glands whereas terrestrial species (including ducks, waders and others) must avoid excessive salt intake to maintain osmotic balance within the body. Mechanisms for avoiding salt intake while foraging in hypersaline waters have been recognised and discussed in the literature and involve physiological and behavioural strategies [18, 51].

This hypothesis is consistent with the effects of hypersalinity on wildlife use (and inferred ingestion) of hypersaline water and is consistent with observed data. This hypothesis is supported for both drinking and foraging behaviour.

Hypothesis 8: WAD cyanide in hypersaline waters is lost at rates sufficient to have a substantial beneficial impact on the area of wildlife inhabitation to contained WAD cyanide.

The thermodynamic driving forces for higher cyanide volatilisation with increased salinity are known. However, the degradation of cyanides within the TDZ was variable and at times non-existent (as measured by lucky spigot sampling) and does not eliminate wildlife exposure to concentrations greater than 50 mg/L WAD cyanide. The tailings solutions at BGS are pH-stabilised (greater than 9.1), which hinders free cyanide volatilisation even at the higher salinities. Degradation of cyanides was found to be evident at BKB and GSI, however both of these sites discharge tailings at less than pH 9.1.

This hypothesis is inconsistent with data collected and is not supported at BGS.

Hypothesis 9: Hypersaline tailings solutions have sufficient buffering capacity (excess carbonate) to inhibit free cyanide liberation of ingestion.

Special Project 3 from the M398 study investigated the buffering potential of high carbonate levels in hypersaline solutions to inhibit free cyanide liberation within animal stomachs. Free cyanide is liberated from WAD cyanide within the stomach of animals by acidic stomach juices. It was theorised that under some conditions alkalinity (carbonates) may inhibit the liberation of free cyanide by buffering against the acidity of stomach liquids. However in Special Project 3 it was found that higher salinities resulted in increased free cyanide liberation when exposed to hydrogen chloride (a substitute for gastric juices). The effect of increased salinity on HCN liberation therefore appears to outweigh the carbonate buffering effect in these solutions, rendering Hypothesis 9 invalid.

This hypothesis is not supported.

Limitations

As with all research, some limitations have been identified. Limitations are presented here in conceptual, generic terms and within the scope for compliance with the Code. These limitations identify gaps of knowledge or data. The subsequent recommendations are used to address these limitations to enable BGS to move toward Code compliance.

A temporal-skewed dataset

The BGS tailings system has been hypersaline since 8 May 2010 and the data collected under such conditions is limited to May to August 2010. The limitations of this are not critical as ecological and cyanide data has been collected since 2006 and consequently the ecology and risks are known. This has enabled the prediction and assessment of risks for species not yet recorded under hypersaline conditions during different seasons. Nevertheless, expert observations during the migratory wader seasons (September and October, and again in March) are warranted for completeness.

Demonstration of no wildlife deaths on large tailings cells

The tailings cells at BGS are large for accurate on-site staff wildlife monitoring and some areas of the TDZ are not easily monitored at times (depending on location of the TDZ within the cell). Observational distances were measured at up to 280 m, depending on the tailings cell. These observational distances will produce a level of inaccuracy especially for on-site monitoring using binoculars and short observation periods.

Demonstration that an impact does not occur is very difficult if at all possible. DES uses high quality telescopes to conduct specialist wildlife and carcass monitoring. Implementing a process to measure carcass detectability is warranted. The use of balloons is an important element to measure monitoring efficiency in both on-site and DES monitoring regimes. While balloons do not completely replicate bird carcasses they do not persist in the tailings environment and do not attract scavengers (as using real animal carcasses might).

Specialist monitoring and the use of carcass replicates (balloons) will need to continue to validate the accuracy of no recorded impact by on-site monitoring.

Freshwater control tailings system

The use of a freshwater tailings system for direct comparison has not been available apart from a limited dataset from MTGM. Considering the limitations of using data from a site that is no longer operational, comparisons with BGS have been made in the broadest scope. It has not been possible to assess the accuracy of the wildlife and cyanide-monitoring regime at MTGM or explore the species composition or habitat preferences.

To the author's knowledge, almost all freshwater peripheral-discharge paddock tailings systems that discharge WAD cyanide concentration above 50 mg/L experience a considerable number of wildlife deaths, including Red-capped Plover and Welcome Swallow, which are common at BGS TSF. This data is not publicly available for comparison.

Nocturnal wildlife interaction

Bat activity, behaviour and presence are documented by echolocation data loggers (Anabats SD1). Data has shown a gross difference in bat activity at hypersaline TSFs compared to alternative non-saline water bodies. Bat interaction with tailings could not be determined and would require ongoing quarterly monitoring in a manner similar to the methodologies used in this work.

Nocturnal interaction with TSFs by avifauna is expected from Red-capped Plover but could not be documented or quantified. It is not anticipated to pose a greater risk compared to diurnal interactions.

Routine observations within three hours of sunrise (routine monitoring specification) attempts to address this limitation by documenting if any carcasses are present from interaction during the previous night. Scavenging is also assessed by routine daily wildlife observations and can be detected by assessment of the wildlife species composition.

Cyanide dose from ingestion

The cyanide dose (ingested quantities) cannot easily be determined through observation and direct dosage experiments are either difficult or not possible. Any effects from interaction with cyanide-bearing substrates can, however, continue to be documented. The lack of dosage quantifiable data limits the ability to determine toxicity thresholds. Consequently, safe operating parameters, not toxicity threshold, are provided as a recommendation for Code compliance. These should continue to be assessed through observation of wildlife presence and behaviour along with concurrent cyanide data.

QA and QC of chemistry data (on-site and off-site)

Reliability of chemistry data is critical to managing the risk to wildlife in the TSF. Discrepancies in results were found between on-site and off-site laboratories, between the two off-site laboratories and also within analyses at off-site laboratories (free cyanide values given as slightly higher than WAD cyanide values on some occasions). Accurately determining cyanide values from field samples is difficult due to analytical and sample error. Consequently a level of error is expected in results, which is normal and unavoidable throughout the industry. A variability of 10% between on-site and off-site results for duplicate sampling is acceptable. Despite this, a good understanding of the TSF chemistry has been gained over the course of this and previous projects through repeated testing, duplicate samples and other QA and QC techniques. To maintain reliability of cyanide chemistry data, QA and QC activities must be ongoing.

Accuracy of automated analysers (if installed) is dependent on regular calibration, servicing and maintenance. Duplicate sampling QA and QC is still necessary.

Key recommendations

Recommendations have been developed in the context of the relevant standards of practice specified in the Code. They address any perceived limitations as described above and identify requirements for compliance with the Code. Since no wildlife cyanosis deaths were recorded under hypersaline conditions, the recommendations address maintenance of the protective measures already in place, continued verification of the lack of wildlife deaths and modification of the current procedures where necessary.

Key recommendations are presented here specific to BGS and are not extrapolated from other sites or data. These recommendations have been developed on the basis of the formulated hypotheses and the supporting scientific bases as applied to the body of data collected, identified limitations and assessment of the Code. Operating parameters have been determined using chemistry data from TSF samples collected between 8 May 2010 (when the TSF became hypersaline) and 21 August 2010 and analysed off-site by the ALS laboratory (NATA-registered). They are considered to be achievable in the long term based on the dataset obtained. However these parameters are developed as an adaptive management strategy and data collected or knowledge gained in the future should be used to update, remove or include additional recommendations.

As determined by DES and on-site wildlife observations, wildlife has been present essentially on all observational days. A set of operating parameters for the BGS tailings system is required as wildlife does interact with the cyanide-bearing solutions and substrates. A toxicity threshold will exist but no such threshold for the hypersaline system was determined from this work. It is therefore considered that the hypersaline BGS TSF has operating protective mechanisms for wildlife at the operating parameters measured.

After consideration of plant metallurgical data and management, literature and field observations, the critical operating parameters to maintain the protective mechanisms are determined as:

- WAD cyanide at spigot and supernatant; and
- salinity at the spigot and in the supernatant.

The recommended operating parameters for cyanide (at spigot and supernatant) are given as a maximum discharge concentration (95th percentile) and an 80th percentile (Table 26). The 95th percentile is used as the maximum due to the presence of outliers (very high cyanide readings) in the dataset, which are likely to be due to operational aberrations or laboratory analysis error rather than normal operating conditions. The 80th percentile is given for WAD spigot discharge in addition to the maximum to represent a figure under which the site should aim to operate for 80% of the time. The aim of this is to replicate the regime and the distribution of WAD concentrations that operated during the course of the project while the TSF was hypersaline. Discharging at or near the maximum operating parameter continuously increases the risk of breaches above the maximum due to normal fluctuations in cyanide concentrations. It would also result in an increase in the WAD cyanide level in the supernatant beyond that assessed during this project. Consequently the 80th percentile value should be the primary cyanide management value.

The operating parameter for salinity is determined as a minimum of 50 000 mg/L TDS at spigot discharge and within the TSF as this exceeds the maximum known salinity that wildlife has been observed to be capable of drinking.

The following recommendations apply when the tailings system discharges above 50 mg/L WAD cyanide concentration.

Recommendation 1: Operating parameters

Recommended WAD cyanide and salinity operating parameters are given in Table 26.

Table 26. Recommended target operating parameters for BGS

	Maximum WAD cyanide mg/L	WAD cyanide 80th percentile mg/L	TDS mg/L
Spigot	83.3	71.7	>50 000
Supernatant	40	N/A	>50 000

Recommendation 2: Write an articulated tailings management plan

An articulated tailings management plan must be written and be known to relevant staff to facilitate the operational compliance with the pertinent recommendations (such as adherence to operating parameters). It would guide decision-making and reduce subjectivity in tailings management. It may include (but not be limited to) the following:

- all recommendations of this report;
- consideration of which dataset is to be used for decision making;
- target concentrations of cyanide at discharge that would result in operating parameters being met at the spigot and in the supernatant (the 80^{th} percentile for cyanide would be appropriate);
- target concentrations of salinity at discharge that would result in operating parameters being met (above 50 000 mg/L TDS in all habitats);
- hierarchy of controls to manage cyanide and salinity concentrations within the TSF;
- investigating a correlation of free cyanide concentration in the mill process with free cyanide concentrations at spigot discharge;
- monitoring critical operating parameters (salinity and cyanide) within the mill to ensure they are met at spigot discharge;
- identify the cause and actions to be taken once certain parameters are breached;
- actions to be taken in the event of mechanical failure that may affect either cyanide or salinity concentrations in the TSF;
- actions to be taken in the event of wildlife mortality;
- documenting all actions taken (such as actions to address excursions beyond operating parameters) for auditing purposes and incident review;
- documenting tailings management activities;
- determining circumstances when external expertise is required;
- an updated plan as necessary, incorporating relevant changes within the mill and TSF;
- ensuring staff changes do not compromise tailings management; and
- incorporating wildlife and chemistry monitoring regimes into this plan.

Recommendation 3: Assessment of risk to wildlife on a continual basis

DES determines wildlife cyanosis risk by careful and deliberate observations of wildlife and sampling of cyanides according to the methodology used in this study. Although no increased risk is predicted, continuation of expert monitoring is necessary for completeness (see limitations). The use of balloons is an important element in measuring monitoring efficiency in both on-site and DES monitoring regimes and will need to continue.

This requires a continuation of the wildlife (including bat monitoring) and cyanide methodology used in this work by experts to the satisfaction of the peer reviewers (or their delegate) including the migratory wader passage-migration seasons (usually September, October and March) for species such as, but not limited to, Red-necked Stint, and during extreme water deprivation conditions (usually January and February). This is referred to as targeted seasonal condition surveys. The data collected during these survey times shall be assessed for consistency with existing knowledge of the ecology of the BGS TSF and associated risks. These findings shall be articulated in report form for peer review. If the peer reviewer panel is satisfied that sufficient knowledge has been gained and no increase risk is identified, it can determine that no further site surveys to target these conditions be warranted. An auditor of the Code must be satisfied with the reasoning for such a conclusion.

To address the possible inaccuracy of on-site staff wildlife surveys on large tailings cells, those considered experts to the satisfaction of the peer reviewers (or their delegate) shall conduct quarterly wildlife and cyanide monitoring according to this work. It can be incorporated with the targeted seasonal condition surveys. The results of quarterly monitoring shall be presented in report form on a six-monthly basis to the peer reviewers or delegate. If the peer reviewer panel is satisfied that sufficient knowledge has been gained and no increase risk is identified, the panel can determine that no further quarterly site surveys are warranted. An auditor of the Code must be satisfied with the reasoning of such a conclusion.

Recommendation 4: Continuation of structured on-site monitoring regimes

Cyanide and chemistry monitoring

The following chemistry parameters should be monitored at least daily within the TSF:

- total, WAD and free cyanide at the spigot and supernatant;
- salinity at the spigot and supernatant; and
- pH at the spigot and supernatant.

Weekly samples and analysis of copper concentrations at the spigot and supernatant should be conducted.

This monitoring regime will allow investigation of:

- ongoing assessment of the risk to wildlife in the TSF;
- the relationship between spigot discharge concentrations of cyanide and salinity with those in the supernatant;
- the effects of rainfall on salinity; and
- deviations from normal operating parameters.

Table 27. Summary of recommended chemistry monitoring regime

Analytes	Location	On-site sampling and analysis	External laboratory analysis (QA and QC sampling)	Comments
TSF sampling				
WAD cyanide	Spigot	Daily	Duplicate samples taken weekly	Samples should be taken as early in the morning as possible.
	Supernatant	Daily	Duplicate samples taken weekly	Samples should be taken as early in the morning as possible.
Free cyanide	Spigot	Daily	Duplicate samples taken weekly	Samples should be taken as early in the morning as possible.
TDS	Spigot	Daily	Duplicate samples taken weekly	
	Supernatant	Daily	Duplicate samples taken weekly	
pH	Spigot	Daily	Duplicate samples taken weekly	
	Supernatant	Daily	Duplicate samples taken weekly	
Copper	Spigot	Weekly	Duplicate samples taken weekly	
	Supernatant	Weekly	Duplicate samples taken weekly	
Carcasses detected	Spigot and supernatant	As soon as practical	Duplicate samples	

QA and QC on all chemistry sampling should be conducted and assessed. Installation of an automated WAD analyser may necessitate changes to the operating parameters to reflect the different monitoring location. A relationship would need to be established between the readings from the analysers and the resulting concentrations at the spigot. Accuracy of automated analysers is dependent on regular calibration, servicing and maintenance where required and it would be necessary to ensure that these occur and are documented. QA and QC sampling of the spigot may still be necessary with samples sent to an off-site laboratory for analysis.

Duplicate tailings samples to be taken from the spigot discharge point

Duplicate tailings samples should be taken on a weekly basis from the spigot discharge point for WAD cyanide, free cyanide, copper, salinity and pH. Samples should be preserved according to a procedure that is acceptable by a NATA-accredited laboratory. Samples should then be sent to a NATA-accredited laboratory for analysis. The data collected should be assessed to determine any discrepancies in chemistry analysis and used to improve on-site laboratory practices.

Daily wildlife monitoring by trained staff

Environment or technician staff trained in environmental monitoring techniques will need to gather data on at least a daily basis. This monitoring regime is summarised in the following table and is identical to the current on-site staff wildlife monitoring regime.

The monitoring regime is designed to collect data to assess the risk (if any) and record impacts (if any). It will document the presence of wildlife and carcasses but not the precise magnitude of an impact. This, coupled with the proposed cyanide and chemistry monitoring regime, will provide data and allow some level of assessment of wildlife cyanosis risk.

The wildlife monitoring regime to be conducted by environmental or suitably trained technical staff and should include the components outlined in Table 28.

Table 28. Proposed environmental and trained technical staff routine wildlife monitoring program for the TSFs and supernatant ponds

Frequency	Water body	Time	Observations	Description
Daily Note – Daily surveys are required as long as discharge concentrations are ≥50 mg/L WAD cyanide.	Active TSF cell	Within 3 hours of sunrise	Start and finish times; species ID number; habitat usage; behaviour; condition; time in contact with water body; observer's name; location, Record zero bird presence on the data sheet if applicable.	Record habitats as: S – supernatant (water body on top of tailings) B/WT – beaches/wet tailings B/DT – beach/dry tailings B/W – beach/walls A – Aerial DT – dry tailings WT – wet tailings Record condition as alive, stressed or dead.
			Carcasses present	Concurrent with wildlife surveys. A thorough search of all habitats on the TSF by walking or driving close to the various habitats and using optics. Record any carcasses (location and species) and photograph them. If any at-risk species are present (alive), attempts should be made to haze them from the TSF.
Same day – if carcasses present	All cyanide-bearing water bodies where carcasses present.	Afternoon	Carcasses present	If carcass detected, then carcass counts to be conducted again that afternoon to determine carcass in-situ residence time and fate.

The above-mentioned wildlife monitoring protocols should be incorporated into existing environmental monitoring documentation. Blind test balloon detection trials should be conducted to test carcass detection efficiency of the designated wildlife observers. These tests should be conducted at between four to eight week intervals. The results of such tests shall be documented.

In the event of wildlife deaths on the TSF, independent experts shall be engaged to determine if operational or procedural changes are required to maintain Code compliance.

Wildlife monitoring data management

To ensure accurate recording of wildlife monitoring data, both the technicians and environment staff should continue to record the results of their wildlife monitoring into a single electronic database or spreadsheet to which all parties have access (as currently being done). This will provide the opportunity to compare daily wildlife observations from each monitoring regime. Data from one regime can be used to validate the data collected by the other. This type of data verification can be input into adaptive management procedures to improve wildlife monitoring protocols and ensure the consistency and robustness of data collected.

Ensure that sufficient data collection is undertaken to enable statistical relationships between monitoring cyanide concentrations and wildlife visitation data. This will enable a risk-based management approach to continue to avoid cyanide impacts on wildlife [59].

Wildlife monitoring training for observers

To ensure that wildlife monitoring data collected by environment and technical staff is robust and consistent, all staff involved in monitoring must be adequately trained to observe and identify wildlife guilds, particularly guilds common to the region, that are at risk from cyanosis. Environmental and technical staff are not expected to identify individual species. Guilds of species such as ducks, waders, swallows and martins are sufficient. They must be aware of the range of habitats that different guilds of at-risk species are attracted to and which of these habitats represent significant cyanosis risks. All monitoring staff should have some general knowledge of the typical range of 'normal' behaviour displayed by at-risk species so that they can identify signs of distress that may indicate birds suffering from cyanosis.

Appropriately qualified staff must conduct training. This may include internal staff members with sufficient avifauna monitoring experience, or external experts [59]. Refresher training should also be provided regularly to ensure that all monitoring staff are kept up to date with the necessary skills and knowledge required for wildlife monitoring.

Recommendation 5: Ongoing assessment of laboratory practices to ensure continual improvement in accuracy of analysis

Laboratory analysis is a critical function that guides mill and tailings management. Consequently the accuracy of laboratory results is of paramount importance. Currently, the variability in chemistry analysis may mask a risk to wildlife in the TSF or result in unnecessary actions taken. A QA and QC program within the laboratory including review of procedures is recommended to ensure analysis results are within acceptable error ranges (generally 10%).

Recommendation 6: Ongoing assessment of adherence to these conditions

The operation shall be assessed and reviewed initially within three to six months, thereafter at least annually against all the conditions provided here. Such an assessment can be made available to an auditor of the Code.

Recommendation 7: Minimise infrastructure in the vicinity of cyanide-bearing habitats

Infrastructure minimisation on the BGS TSF is required to reduce wildlife diversity and exposure pathways. This includes, but is not necessarily limited to, maintaining the tailings system devoid of waste materials other than tailings.

Recommendation 8: Vegetation suppression and removal in and near cyanide-bearing water bodies

Suppress all vegetation growth and subsequent regrowth within the perimeter of the TSF cells and not the outer slopes or surrounding drains. The presence of vegetation, alive or dead, in and around a water body significantly increases wildlife abundance, diversity and interaction with cyanide-bearing solutions.

Conclusion

The limitations of this work have been identified and addressed by the recommendations. There is no more than a minimal identified risk to wildlife if operating parameters are adhered to. Consequently the limitations of this work should not hinder Code compliance with Standard of Practice 4.4 of the Code. These recommendations are more descriptive and stringent than those of SDGM, BKB, GSI, which reflects the increased knowledge gained. These recommendations are industry-leading practices and exceed any other Code compliant operation with reference to Standard of Practice 4.4.

Photo essay

TSF and tailings discharge zone

Included below is a photo essay of the BGS tailings system and surrounds to provide a descriptive image of the studied environments.

Plate 1. Tailings discharge showing spigot pool, channelled stream and sheet tailings flow, May 2010.

Plate 2. Wet and dry tailings, Cell 2, July 2010.

Plate 3. Overveiw of TSF cell 3, May 2006.

Plate 4. Spigot pool at edge of TSF cell 2, may 2010.

Plate 5. Dry tailings beach as photographed by an infrared camera.

Plate 6. The edge of the Tailings Discharge Zone (TDZ) whowing the wet tailings/dry tailings beach, August 2010.

Chemistry and wildlife monitoring

Plate 7. *Chemistry sampling of the supernatant.*

Plate 8. *The radio controlled boat (RCB) on its way to collect a sample, January 2008*

Plate 9. *Wildlife and carcass monitoring of the TSF.*

Plate 10. Anabat and songmeter equipment at the TSF

Plate 11. Infrared camera at the TSF.

Plate 12. Malaise trap set up on an inactive TSF cell.

Plate 13. Yellow pan trap at the edge of the active TSF cell.

Carcasses

Plate 14. Red-capped Plover carcass located on wet tailings close the decant finger, 1 May 2010.

Carcasses detection trials (using balloons)

Plate 15. Balloons resting in shallow supernatant.

Plate 16. Red-capped Plovers foraging in the supernatant.

Plate 17. Red-capped Plover on wet tailings, May 2010.

Plate 18. Red-capped Plovers roosting in shallow supernatant.

Plate 19. Red-capped Plover nest with two eggs. These eggs are believed to have successfully hatched with young observed on a subsequent trip.

Plate 20. Location of Red-capped Plover nest next to tailings pipe on the decant finger.

Plate 21. Red-capped Plover foraging on dry tailings beach photographed by the infrared camera.

Plate 22. Red-necked Stints foraging on dry tailings beach, April 2008.

Plate 23. Red-necked Stints foraging on dry tailings beach, April 2008.

Plate 24. Red-necked Stint foraging in shallow supernatant on dry tailings beach, April 2008.

Plate 25. Australian Shelducks roosting on the supernatant, May 2008.

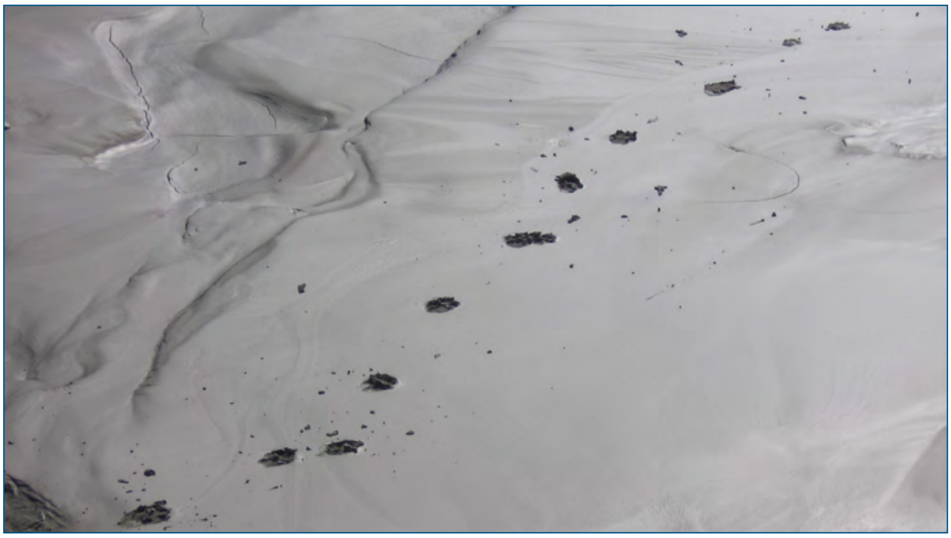


Plate 26. Possible cat tracks on wet tailings.

Plate 27. Moth stuck to wet tailings in the active TSF cell.

Alternative water bodies

Plate 28. The saline seepage trench along the east wall of the TSF, April 2010

Plate 29. The seepage trench showing pooling, vegetative debris and algae.

Plate 30. Algae in the seepage trench.

Plate 31. Shelducks foraging in the saline wash (duck pond)

Plate 32. Winditch Pit taken from the TSF cell 2 wall.

Plate 33. Goanna Pit.

Plate 34. Phoenix Pit

Plate 35. The haul road lakes.

Plate 36. The songmeter, infrared camera and anabat at the haul road lakes

Plate 37. Australian Shelducks photographed by the infrared camera at the haul road lakes

Plate 38. Australian Wood Ducks photographed by the infrared camera at the haul road lakes.

Plate 39. Magpie-lark photographed drinking by the infrared camera at the haul road lakes.

References

1. International Cyanide Management Institute, The International Cyanide Management Code, October 2009. 2009, International Cyanide Management Institute. p. www.cyanidecode.org.
2. International Cyanide Management Institute, Auditor Guidance for Use of the Gold Mining Operations Verification Protocol, October. 2009, International Cyanide Management Institute.
3. International Cyanide Management Institute, Implementation Guidance for the International Cyanide Management Code. 2007.
4. International Cyanide Management Institute, The Code: The newsletter of the International Cyanide Management Institute, Second Quarter. 2008.
5. International Cyanide Management Institute, The Code: The Newsletter of the International Cyanide Management Institute, Third Quarter. 2008, International Cyanide Management Institute.
6. International Cyanide Management Institute, The Code: The Newsletter of the International Cyanide Management Institute, First Quarter. 2008, International Cyanide Management Institute.
7. International Cyanide Management Institute, The Code: The Newsletter of the International Cyanide Management Institute, First Quarter 2009, International Cyanide Management Institute.
8. International Cyanide Management Institute, Implementation Guidance for the International Cyanide Management Code. 2009.
9. Adams, M.D., D.B. Donato, R.S. Schulz, and G.B. Smith, Influences of Hypersaline Tailings on Wildlife Cyanide Toxicosis; MERIWA Project M398 (II) 'Cyanide Ecotoxicity at Hypersaline Gold Operations' Draft Final Report Volume 2 – Definitive Investigation. 2008, MERIWA: Perth.
10. International Cyanide Management Institute, Auditor Guidance for Use of the Gold Mining Operations Verification Protocol, September. 2007, International Cyanide Management Institute.
11. International Cyanide Management Institute, Implementation Guidance for the International Cyanide Management Code. 2005, International Cyanide Management Institute, November.
12. Smith, G.B., D.B. Donato, C.G. Gillespie, and S.R. Griffiths, Ecology of a goldmining tailings facility in the Eastern Goldfields of Western Australia; A case study. International Journal of Mining, Reclamation and Environment, 2008. 2(22): p. 154-173.
13. Donato, D.B., N. O., H. Possingham, M. Moore, P.F. Ricci, and B.N. Noller, A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife. Environmental International, 2007. 33: p. 974-984.
14. Skadhauge, E. and S.D. Bradshaw, Saline drinking and cloacal excretion of salt and water in the zebra finch. American Journal Of Physiology, 1974. 227(6, December): p. 1263-1267.
15. Oksche, A., D.S. Farner, D.L. Serventy, F. Wolff, and C.A. Nicholls, The hypothalamo-hypophyseal neurosccretory system of the Zebra Finch, Tasniopygia castanotis. Z. Zelljorsch., 1963. 58: p. 846-914.
16. Rubega, M.A. and L.W. Oring, Excretory organ growth and implications for salt tolerance in hatchling American avocets Recurvirostra americana. Journal Of Avian Biology, 2004. 35: p. 13-15.

17. Goodsell, J.T., Distribution of Waterbird Broods Relative to Wetland Salinity and pH in South-western Australia. Australian Wildlife Research, 1990. 17: p. 219-29.
18. Mahoney, S.A. and J.R. Jehl, Adaptations of migratory shorebirds to highly saline and alkaline lakes: Wilson's Phalarope and Ameriacn Avocet. The Condor, 1985. 87: p. 520-527.
19. Reynolds, R.G., W.D. Watson, and D.J. Collins, Water resources aspect of drought in Australia; Water 2000. Consultants report number 13. 1983, Australian Government Publishing Services.
20. Gentilli, J., Climates of Australia and New Zealand, In: World survey of climatology. 1971, Amsterdam: Elsevier.
21. Beard, J.S., Vegetation of Western Australia; Mapped at 1:3,000,000. 1981, Government Printer, Western Australia.
22. Dunlop, J.N., J.E.D. Fox, and J.M. Osborne, Mt Keith Ecological Assessment. Prepared for Australian Consolidated Minerals. 1989, Curtin University: Perth.
23. Pringle, H.J.R., A.M.E. Van Vreeswyk, and S.A. Gilligan, An inventory and condition survey of the north-eastern Goldfields, Western Australia, Technical Bulletin No. 87. 1994, Department of Agriculture Western Australia.: Perth.
24. Cockerton, G.T.B. and K.S. Stratford, Habitat mapping project. 1997, Landcare Services Pty Ltd: York.
25. Donato, D.B. and G.B. Smith, Summary of Findings: ACMER Project 58, Sunrise Dam Gold Mine Sponsor's Report, Anglogold Ashanti Australia. 2007: Donato Environmental Services, Darwin.
26. Pennay, M., B. Law, and K. Reinhold, Bat calls of New South Wales: Region based guide to the echolocation calls of Microchiropteran bats. 2004, NSW Department of Environment and Conservation: Hurstville.
27. Higgins, P.J. and S.J.J.F. Davies, Handbook of Australian, New Zealand and Antarctic Birds: Volume 3 Snipe to Pigeons. Vol. 3:. 1996, Melbourne: Oxford University Press.
28. Kingsford, R.T. and F.I. Norman, Australian waterbirds – products of the continent's ecology. Emu, 2002. 102: p. 47-69.
29. BOM, Climate variability and El Nino, Bureau of Meteorology, Editor. 2010, Australian Government.
30. Troccoli, A., M. Harrison, D. Anderson, L. T., and S. Mason, J., eds. Seasonal Climate: Forecasting and Managing Risk. NATO Science Series. Vol. 82. 2008, Springer: Netherlands.
31. Wahlquist, A., Thirsty Country: Options for Australia. 1st ed. 2008, NSW, Australia: Allen and Unwin.
32. Trewin, D., Year Book, Australia. Number 86. ABS Catalogue No. 1301.0. 1st ed, ed. Australian Bureau of Statistics. 2004, Canberra.
33. Pink, B., Year Book Australia No. 90. ABS Catalogue No. 1301.0. 1st ed, ed. Australian Bureau of Statistics. 2008, Canberra.
34. Donato, D., Bird Usage Patterns on Northern Territory Mining Water Tailings and their Management to Reduce Mortalities, Public Report. 1999, Darwin, Northern Territory: Department of Mines and Energy. 179.
35. Henny, C.J., R.J. Hallock, and E.F. Hill, Cyanide and Migratory Birds at Gold-Mines in Nevada, USA. Ecotoxicology, 1994. 3(1): p. 45-58.

36. Sinclair, G., A. McMullen, and R. Peters. A case study of bird mortality and cyanide management at Northparkes. in Short course notes on management of cyanide in mining. 1997. Perth: Australian Centre for Minesite Rehabilitation Research.

37. Eisler, R., Cyanide Hazards to Fish Wildlife and Invertebrates a Synoptic Review. U S Fish and Wildlife Service Biological Report, 1991. 85(123): p. 1-55.

38. Standards Australia, HB 203:2004 Environmental risk management – Principles and process. 2006, Standards Australia/Standards New Zealand Third Edition: Canberra.

39. Agency for Toxic Substances and Disease Registry, A quick guide to evaluating environmental exposures. Centers for Disease Control and Prevention. 2001, DKH 01-0391. : ATSDR, Oct, 65: Atlanta (GA).

40. Environment Australia, Cyanide Management: A Booklet in the Series on Best Practice Environmental Management in Mining. 1998, Canberra: Environment Australia.

41. Abensperg-Traun. M. and C.R. Dickman, Distributional Ecology of Red-Capped Plover, Charadrius Ruficapillus (Temminck, 1822), on Western Australian Salt Lakes. Journal of Biogeography, 1989. 16(2): p. 151-157.

42. Williams, W.D., P. De Deckker, and R.J. Shiel, The limnology of Lake Torrens, an episodic salt lake of central Australia, with particular reference to unique events in 1989. Hydrobiologia, 1998. 384: p. 101-110.

43. Kingsford, R.T., Occurrence of high concentrations of waterbirds in arid Australia. Journal of Arid Environments, 1995. 29: p. 421-425.

44. Purdue, J.R. and H. Haines, Salt Water Tolerance And Water Turnover In The Snowy Plover. The Auk, 1977. 94(April): p. 248-255.

45. Schmidt-Nielsen, K. and Y.T. Kim, The effect of salt intake on the size and function of the salt gland of ducks. The Auk, 1964. 81(April): p. 160-172.

46. Bennett, D.C. and M.R. Hughes, Comparison of renal and salt gland function in three species of wild ducks. J. Exp. Biol. Rev., 2003. 206: p. 3273–3284.

47. Marchant, S. and P.J. Higgins, Handbook of Australian, New Zealand and Antarctic Birds. Vol. 2: Raptores to Lapwings. 1993, Melbourne: Oxford University Press.

48. Higgins, P.J., J.M. Peter, and W.K. Steele, Handbook of Australian, New Zealand and Antarctic Birds. Vol. 5: Tyrant-flycatchers to Chats. 2001, Melbourne: Oxford University Press.

49. Baudinette, R.V., Norman F. I., and J. Roberts, Salt Gland Secretion in Saline-Acclimated Chestnut Teal, and its Relevance to Release Programs. Aust. J. Zool., 1982. 30: p. 407-415.

50. Strahan, R., ed. The Mammals of Australia. ed. C.H.S. Watts and P.A. Woolley. 1995, REED Books: Melbourne.

51. Mahoney, S.A. and J.R. Jehl, Avoidance Of Salt-Loading By A Diving Bird At A Hypersaline And Alkaline Lake: Eared Grebe. The Condor, 1985. 87: p. 389-397.

52. Jehl, J.R.J., The Caspian Tern At Mono Lake. Western Birds :. 1986. 17: p. 133-135.

53. Winkler, D.W. and S.D. Cooper, Ecology of migrant black-necked grebes Podiceps nigricollis at Mono Lake, California. Ibis, 1986. 128(4).

54. Kingsford, R.T. and J.L. Porter, Waterbirds Of Lake Eyre, Australia. Biological Conservation, 1993. 65: p. 141-151.

55. Timms, B.V., A comparison between saline and freshwater wetlands of Bloodwood Station, the Paroo, Australia, with special reference to their use by waterbirds. International journal of salt lake research, 1997. 5(4): p. 287 – 313.

56. Schmidt-Nelson, K., Desert Animals: Physiological Problems of Heat and Water Loss. 1964, London: Oxford University Press. 277.

57. Hughes, M.R., Regulation of salt gland, gut and kidney interactions. Comparative Biochemistry and Physiology Part A, 2003. 136: p. 507–524.

58. Sabat, P., Birds in marine and saline environments: living in dry habitats. Revista Chilena de Historia Natural, 2000. 73(3, Santiago set).

59. International Cyanide Management Institute, Implementation guidance for the International Cyanide Management Code. 2002, International Cyanide Management Institute, May.

Appendices:

1: Hypersalinity and its impact on wildlife cyanide toxicosis at gold mines within the Eastern Goldfields of Western Australia: a literature and knowledge review

2: Chemistry survey

3: Wildlife survey

APPENDICES

DES
DONATO
ENVIRONMENTAL SERVICES

Carbon
Planet
Donato Environmental Services is
Carbon Managed.

Appendix 1

Hypersalinity and its impact on wildlife cyanide toxicosis at gold mines within the Eastern Goldfields of Western Australia: a literature and knowledge review

September 2010

1. Table of Contents

-

2. Introduction

A concentration of 50 mg/L weak acid dissociable (WAD) cyanide or lower at discharge is viewed as being safe for most vertebrate wildlife other than aquatic organisms [1], although this is considered an interim benchmark [2]. This no-observed-effect limit has largely been determined by laboratory experiment (see [3]) and is justified by field observation [4, 5] derived from fresh tailings systems at salinity concentrations palatable to wildlife.

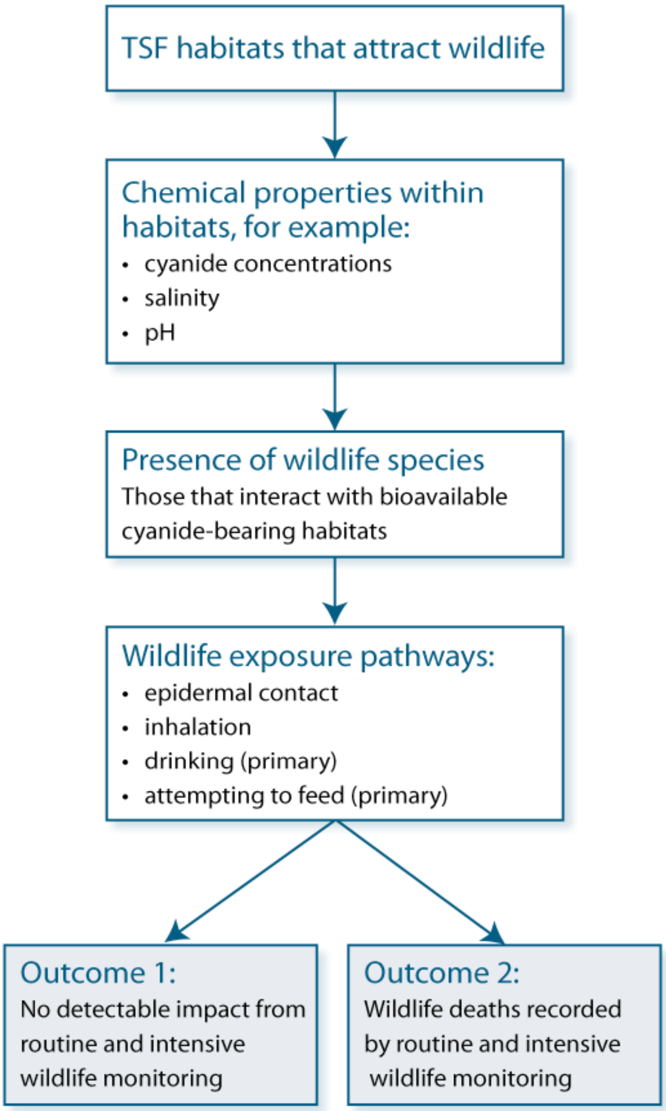
Most gold mine operations use relatively fresh water with salinity usually less than 1 500 mg/L TDS, significantly less than sea water (approximately 35 000 mg/L TDS). Uniquely the gold mines of the Kalgoorlie goldfields region of Western Australia use hypersaline groundwater for their operations. The ground water used by most mines in the region is within the range of 40 000–220 000 mg/L TDS, up to six times more saline than sea water. Anecdotal information from this region suggests that few wildlife deaths occur at some (unknown) cyanide concentration level above the recognised threshold. It is argued that hypersalinity influences wildlife behaviour, exposure and ingestion on and within the supernatant and wet tailings, and consequently influences cyanide toxicosis risk.

- ***Wildlife cyanide toxicosis risk-contributing factors***

Five factors that primarily influence the risk of wildlife cyanide toxicosis at gold mines are:

- toxic concentrations of bioavailable cyanide in tailings slurry discharged to TSF's [4, 6];
- the presence and range of wildlife-attracting habitats at TSF's where bioavailable cyanide is present [5];
- tailings chemistry, for example pH, salinity;
- the presence and abundance of food within the TSF's; and
- the presence of at-risk species in the area [5].

The first factor (cyanide concentration) is the hazard and the other four factors influence the exposure of wildlife to the hazard.



Until recently within the gold mining industry, cyanide toxicosis risk was predicted only by cyanide concentration above the perceived threshold (50 mg/L WAD) with no consideration given to the other risk factors. This has lead to an underestimation of the risk in many instances, but possibly an overestimation of the risk where factors such as hypersalinity affect wildlife behaviour to reduce exposure.

3. Wildlife Cyanide Toxicosis from Mine Waste Tailings in The Gold Industry

The issue of wildlife cyanide toxicosis at gold mines has been critically reviewed in a recent article: ‘A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife’ by [7, 8]. This article provides a robust review on the issue and available literature and is summarized here; the full article is attached as Appendix A. This paper does not consider in any depth the influence of hypersalinity on wildlife cyanide toxicosis as little literature has been available up until very recently. A recent study within the goldfields region of Western Australia has shed some light on this subject and resulted in some published material becoming available. This review will expand on [7, 8] focusing on hypersalinity.

3.1 'A critical review of the effects of gold cyanide-bearing tailings solutions on wildlife' by Donato et al. (2007): A Summary

Critical Measurements of Cyanide Bioavailability in Mine Wastewater

Monitoring WAD cyanide as well as free cyanide is necessary to determine wildlife risk. WAD cyanide is resilient in the tailings dam environment [6, 7, 9, 10] and subsequently release cyanide ions upon ingestion by wildlife [4, 5, 11] which can lead to toxicity. The main complexes constituting WAD cyanide in mining tailings waste are $Cu(CN)_3(s)$, $Zn(CN)_4(s)$, $Ni(CN)_4(s)$ and $Fe(CN)_6(s)$ [11, 12], which readily dissociate in the gut following ingestion hence a distinction between free, WAD and total cyanide is required for monitoring purposes [13].

The spatial distribution of cyanide in various habitats is important because it could influence the risk to wildlife if a concentration gradient of excessive cyanide concentration exists [4, 5]. The rate of degradation and corresponding lowering of cyanide toxicity are variable with the tailings environment [9, 14]. Although cyanide degradation and attenuation pathways have been reasonably well documented [14-16], further detail is needed to quantify cyanide levels associated with the different chemical degradation pathways [2] and the interrelation of cyanide concentration gradient with habitats used by wildlife particularly birds. There is an associated risk in relying on natural degeneration of cyanide, as tailings chemistry, in-situ environmental conditions and gold extraction processes are dynamic and controlled by local physio-chemical processes. Bioavailability and cyanide concentrations also vary considerably in the tailings environment due to varying concentrations of metals in ore gold extraction recovery targets, ore blending and changing tailings dam environmental conditions. Reference is made to the influences of hypersaline tailings conditions on cyanide fate through the vertical tailings structure that is likely to influence cyanide speciation [14, 17]. Salinity reduces wildlife usage and interaction behaviour on tailings dam however there is a need to better understand the influences of hypersaline tailings conditions on cyanide chemistry and wildlife interaction.

Wildlife Cyanide Toxicosis from Mine Waste Solutions

Cyanide is the most significant contaminant in gold mining that influences wildlife mortality [4], although some deaths may not be directly explained by cyanide levels [9].

A causal link with the presence of cyanide, its metal complexes and cyanide degradation products is inferred in mortality events and is supported by observational data [4]. Wildlife deaths have been observed at 62 mg/L cyanide, and a flock of waterfowl remained unaffected at 19 mg/L WAD cyanide concentrations respectively [4]. Wildlife can recover from cyanide toxicity once they stop drinking [4]. Waterfowl of the same species show different responses to cyanide ingestion as illustrated by field observations on cyanide-bearing mine waste and repeated under laboratory conditions [4]. Birds are thought to be particularly susceptible to cyanide in tailings dams, but it is not known if this sensitivity is physiologically-related [18] or related to birds access to TSF's making them relatively more vulnerable than other biota [19]. Limited published work, that documents wildlife deaths from cyanide toxicosis on gold mining cyanide-bearing solutions and effluent, exists [4-7, 20].

Wildlife, particularly birds and insectivorous bats, can gain access to cyanide solutions [2] in tailings dams and heap leach facilities unless deterred or controlled. Death to birds, insectivorous bats, cattle, goats, frogs, lizards and marsupials may be widespread [2].

In contrast, work conducted in Australia between 1996 and 1998 [21] documented that:

(1) wildlife deaths occurred at 5 of the 7 gold mining operations surveyed;

(2) at-risk wildlife species were frequently recorded at all tailings dams;

(3) seasonal variation and migratory patterns influenced abundances;

(4) 972 wildlife deaths were recorded from four mining operations in a calendar year;

(5) wildlife deaths were grossly underestimated by mine staff;

(6) all mining operations that experienced deaths had incidents where more than 20 deaths were recorded in 1 day within one calendar year; and

(7) all mining operations that discharged at greater than 50 mg/L WAD cyanide concentrations experienced wildlife deaths [5].

In Nevada, USA, 9512 carcasses were reported from over 100 species for the State of Nevada between 1986 and 1991, this was an underestimation due to reporting being voluntary [4]. Birds comprised 80–91% of vertebrate carcasses reported annually [4]. Northparkes Mine operated a carbon-in-pulp processing circuit and the transition to sulphide ores with high copper content concentration led to a build up of soluble copper–cyanide complexes [6, 18] which resulted in 2700 bird deaths over a four-month period [18]. Consensus suggests [2, 9] that cyanide will generally not kill wildlife at a concentration of less than 50 mg/L WAD cyanide, although this is regarded as an interim bench mark [2]. Fieldwork has not determined nor implied a specific cyanide concentration [4], although this is thought to be the case [3]. No mortalities were recorded from two mining operations that consistently discharged below this threshold over a two-year period [5, 19].

Some at-risk wildlife species are migratory, and the impacts of the presence of numerous toxic ponds along a migratory pathway can only be speculated [4]. In Australia, waders, waterbirds [5, 6, 18, 19], ducks, pratincoles, terns, raptors [5, 19], and in the USA waterfowl, shorebirds, perching birds and gulls [4] are all documented as being at-risk.

Risks to Insectivorous Bats

Despite the diversity and importance of insectivorous bats (Microchiroptera) in Australian faunal assemblages, comparatively little is known of their ecology, or the impact that disturbance processes have on population dynamics [22]. The relative scarcity of information is directly related to logistical difficulties associated with observing bat behaviour.

In relation to the risk of cyanide toxicosis associated with gold mining, surveys in North America have shown that insectivorous bats are among the most numerous of mammals found dead of cyanide poisoning at cyanide-bearing water bodies [23-25]. Despite this information being widely available, monitoring of insectivorous bats at the majority of gold mines in Australia is either inadequate or non-existent. At sites where adequate stock and wildlife proof fencing has been installed, insectivorous bats comprise close to 100% of mammal visitations to tailings dams and other water bodies (Donato Environmental Services, unpublished data). However, field based methodology to study consumption of surface water by insectivorous bats in the field remains particularly elusive and difficult [26]. For many mining areas in Australia basic inventories of the local bat fauna have not been carried out, making it impossible to determine what species may occur at a particular site and if foraging or drinking activity takes place at cyanide-bearing water bodies.

Insectivorous bats utilise similar habitats present at TSF’s to those used by avian guilds such as swallows and martins: airspace (the aerial space above the TSF), supernatant (open water) and bare ground [27]. Field observations in Australia, Africa and North America, along with limited laboratory data, indicate that ‘fresh’ (surface) water bodies with WAD cyanide concentration of approximately 50 mg/L represent an uncontrolled risk to bats [28-30]; Donato Environmental Services, unpublished data). The majority of these observations were from gold mines with relatively fresh water, within a TDS range that mammals are likely to drink.

Monitoring Wildlife Deaths from Mine Waste Solutions

Systematic wildlife monitoring was not conducted within the gold industry until the late 1990’s and when implemented subsequently were often inadequate leading to ‘gross underestimation of the wildlife deaths and misrepresentation of the composition of at-risk species’ [5].

Only trained environment staff can be considered to adequately document the risk and impact to wildlife [5]. Wildlife deaths are underestimated due to the following factors:

(1) small carcasses being quickly scavenged by predator species [5, 31];

(2) carcasses being covered by tailings sediment [5, 31];

(3) carcasses sinking in liquor or supernatant [5, 6];

(4) the size of the tailings dam making it difficult to observe carcasses [5, 6];

(5) lack of appropriate optics;

(6) lack of observer skill [5]; and

(7) no monitoring on the assumption that there are no wildlife deaths.

No standard or verified monitoring protocol exists to monitor wildlife on cyanide-bearing mine solutions, although many mining operations are obligated to report wildlife deaths to regulatory authorities and in accordance with the International Cyanide Management Code (International Cyanide Management Institute, 2005).

Wildlife Tailings Dam Utilisation

It has been argued that animals favour natural waters over tailings facilities although it is acknowledged that some fauna drink from such facilities [32]. Others argue that there is no reason to believe that birds are able to distinguish between TSFs and any similar area of water [31]. It has however been demonstrated that wildlife use TSFs and over a 4 month period 2700 wildlife visitations were reported at a TSF and this is regarded as an underestimation [6]. Additionally a list of species that interact with TSFs has been constructed for some regions such as in northern Australia [5]. Some wildlife appear to be attracted to TSFs for the purpose of resting [4] however other wildlife interact with mine waste solutions despite limited food resources.

Published Guidelines for Mining Industry to Manage the Risk

Risk management guidelines have been published in a number of gold producing regions around the world [21, 33, 34]. The Code now provides principles and standards of practice governing the use and disposal of cyanide within the gold mining industry in a manner complimentary to existing regulations. Guidelines have been produced in northern Australia to specifically reduce the risk to wildlife [21].

Elimination or Reduction of the Concentration of Bioavailable Cyanide to Below Toxic Levels in the Tailings Environment

Methods of treatment of cyanide-bearing mine waste are summarised as follows:

(1) Biological treatment by micro-organisms;

(2) Chemical oxidation with air;

(3) Oxidation with oxidants such as chlorine or hydrogen peroxide; acidification/volatilisation/reneutralisation; and

(4) Electrochemical treatment [35].

Cyanide destruction, recovery and recycling methods are well documented and have been used for many years [11, 15, 18, 36-40]. The economic viability of treatment is identified as site specific.

Detoxification as a contingency option is ineffectual, taking up to six weeks to take effect within one tailings dam [18]. Once toxic, tailings systems and particularly periphery discharges are difficult, expensive and time-consuming to detoxify.

Eliminate or Reduce Wildlife Interaction and Habitat Provisions with Cyanide-Bearing Tailings Solutions

Wildlife interaction with TSFs can be reduced by modification of habitats to reduce attractiveness of the TSF and surrounding landscapes to wildlife. This can influence the number of wildlife visitations and contact time with TSF habitats.

Habitat modifications to reduce wildlife interaction include:

(1) reducing supernatant surface area;

(2) thickening tailings to prevent supernatant formation (central discharge systems);

(3) screening decant ponds;

(4) lining dam walls with steep sloping high-density polyethylene;

(5) removing nearby vegetation;

(6) avoiding supernatant resting against dam walls [5];

(7) avoiding uneven dam floors that form islands [5];

(8) disposing of tailings other than in a TSF; and

(9) providing alternative water sources [18].

Denying Wildlife Access

Ambulatory wildlife can be denied access by fencing TSFs, and thus wildlife cyanide toxicosis relates essentially to birds [4, 5, 9] and insectivorous bats [24]. Hazing techniques such as gas guns to scare wildlife away, alone are ineffective [5, 9, 41, 42], although when used in combination with decoy wetlands and habitat modification techniques, they have some merit [5]. High-density polyethylene floating balls are effective on constructed decant ponds, but become bogged in tailings. Netting is expensive and technically difficult for large ponds like TSFs and can entangle wildlife [5, 9]. Deterring birds and insectivorous bats from large water bodies is virtually impossible [4]. Propane gas guns, loud music, floating buoys, flagging tap, flying kites with predator silhouettes, scarecrows and fishing line strung across TSFs have been used under different conditions and have repeatedly proved unsatisfactory to mine operators [5, 43]. Gas guns and loud music may have some effect on small water bodies, but habituation to these scaring techniques is an issue [5]. Helicopters have been effective at Northparkes as a contingency measure [6]. The discharge of ammunition has been effective in flushing some birds from cyanide-bearing solutions [4, 5], although this is ineffective once wildlife are exposed to the toxic solutions [19]. Human disturbances can reduce waterfowl interaction with wetlands [44], but the size of TSFs usually render this ineffective in reducing wildlife risk [19].

3.2 Additional Information on Cyanide Toxicity and Cause of Death in Wildlife

The variability in susceptibility to cyanide toxicity between wildlife groups, species and even individuals of the same species may influence the length of time to incapacitation. Incapacitation is rapid from sodium cyanide or free cyanide followed by a raid death or a rapid recovery [45]. However some birds may not die immediately after drinking lethal cyanide solutions [46] where the source of cyanide is metal cyanide complexes which liberate cyanide in the avian digestive tract (pH 1.3 to 6.5) [47-49] are comparatively slow [46]. A high rate of cyanide absorption is critical to acute toxicity, and absorption may be retarded by the lower dissociation rates of metal–cyanide complexes [4]. In Arizona, a red-breasted merganser (*Mergus serrator*) was found dead 20 km from the nearest known source of cyanide, and its pectoral muscle tissue tested positive for cyanide [24]. The proposed mechanism to account for this phenomenon involves WAD cyanide compounds. Cyanide bound to certain metals, usually copper, is dissociable in weak acids such as stomach acids [46]. Some larger birds have been observed to survive incapacitated for over 12 hours after initial ingestion of supernatant containing tailings before dying (Smith, G, pers. obs.). Whether cyanide was the sole cause or led to secondary factors such as shock, from which birds often don't recover, is unknown. Many birds that survived an initial dose of cyanide have been observed to continue to drink mine waste solutions at regular intervals and gradually lose condition resulting in death (Donato, D, pers. obs.). Clark and Hothem (1991) suggested that drinking of lethal cyanide solutions by animals may not result in immediate death if the cyanide level is sufficiently low; these animals may die later when additional cyanide is liberated by stomach acid [46]. Symptoms from non-lethal cyanide doses include lateral bill shaking [4], lethargy, eye-rubbing, gulping and continued drinking [46, 50]. Wildlife that suffer lethargy from non-lethal doses may drown if they are unable to keep their heads above the water (Donato, D, pers. obs.).

Cyanide does not appear to be mutagenic, teratogenic, or carcinogenic in mammals [46, 51].

3.3 Spatial Distribution of Cyanide within the Tailings Environment and its Impact on the Risk to Wildlife.

Cyanide is not homogeneously distributed throughout the tailings environment. Cyanide concentration is highest at the spigot and forms a gradient to its lowest points in the supernatant and non-aqueous habitats. The rate of cyanide degradation is influenced by many factors [15] as explored fully in the associated chemistry literature review. Wildlife have access to cyanide concentrations elevated above the tailings average primarily at pools near the discharge spigots; tailings streams that run from the spigot to the supernatant and hot plumes within the supernatant where the tailings stream enters the supernatant pond. Access to these points to obtain and process water samples is often not possible and it is therefore not often possible to determine the maximum cyanide concentration that fauna are exposed to.

3.4 Heavy Metals and other Toxicants in Tailing Solutions

Tailing solutions often contain a range of metals, metalloids and chemicals, many of which are toxic to wildlife at various concentrations. While cyanide is the focus of this review where additional constituents are present at or approach toxic levels within the tailings this may have an impact on the toxicity of cyanide and the tailing as a whole. Mine waste constituents are highly variable and site specific depending on the chemistry of the ore body.

The presence of heavy metals, other chemicals and high or low acidity do not appear to stop wildlife interacting with or ingesting tailings solutions as wildlife interaction with TSFs is well documented [52]. Wildlife have been recorded interacting with solutions containing a wide range of contaminants at various sites[5]. Hence it appears that birds, insectivorous bats and other mammals can not smell or taste such contaminants, or that the smell or taste does not deter them from interacting with the liquor. A range of wildlife species have been recorded interacting with mine waste solutions containing a mixture of toxicants, these solutions typically have a pungent and strong smell that is detectable to human olfactory receptors (Donato, D, pers. obs.).

Effects of Metal and Metalloid Toxicity on the Vertebrate Body

Metals and metalloids can have a wide range of toxic effects on animals [53, 54] but often effect the same organs. The organs most likely to be effected are the liver [55-58], kidney [56, 59], Central Nervous System [54], lungs, nervous system, and accumulation and damage can occur to the bone marrow [54, 56]. Other widespread effects include anaemia through interference with iron absorption [56] and disruption to reproduction [60].

Long-Term Effects

Industrial liquors that contain complex combinations of toxicants are likely to have a range of toxic effects. Some of these may be acute or chronic and short-term other effects may be long-term. Heavy metals are known to negatively effect survival and reproduction success in birds [60]. It is recognised that with some toxicants the main issue of concern is the indirect risks associated with longer-term bioaccumulation and biomagnifications [61]. Mercury, lead and cadmium are known to bioaccumulate others, such as aluminium, are not bioaccumulative and have a relatively short residence time in the body [62, 63].

Effects of Acidity on Vertebrate Biota

Acids are corrosive agents that produce severe burns on contact with tissue. Such corrosive effect is described as a coagulation-type necrosis, which can cause destruction of surface epithelium and submucosa [64]. When determining the potential effect of an acid solution, the severity is directly related to the acid concentration and contact time. Acids with lower concentrations, also having higher pH values, are regarded as less corrosive irritants [64]. Such acids may cause nausea and vomiting if ingested. Acid exposure is usually brief, as it incurs immediate pain. Despite the absence of obvious burns to the mouth or throat in some cases, this does not rule out oesophageal and stomach burns [65].

Eye contact with acid causes corneal ulceration, intense pain and blepharospasm (spasmodic winking caused by the involuntary contraction of an eyelid muscle). Even diluted sulphuric acid can irritate the skin and mucous membranes and cause scarring of the face and irreparable damage to the cornea, resulting in blindness [65].

Inhaling acid mists, vapours, or aerosols can cause severe irritation and corrosive damage [66]. The lethal concentration of sulphuric acid aerosols is known to vary for different animal species studied. For example, the lowest concentration of acid sulphuric vapour known to have resulted in death in rats is 383mg/m^3, while mice and guinea pigs are considerably more susceptible [67].

The prognosis for minor exposures to acids is good, as long as intervention is rapid and care can be given to the animal [64].

Combined Effect of Two or More Toxicants in Solution

Toxicity of substances is determined by single chemical testing, however when chemicals are present in combination interactions may occur that may alter their toxicity. Chemical mixtures can result in either additive toxicity, greater-than-additive toxicity (also known as synergism), or less-than-additive toxicity (antagonism) [61].

The greater-than-additive effect means that the toxicity levels of the constituents can be lower than for the individual constituents [56, 68]. In one study mixtures of arsenic and cadmium were found to be more toxic than either metal alone [68] indicating an amplifying effect. This is reflected in the guidelines where safe levels of individual metals and metalloids in human consumption drinking water are revised downwards in the presence of certain other metals and metalloids [61].

Single-chemical toxicity tests do not account for such factors, and the extrapolation of the results to environmental impacts carries much uncertainty. While methods exist for predicting the toxicity of mixtures by using data from single chemical toxicity tests [61], they obviously require knowledge of the chemical components and their interactions. This knowledge is often not available for complex solutions.

Effects of chemical mixtures on the toxicity of cyanide has been little explored in the literature however there is some evidence that greater-than-additive cyanide toxicity is found for some chemical mixtures. The following is an extract from the [69].

“Additive toxicity of free cyanide to aquatic fauna has been reported in combination with ammonia [70-73] or arsenic [71]. However, conflicting reports on the toxicity of mixtures of HCN with zinc or chromium [71-74] require clarification. Formation of the nickel-cyanide complex markedly reduces the toxicity of both cyanide and nickel at high concentrations in alkaline pH. At lower concentrations and acidic pH, solutions increase in toxicity by more than 1000-fold, owing to dissociation of the metallocyanide complex to form hydrogen cyanide [74]. Mixtures of cyanide and ammonia may interfere with seaward migration of Atlantic salmon smolts under conditions of low dissolved oxygen [70]. The 96-h toxicity of mixtures of sodium cyanide and nickel sulphate to fathead minnows is influenced by water alkalinity and pH. Toxicity decreased with increasing alkalinity and pH from 0.42 mg CN/L at 5 mg $CaCO_3$/L and pH 6.5, to 1.4 mg CN/L at 70 mg $CaCO_3$/L and pH 7.5; to 730 mg CN/L at 192 mg $CaCO_3$/L and pH 8.0 [75].”

Cadmium induces the synthesis of metallothionein, a protein that binds divalent metals which can lead to zinc and other heavy metal accumulation in the liver [76].

3.5 Carcass Residence Time and Detection Rates

While mortality events may be inferred through presence of toxic concentrations of cyanide and concurrent presence of wildlife they can only be confirmed by detection of wildlife carcasses. Carcass detection rates are influenced by a number of factors including carcass size, species behaviour, pattern and colour of carcass, carcass residence time, substrate, observer skill and cover [77-79] and specifically within tailings facilities also by TSF size, monitoring regime and equipment quality [5]. Carcass residence time is influenced by scavenging rates, decomposition rates, covering by tailings, sinking (in aqueous solutions) [5].

In one study of botulism at a natural lake the residence time of mallard carcasses depended on substrate and cover with those in “exposed positions on land persisted an average of 1.5 days; carcasses on land but concealed by vegetation persisted an average of 3.3 days and those exposed in water persisted 7.6 days” [77]. Carcass residence time has been found to be short in terrestrial environments where scavengers are common and monitoring within 24 hrs of possible mortalities was recommended [80].

Methods for in-situ carcass detection have been developed and implemented at a number of sites in Australia and elsewhere [5]. While monitoring methods are not sufficient or intended to accurately measure the number of mortalities they have been demonstrated to identify impacts and record the composition of at risk species. It is not possible to obtain a statistical error of carcass observation for systems that have either no, or very low mortalities. Consequently monitoring methods cannot prove that no mortality has occurred on a system, only that mortalities are below detection limits of the monitoring system used.

Adequate monitoring methods for ex-situ carcasses, those found away from the toxic source, have not been developed or explored. There is little discussion in the literature on the issue of delayed wildlife mortality from cyanide and few examples of carcasses found away from cyanide sources attributed to cyanide poisoning although examples do exist [24]. Whether this reflects the difficulty in fingerprinting cyanide as a lethal toxicant in wildlife, the difficulty in finding ex-situ carcasses and the lack of search effort for ex-situ carcasses is unknown although it appears that there has been little search effort. The occurrence and frequency of wildlife cyanide toxicosis away from the source is not possible to determine for specific sites or within the industry as a whole.

4. Hypersalinity and Wildlife Cyanide Toxicosis

4.1 Ecology of Hypersaline Lakes of Western Australia

Hypersaline lakes represent specialised habitats for plants, animals and aquatic invertebrates and consequently they contain far less biodiversity than saline and freshwater systems [81, 82]. The ecology of hypersaline lakes is often very simple and although biodiversity is usually low abundances can be great for the species adapted to these harsh environments [83]. Hypersaline lakes in arid and semi-arid regions of Australia are generally ephemeral being either intermittent (seasonally filled) or episodic (filled unpredictably) [84] [85]. The composition of animal and plant communities in hypersaline waters is influenced by a number of factors such as hydrological regime, oxygen concentration, ionic composition, pH, geographical position, past climatic events, competition and predation [84]. Salinity appears not to be the primary determinant of community structure in hypersaline lakes [84]. Where fish populations are high invertebrate populations that form their prey may be low and where fish are absent invertebrate populations can reach very high densities [84].

Hypersaline lakes are particularly prevalent in some arid and semi-arid areas of Western Australia such as the eastern goldfields region [86]. The ecology of these environments has received increased attention over the last 25 years through a number of studies [82, 84, 86-88].

4.1.1 Aquatic Plants

The macrophyte flora of hypersaline lakes in Western Australia is very restricted and [87, 89] found just 5 species in their study. Of these species four are angiosperms belonging to the genera *Ruppia* (3 species) and *Lepilaena* (1 species) and one is the charophyte algae *Lamprothamnium papulosum* [89]. All of these species have very wide salinity tolerance (Table 1) and all have been found in salinities of greater than 120 ppt [89]. None of these species were found in the Kalgoorlie region by [87, 89] but whether this reflects actual distributions or sampling effort is not clear.

All major algal groups found in inland Australia have representatives in salt lakes [84]. Some species can tolerate very high salinities such as *Dunaliella salina*, up to 300 ppt, *Enteromorpha intestinalis* and *Ctenocladus circinatus* both found up to 200 ppt [84].

Table 1. Salinity thresholds for aquatic plants recorded in hypersaline lakes of arid Western Australia. Adapted from Gedes et al. (1981).

Species	Approximate minimum salinity threshold (ppt TDS)	Approximate maximum salinity threshold (ppt TDS)
Ruppia megacarpa	10	150

Ruppia polycarpa	1.4	125
Ruppia ruberosa	16	160
Lepilaena preissii	6.5	150
Lamprothamnium papulosum	9	125

4.1.2 Aquatic Invertebrates

While the aquatic invertebrate fauna of hypersaline lakes is far less diverse than for saline, mesosaline and freshwater systems the few species that live there can often become abundant due to the lack of competition [81-83]. The causes of reduced diversity at higher salinities is complex and involves reduced oxygen content of the water, pH, ionic composition of the water, hydrological patterns, historical events and biological interactions [84]. Species that can cope with hypersalinity have special adaptations and most of the fauna are exclusively found in hypersaline waters and unable to live in less saline environments [84]. Some species are able to tolerate very high salinities for example *Artemia salina* has been found in 340 ppt (approximately 10 times sea water) (WA Government 2006). Pinder et al. (2005) [82] found in south west Western Australia that hypersaline lakes often contained over ten species of aquatic invertebrates up to 130 ppt and up to 5 species for salinities of up to 240 ppt TDS. Three lakes of 300 ppt TDS and two lakes of 330 ppt TDS contained between one and three species. The bulk of species found in hypersaline waters (Table 2) were from crustacean groups (Anostraca, Cladocera, Ostracoda, Copepoda) and the insect orders Diptera (flies and mosquitos) and Coleoptera (beetles) [82]. Rotifers, snails (gastropoda), nematodes and enchytraeid oligochaetes were also well represented and often common in hypersaline lakes [82]. An earlier study by Geddes et al. (1981) [86] focussed on salt lakes of Western Australia found 3 species of Anostraca, 1 Cladocera, 4 species of Copepoda, 7 species of Ostracoda and gastropods of the genus *Coxiella* in the goldfield regions.

Table 2. Salinity thresholds for aquatic invertebrates recorded in hypersaline lakes of arid Western Australia.

Taxa	Invertebrate Class	Invertebrate Order	Maximum salinity (Pinder et al. (2005)) (ppt TDS)	Maximum salinity (Gedes et al. (1981)) (ppt TDS)
Hexarthra fennica	Rotifera		240	
Brachionus plicatilis s.l.	Rotifera		79	
Lecane grandis	Rotifera		180	
Lecane thalera	Rotifera		180	
Coxiella striatula	Mollusca	Gastropoda	120	
Coxiella exsposita	Mollusca	Gastropoda	130	
Coxiella glabra	Mollusca	Gastropoda	130	
Coxiella species 1	Mollusca	Gastropoda	110	
Coxiella species 2	Mollusca	Gastropoda	70	
Manayunkia sp.	Annelida	Polycheata	120	
Artemia parthenogenetica	Crustacea	Anostraca	220	
Parartemia contracta	Crustacea	Anostraca	240	106.6
Parartemia serventyi	Crustacea	Anostraca	135	

Parartemia informis	Crustacea	Anostraca	58	186.2
Parartemia longicaudata	Crustacea	Anostraca	225	192.6
Parartemia longicaudata subspecies a	Crustacea	Anostraca	300	
Parartemia sp. Nov 1	Crustacea	Anostraca		137.6
Parartemia sp. Nov 7	Crustacea	Anostraca	120	
Daphniopsis pusilla	Crustacea	Cladocera	85	
Daphniopsis queenslandensis	Crustacea	Cladocera	160	
Daphniopsis truncata	Crustacea	Cladocera	60	
Daphniopsis sp. A	Crustacea	Cladocera	120	
Australocypris insularis	Crustacea	Ostracoda	130	
Australocypris 'bennetti'	Crustacea	Ostracoda	240	
Cyprinotus edwardi	Crustacea	Ostracoda	130	
Diacypris dictyote	Crustacea	Ostracoda	130	
Diacypris spinosa	Crustacea	Ostracoda	125	
Diacypris compacta	Crustacea	Ostracoda	130	
Diacypris fodiens	Crustacea	Ostracoda	165	
Diacypris phoxe	Crustacea	Ostracoda	75	
Diacypris whitei	Crustacea	Ostracoda	150	
Diacypris sp. 523	Crustacea	Ostracoda	80	
Diacypris 'gunyidi'	Crustacea	Ostracoda	130	
Mytilocypris tasmanica chapmani	Crustacea	Ostracoda	130	
Reticypris clava	Crustacea	Ostracoda	65	
Reticypris sp 556	Crustacea	Ostracoda	240	
Reticypris sp. LA	Crustacea	Ostracoda	85	
Reticypris sp 557	Crustacea	Ostracoda	130	
Reticypris pinguis?	Crustacea	Ostracoda	120	
Platycypris baueri	Crustacea	Ostracoda	160	
Calamoecia clitellata	Crustacea	Copepoda	130	
Calamoecia salina	Crustacea	Copepoda	115	
Calamoecia trilobata	Crustacea	Copepoda	240	
Metacyclops sp. 3	Crustacea	Copepoda	90	
Apocyclops dengizicus	Crustacea	Copepoda	80	
Meridiecyclops baylyi	Crustacea	Copepoda	240	
Mesochra nr flava	Crustacea	Copepoda	130	
Schizopera sp. 1	Crustacea	Oniscoidea	115	
Nitocra sp. 5	Crustacea	Oniscoidea	180	
Haloniscus searlei	Crustacea	Isopoda	130	
Necterosoma penicillatus	Insecta	Coleoptera	135	
Berosus discolor	Insecta	Coleoptera	120	
Berosus munitipennis	Insecta	Coleoptera	90	
Aedes camptorhynchus	Insecta	Diptera	90	
Monohelea sp. 3	Insecta	Diptera	115	
Forcypomyia sp. 6	Insecta	Diptera	70	
Dolichopodidae sp. A	Insecta	Diptera	220	
Dolichopodidae sp. B	Insecta	Diptera	130	
Ephydridae sp. 3	Insecta	Diptera	220	
Ephydridae sp. 6	Insecta	Diptera	130	
Muscidae sp. A	Insecta	Diptera	300	
Muscidae sp. B	Insecta	Diptera	300	
Muscidae sp. H	Insecta	Diptera	298	

Procladius paludicola	Insecta	Diptera	240
Compterosmittia? Sp B	Insecta	Diptera	120
Orthocladiinae sp. G	Insecta	Diptera	130
Orthocladiinae sp. P	Insecta	Diptera	180
Orthocladiinae SO_3 sp. C	Insecta	Diptera	90
Tanytarsus barbitarsis	Insecta	Diptera	210

4.1.3 Terrestrial Invertebrates

A variety of invertebrates such as spiders, scorpions, beetles, ants and crickets occur on dry salt lakes and most are endemic to salt lakes [90]. One species of wolf spider *Lycosa alteripa* is known to occur on dry salt lakes in Western Australia [90]. Apart from species that live on the surface of salt lakes many other invertebrates are likely to be wind blown or fly over these habitats.

4.1.4 Fish

De Deckker (1983) [91] reports that the salinity threshold for six Australian inland fish species was 31,000 mg/L however one species Craterocephalus eyeresii was found in salinities of up to 110,000 mg/L in the Murray Darling drainage system. Some species of fish have been recorded in Australia from water bodies with salinities of 100 000mg/L TDS or over for example *Craterocephalus eyeresii* in the Murray Darling drainage system [91]. No fish have been recorded in hypersaline lakes of Western Australia, which may reflect their generally ephemeral nature.

4.1.5 Birds

Birds are attracted to feed on available food resources and species composition depends on weather fish or invertebrates dominate [92]. With ephemeral saline lakes evaporation increases salinity of the water then and the lake dries out completely. Any birds present must then leave the waterbody or face death from starvation. A variety of waterbirds and waders utilise hypersaline lakes in Australia and while species diversity is often not as great compared to fresh systems, abundance of birds can be much greater [92-94]. Consequently birds that feed on the species present within hypersaline lakes often attain very high numbers for example over 350 000 Banded Stilts at Lake Barlee, Western Australia in 1980 and 100 000 Banded Stilts at Lake Torrens, South Australia in 1990 [92, 94, 95]. One study of Lake Carey, Western Australia recorded 11 species of birds using the lake which had a salinity of approximately 110 000 mg/L TDS at the time [85]. Generally at any one time somewhere in inland Australia, there is often saline water supporting many waterbirds [96]. All species that utilise saline lakes are nomadic, reflecting the ephemeral nature of the these water bodies [97]. Many species such as ducks breed in ephemeral fresh waters after large rainfall events and move to nearby saline lakes as waters dry [92, 98].

Species that are characteristic of hypersaline lakes include Banded Stilt *Cladorhynchus leucocephalus*, Red-necked Avocet *Recurvirostra novaehollandiae*, Red-capped Plover *Charadrius ruficapillus*, Grey Teal *Anas gracilis*, Australian Shelduck *Tadorna tadornoides*, Black Swan *Cygnus atratus*, Australasian Pelican

Pelecanus conspicillatus and Silver Gull *Larus novaehollandiae* however at least 47 species will use hypersaline lakes to some degree (Table 3).

Table 3. Bird species that will use inland saline and hypersaline lakes and salinity tolerances as documented in the literature.

Common name	Scientific name	Max. salinity usage recorded in literature, (mg/L TDS)	Location	Reference
Australian Pelican	*Pelecanus conspicillatus*			
Musk Duck	*Biziura lobata*			
Freckled Duck	*Stictonetta naevosa*			
Black Swan	*Cygnus atratus*	110 000	Lake Carey, WA	Smith (2004)
Australian Shelduck	*Tadorna tadornoides*	245 000	Rotnest Island, WA	Riggert (1977)
Australian Wood Duck	*Chenonetta jubata*	110 000	Lake Carey, WA	Smith (2004)
Pacific Black Duck	*Anas superciliosa*	110 000	Lake Carey, WA	Smith (2004)
Australasian Shoveler	*Anas castanea*			
Grey Teal	*Anas gracilis*	110 000	Lake Carey, WA	Smith (2004)
Chestnut Teal	*Anas castanea*	110 000	Lake Carey, WA	Smith (2004)
Pink-eared Duck	*Malacorhyncus membranaceus*			
Hardhead	*Aythya australis*			
Great Crested Grebe	*Podiceps cristatus*			
Australasian Grebe	*Tachybaptus novaehollandia*			
Hoary-headed Grebe	*Poliocephalus poliocephalus*	110 000	Lake Carey, WA	Smith (2004)
Little Black Cormorant	*Phalacrocorax sulcirostris*			
Little Pied Cormorant	*Phalacrocorax melanoleucos*			
Pied Cormorant	*Phalacrocorax varius*			
Great Egret	*Ardea alba*			
Little Egret	*Egretta garzetta*			
White-faced Heron	*Egretta novaehollandiae*	110 000	Lake Carey, WA	Smith (2004)
White-necked Heron	*Ardea pacific*			
Australian White Ibis	*Threskiornis molucca*			
Straw-necked Ibis	*Threskiornis spinicollis*			
Yellow-billed Spoonbill	*Platalea flavipes*	110 000	Lake Carey, WA	Smith (2004)
Purple Swamphen	*Porphyrio porphyrio*			
Dusky Moorhen	*Gallinula tenebrosa*			
Black-tailed Native Hen	*Gallinula ventralis*			
Eurasian Coot	*Fulica atra*			
Common Greenshank	*Tringa nebularia*	110 000	Lake Carey, WA	Smith (2004)
Marsh Sandpiper	*Tringa stagnatilis*			
Red-necked Stint	*Calidris ruficollis*			
Sharp-tailed Sandpiper	*Calidris acuminata*			
Curlew Sandpiper	*Calidris ferruginea*			
Black-winged Stilt	*Himantopus himantopus*	110 000	Lake Carey, WA	Smith (2004)
Banded Stilt	*Cladorhynchus leucocephalus*	145 000	Port Phillip Bay, Vic	Marchant and Higgins (1993)
Red-necked Avocet	*Recurvirostra novaehollandiae*	146 000	Laverton	Marchant and Higgins (1993)
Red Capped Plover	*Charadrius ruficapillus*	110 000	Lake Carey, WA	Smith (2004)
Black-fronted Plover	*Elseyornis melanops*			
Hooded Plover	*Thinornis rubicollis*			

Red-kneed Dotterel	*Erythrogonys cinctus*
Banded Lapwing	*Vanellus tricolor*
Masked Lapwing	*Vanellus miles*
Silver Gull	*Larus novaehollandiae*
Gull-billed Tern	*Sterna nilotica*
Whiskered Tern	*Chlidonias hybridus*
Caspian Tern	*Sterna caspia*

4.1.6 Terrestrial vertebrates

There are few references within the literature to the use of hypersaline waters in Australia by terrestrial mammals. None are likely to use such environments other than opportunistically. It is possible that predators such as dingos, cats, foxes, snakes and varanids will venture into shallow waters of saline lakes looking for prey such as bird fledglings or to cross to islands where birds may be breeding.

Hypersaline lakes do provide habitat for some specialized species when they are dry [94], for example the Lake Eyre Dragon *Ctenophorus maculosus* [99].

4.1.7 Insectivorous Bats

Can insectivorous bats drink saline or hypersaline water? It is apparent that no research has been conducted to examine the salinity tolerance of insectivorous bats in relation to drinking water. Furthermore, there are no published records documenting insectivorous bats foraging within, or drinking from the surface of hypersaline lakes. Generally speaking, salinity tolerances of Australian native mammals are not well understood. However, tolerance of livestock to salinity in drinking water has been reasonably well studied. Most livestock cannot withstand drinking water with greater than 10 000 mg/L TDS (see Table 6) and salinity greater than this is considered harmful to all livestock [100]. Given this information, it seems very unlikely that any Australian non-marine mammals, including insectivorous bats, could drink water with salinity equal to, or greater than seawater.

4.2 Ecology of Hypersaline TSF’s

Limited literature exists on the ecology of tailings dams, although wildlife visits TSFs to rest and forage for food [9], while some fauna may drink from such facilities [20]. A list of bird species that interact with TSFs in northern Australia exists [5]. Birds are the most documented fauna group to use tailings systems [4, 5, 9, 20], although bats and terrestrial fauna have been recorded elsewhere [23, 24, 29]. On an industry-wide basis, observations on TSFs have been ad hoc [19] and opportunistic although more rigorous methodologies are being implemented under the auspices of the International Cyanide Management Code [1].

While TSFs generally look featureless to a large extent, a number of habitats are present which may attract wildlife. Supernatant ponds are attractive to a variety of waterbirds and some waders, tailings beaches resemble natural mud flats and dry tailings can look like open arid plains, which are used by some species. TSF habitat categories identified in previous work are defined in Table 4 with wildlife guilds identified that are most likely to use them.

Table 4. TSF habitat categories identified in previous work [5] with definitions and wildlife guilds identified that are most likely to use them.

Data category	Definition	Wildlife Guilds most likely to use habitats
Supernatant	Open water within the tailings paddock	Ducks, Grebes, Cormorants, Swan, Pelican, Banded Stilt, Red-necked Avocet, Swallows, Swifts
Wet tailings	Wet mine waste slurry	Ducks, Waders,
Dry tailings	Dry mine waste slurry	Waders, Corvids, Passerines
Dry tailings/stream	Interface between dry tailings and liquor discharge stream between spigot and the supernatant pond	Ducks, Waders, Passerines,
Beaches/wet tailings	The interface between the supernatant and wet tailings	Ducks, Waders,
Beaches/dry tailings	The interface between the supernatant and dry tailings	Waders, Ducks, Passerines
Aerial	Only for wildlife flying over the TSF	Swallows, Swifts, Raptors
Walls	Outer paddock walls and the decant key wall	Ducks, Waders, Raptors, Corvids, Richards Pipit, Passerines

4.2.1 Aquatic Plants, Aquatic Invertebrates and Fish

Only one ecological study of a gold mining TSF incorporating aquatic biota is known to have been conducted [27]. No aquatic biota including plants, invertebrates or fish were recorded [27]. There are no references in the literature to aquatic biota being present within a gold mining TSF however TSFs from other sectors of the mining industry do at times have aquatic plants and invertebrates living in them [27].

Hypersalinity is unlikely to be a factor in the absence of aquatic biota in the TSFs as demonstrated above by the presence of a range of plants and animals in hypersaline lakes in Western Australia. It is likely that the primary factors effecting presence of aquatic biota are heavy metal concentrations and cyanide concentrations. Cyanide is toxic to all aquatic biota with fish being the most sensitive group [46] and aquatic plants being the least sensitive [101]. Aquatic invertebrates have been found to suffer non-lethal effects for cyanide concentrations of between 18 and 43 μg/L, and lethal effects between 30 and 100 μg/L, although deaths have been recorded for concentrations of between 3 and 7 μg/L for the amphipod *Gummarus pulex* [101]. Aquatic plants are more tolerant of cyanide; adverse effects occur at >160 μg/L free cyanide [101]. Cyanide concentrations found in most TSFs are therefore high enough to preclude the establishment of aquatic biota within the system. A number of heavy metals are also known to be toxic to aquatic life forms (Table 5) and a number of these are generally found in TSF tailings at concentrations considered lethal [25]. It is likely that heavy metals are an important factor in the lack of aquatic biota within TSF supernatant water bodies.

Table 5. Some mine-associated toxic elements and their potential for direct and indirect effects on aquatic food for birds.[1]

Contaminant	Effects on aquatic communities[1]
Aluminium	Toxic to aquatic organisms
Arsenic	Toxic to a variety of aquatic and terrestrial organisms
Boron	Toxic to plants
Cadmium	Toxic to invertebrates
Chromium	Highly toxic to aquatic life
Copper	Highly toxic to aquatic life
Cyanide	Highly toxic to aquatic life
Lead	Highly toxic to all life
Mercury	Highly toxic to all life
Molybdenum	Some phytotoxicity
Nickel	Toxic to some invertebrates
Silver	Highly toxic to aquatic life
Selenium	Low toxicity to most organisms unless concentrated in food
Tin	Low toxicity
Zinc	Highly toxic to aquatic life and terrestrial plants

Source: O’Shea, Clark and Boyle (2001)[1]

4.2.2 Terrestrial Invertebrates

There is little published information on presence and abundance of terrestrial invertebrates within TSFs. One study using yellow pan traps recorded spiders plus seven insect orders [27]. The majority of specimens (92 individuals, 96.8% of the total) were winged adults from seven insect orders including Diptera (30 individuals, 31.6% of total), Hymenoptera (24 individuals, 25.3% of total) and Coleoptera (23 individuals, 24.2% of total) [27]. The remaining specimens (a total of three individuals) were Arachnids. Winged insects were observed within the TSF on a daily basis in addition to those sampled in pan traps. They were generally a few millimetres in length but larger insects of 1 to 3 cm were occasionally observed consisting of dragonflies (Odonata), wasps (Hymenoptera), grasshoppers (Orthoptera) and moths (Lepidoptera). A large number (many hundreds) of locusts (Orthoptera) were also observed on one day soon after dawn within the TSF after heavy rain the previous night [27]. They appeared to be approximately 4 to 5 cm in length and were actively moving over the walls and dry tailings and, to a lesser extent, wet tailings [27].

Invertebrates are probably common-place within TSFs to some degree, with abundance dependant on many environmental and physical factors. While TSFs probably provide minimal habitat and little or no resources for invertebrates their presence within these systems is likely to be due to either being blown by wind and flying or swarming over TSFs.

4.2.3 Birds

In Australia, waders, waterbirds [5, 6, 18, 19], ducks, pratincoles, terns, raptors [5, 19], and in the USA waterfowl, shorebirds, perching birds and gulls [4] are all documented at TSFs, although systematic monitoring studies are few [5].

Wildlife species composition on tailings dams can be predicted by habitat provisions [5] although it may be reasoned that natural wetlands provide better habitat for waterbirds than artificial wetlands [102]. It has been stated that there is no reason to believe that birds are able to distinguish between TSFs and any similar area of water formed from precipitation [31], although it is argued that animals generally avoid tailings dams if natural water is available [9]. Availability of food is likely to influence visitation rates and diversity of wildlife and hence levels of interaction with TSF solutions.

The number and diversity of waterbirds counted on farm dams has been shown to be positively correlated with pond size [103] and to increase with each additional wetland feature [44]. There can be an assumption that larger TSFs with complex habitats attract a greater number and diversity of birds. There are however strong seasonal and environmental influences on visitation rates and habitats used by waterbirds and shorebirds, particularly in the semi-arid and arid regions of Australia [104].

To complicate matters further, a significant proportion of wildlife that use TSFs are active at night [5]. No literature exists regarding nocturnal monitoring on TSFs.

One wildlife study was conducted for 100 hours over 14 days on a hypersaline TSF within the Eastern Goldfields region of Western Australia by Smith et al. (2007) [27] and is summarised below.

This study recorded an average daily abundance of 31.5 ± 24.5 birds with a daily species diversity of 2.75 ± 0.25. A total of 764 birds of 12 species were observed within the TSF during 140 observation hours of point-in-time surveys. One species, Red-capped Plover (*Charadrius ruficapillus*), comprised 86.6% of the records, while the wader guild comprised 91.7% of the records. The only waterbirds were two pairs of ducks (Australian Shelduck, *Tadorna tadornoides* and Grey Teal, *Anas gracilis*) and the remaining observations were of terrestrial and aerial birds.

Foraging behavior was observed for eight species however only six of these were observed successfully taking food within the TSF. No birds were observed drinking from the supernatant however a pair of Red-capped Plovers were possibly observed drinking from pools of rainwater formed on dry tailings substrate.

Half of the species recorded in the TSF were observed using supernatant or wet tailings habitats while the remaining six species were only recorded aerially or using dry habitats.

Red-capped Plovers, an endemic non-migratory wader, was recorded on 77% of observation days and in all observation months. Numbers fluctuated according to the season with fewer birds found in winter and over 100 observed on some days in November. Monitoring of individual birds showed that this species spent the majority of their foraging time (71.3%) on wet tailings, with 6.3% and 2.2% of foraging time on dry tailings and dry tailings/stream respectively. They were observed feeding on small winged insects, one bird was observed consuming a small grasshopper (Orthoptera) and another, a small moth (Leptidoptera). While feeding, Red-capped Plovers made an average of 14 ± 9 pecks per minute. Pecking rates were similar throughout the day, but appeared to be greatest during the hour after sunrise (Average = 18.3 ± 9.4) and the hour before sunset (Average = 16.8 ± 8.0).

Red-necked Stint (*Calidris ruficollis*) was the only migratory wader recorded and was observed on 23% of observation days with all observations occurring during November 2006, corresponding with migration through the region. They were observed resting for 79.4% of the time within the active paddock and only foraged, primarily on wet tailings, for 16.8% of the time. They appeared to be feeding by visual inspection similar to Red-capped Plover, taking mostly small prey on the surface of the liquor and tailings. They were occasionally observed probing wet tailings and putting their bill into the liquor but it appeared that these feeding actions were unsuccessful. Red-necked Stints made an average of 14.8 ± 12.7 pecks per minute while foraging.

Two Australian Shelduck were observed roosting on walls, wet tailings and on the supernatant. They did not interact with the wet tailings or the supernatant and were observed leaving the system. Two Grey Teals were observed foraging intermittently in the supernatant over a period of several minutes. The birds were then seen flying within the system. They were not observed leaving the system but were not present the following morning. Both species were initially resting on the TSF dyke wall until disturbed when they flew to wet tailings or supernatant.

Welcome Swallows (*Hiruno neoxena*) were observed on five days foraging over the supernatant, wet tailings and dry tailings for periods of up to several minutes. They were observed dropping down to touch the surface of the supernatant and tailings on several occasions possibly taking insects.

Corvids (crows and ravens) were recorded on 45% of observation days. Corvids were regularly observed flying at various heights over the TSF and at times they flew quite low over the surface and were observed inspecting wet and dry tailings. On 16 November 2006, following rain the previous night, three Australian Ravens *Corvus coronoides* and four Australian Magpies were observed feeding on an influx of locusts in the TSF on paddock walls and dry tailings.

Banded Stilt (*Cladorhynchus leucocephalus*) is an endemic wader [95] and a hypersaline 'specialist' and was recorded once.

Also of interest was the complete lack of observations of granivorous species such as parrots and pigeons at this hypersaline TSF. These species are commonly observed around water bodies in arid Australia as they need to drink regularly [105, 106]. A complete lack of these species was interpreted as unpalatability of any solutions present.

4.2.4 Terrestrial Mammals

Larger terrestrial mammals are generally only recorded at mine facilities that are not adequately fenced or when gates are left open. Smaller mammal species such as rodents are virtually impossible to exclude from TSFs and will not be kept out by fencing. They are usually attracted to mine solutions when searching for water to drink however a number of species will also use TSF habitats to scavenge for carcasses or look for prey such as rodents and larger invertebrates. The regular presence of scavenging species may indicate a constant supply of carcasses.

Smith et al. (2007) [27] found in their study that the hypersaline TSF which was fenced just with a stock fence recorded no visitations however, dog tracks, cats and kangaroos have been observed previously within the TSF. Mammals were said to be deterred to some degree by the fence but also by the great deal of human activity and the little or no food resources for terrestrial mammals within the system [27].

4.2.5 Insectivorous Bats

To date, only one scientific study has presented quantitative data documenting the presence of insectivorous bats in the airspace above a hypersaline TSF [27]. During 184 hours of passive electronic monitoring at the Kalgoorlie Consolidated Gold Mine (KCGM) Fimiston II TSF system (utilising AnaBat SD1 bat detectors), a total of four species of insectivorous bats were recorded (*Tadarida australis*, *Chalinolobus gouldii*, *Vespadelus baverstocki*, unidentified *Mormopterus* sp.), with an average of 3.6 echolocation calls per hour. Records were dominated by one species, white-striped free-tailed bat (*Tadarida australis*), possibly reflecting this species' preference for foraging high above ground level, as apposed to other species of Australian insectivorous bats which tend to forage at or below the tree canopy, generally within 20 metres of the ground [107].

4.2.6 Comparison of Wildlife Use of Tailings Storage Facility with nearby Sewage Works

Wildlife use of a hypersaline TSF and a nearby non-saline sewage works has been compared and it is clear that most wildlife preferentially use the sewage works rather than the TSF [108]. The apparently higher numbers and greater diversity of wildlife at the sewerage works may be due to a combination of factors including (but not necessarily limited to):

- presence of aquatic macro-invertebrate fauna and aquatic flora (Smith, G, pers. obs.);

- minimal salinity (the sewage ponds are derived from potable town water), which may make the ponds attractive as a source of drinking water; and
- the presence of other birds indicating the availability of food.

While most species appear to preferentially use sewage works some species such as Red-capped Plover and Red-necked Stint may preferentially use TSFs as a foraging habitat in the immediate district, at least at certain times of the year. Red-capped Plovers appeared to live within the system and are likely to be present almost every day of the year. It is possible that they may breed on inactive paddocks.

Also of interest was the lack of observations of granivorous species such as parrots and pigeons at the TSF. Such species were regularly observed at the non-saline sewage works probably coming to drink [108]. This provides further indication that some wildlife guilds are discerning and can differentiate between this tailings dam and other water bodies prior to interacting with waste solutions (or even visiting the system), contrary to reports elsewhere [31, 108].

Insectivorous bats were also present in minimal numbers and diversity within the TSF in comparison to the sewage works [27]. This reflects the paucity of food resources and structural provisions of the Fimiston II TSF compared to the sewage works [108].

4.2.7 Reasons For Avian Use of Tailings Storage Facilities

Vertebrate wildlife utilise the TSFs primarily for the following reasons:

- provision of limited food resources;
- resemblance to natural habitats; and
- structural features provide roosting habitats [109].

Provision of Limited Food Resources

Food resources for wildlife within TSFs have been found to be limited to aerial invertebrates that are wind-blown or fly over the TSF and those that land on or become embedded in the surface of wet tailings and supernatant [109]. Pan trap sampling illustrated that moths, wasps, flies, beetles and bugs are present. They provide a regular food source for some birds and bats. The supernatant pool at one TSF was found to be devoid of aquatic macroinvertebrates and is essentially abiotic [109]. This is likely to be the case for all TSFs that contain cyanide and metals such as copper.

Birds primarily feed on the aerial and terrestrial macro invertebrates by taking them in flight and picking them from the supernatant and wet tailings (Donato, D, pers. obs.).

Many species of flying insects have boom and bust life cycles, for example locusts and termites, and may appear in large numbers over short periods of time [110].

This will influence food availability within TSFs and wildlife interactions with TSF habitats may consequently increase during these episodes [108].

Bat calls recorded above TSFs indicate that they feed upon insects in the airspace above the TSFs [108], however at least one Australian species is known to scurry on open dry ground after prey [107] including, possibly, on dry tailings (Donato, D, pers. obs.). The echolocation hunting technique of bats may exclude detection of dead, partially entombed insects amongst wet tailings or semi-submerged dead insects in the supernatant.

Resemblance to Natural Habitats

A number of Habitats within TSFs, particularly supernatant and tailings beaches resemble natural habitats and attract some avian species despite a complete lack of food [108]. These species either visually inspect for food or interact with habitats to discern if food is available [108]. A lack of food resources (aquatic macroinvertebrates) in these TSF habitats does not therefore deter them from using these habitats until they have ascertained that no food is present. For species that forage visually this will probably occur without interaction with the habitats however for species that filter feed or forage by touch some interaction with TSF habitats will occur before they determine that there is a lack of food [108]. A number of species including waterbirds and waders have been observed foraging for food in supernatant and soft tailings, habitats that have been demonstrated to contain no plant or animal food [109]. Field observations suggest that these species ascertain quickly that there are no aquatic plants or animals present within the TSF as they cease attempting to feed after a few attempts [108].

Structural Features Providing Roosting Habitats

Some species use the TSFs as a place of rest or refuge [109]. Waterfowl, waders, swallows, corvids and even raptors have all been observed roosting within TSFs with little or no attempt to forage [109]. Some species such as Australian Shelduck appear to use the TSF primarily as a place of refuge where predators either have no access or are easily seen from a distance due to the flat unvegetated landscape [108]. Other species such as swallows are often seen roosting on infrastructure such as rails and posts and raptors and corvids often perch on the walls of TSFs to take advantage of the views they afford due to the height above the landscape [108]. In one study Grey teals and Banded Stilts continued to use the structural habitats to roost for a number of hours after having discovered a lack of food within the system and two Australian Shelducks were present for a number of hours and yet were not recorded attempting to forage at any time [109].

4.3 Influence of Hypersalinity on Exposure Pathways of Wildlife to Cyanide at Tailings Storage Facilities

Assessment of wildlife exposure and behaviour is required to understand the influences of hypersalinity on cyanide toxicity risks on tailings systems. There are three ways that wildlife are exposed to cyanide in the tailings environment:

- epidermal absorption (absorption of aqueous cyanide through the skin);
- inhalation of cyanide gas; and
- ingestion (drinking of the supernatant and foraging in supernatant or on wet tailings) [109].

4.3.1 Epidermal Absorption

Cyanide can be absorbed through the skin especially when the skin is wet [2, 45]. Acute wildlife cyanide toxicosis due to skin absorption has not been reported in the literature [4] or observed in the field [5]. Birds roosting on supernatant are the only guild of vertebrate wildlife that have long contact time with cyanides in solution on a tailings system (Donato, D, pers. obs.) Birds have epidermal exposure primarily through their feet, a limited surface area of contact. Birds' feet have low epidermal exchange with the external environment [111]. While it is possible that some cyanide is absorbed through the skin, there was no evidence of an effect on wildlife at cyanide concentrations typically experienced at one site [108] or by the gold industry in general. Considering the literature and field observations, logic follows that this pathway at cyanide concentrations typically experienced in TSF's poses little or no risk to wildlife. This paper does not further consider the influences of hypersalinity on epidermal absorption.

4.3.2 Inhalation of Gaseous Cyanide

Cyanide gas (HCN) on tailings systems results from the liberation of free cyanide as it volatilises from the surface of tailings dams [9-12, 16, 18, 112-116], although atmospheric concentrations immediately above tailings solutions are not considered toxic [116]. Cyanide gas levels will vary from the spigot to the decant pond. Routine monitoring at one site has shown cyanide gas concentrations at below detectible limits (<10 mg/L) and is considered benign to wildlife [108]. Cyanide gas concentrations are often measured and found to be safe within TSF facilities within the gold industry as occupational health and safety standards do not allow workers to be exposed to greater than 10 mg/L cyanide gas. This exposure pathway is not considered a sufficient pathway of exposure to cause cyanide toxicosis to wildlife. Hypersalinity can have an influence on cyanide gaseous liberation but is not further considered by this paper.

4.3.3 Ingestion (Drinking)

A variety of wildlife including birds, kangaroos, livestock and insectivorous bats have been recorded drinking from freshwater TSF's and on-site water bodies [4, 29]. Drinking is a primary avenue of exposure and a major cause of cyanide toxicosis for wildlife within the gold industry [4, 5].

Saline and hypersaline environments present specific problems to wildlife as they have a very strong potential to cause dehydration in animals that use them. This is because the ionic content of hypersaline water is significantly higher than that of vertebrate blood. Where the two liquids are separated by a permeable membrane (such as the stomach) osmotic pressure results in loss of water from the blood and overloading of the blood with ions. Despite this many animals live in or use saline environments including hypersaline environments [81, 84, 86, 88, 91]. Animals manage to use these environments through a combination of physiological and behavioural adaptations [88].

The propensity of wildlife to drink from tailings facilities is influenced by many factors such as climate, availability of cover for wildlife, fencing, water chemistry and salinity. Salinity strongly influences the palatability of drinking water for all vertebrate species.

The salinity tolerance of native terrestrial mammals that interact with tailings systems is not well known. However one desert living American species, the kangaroo rat, can survive by drinking water of the equivalent salinity of sea water (35 000 mg/L TDS) [117]. Salinity tolerance in livestock is well studied and most cannot withstand greater than 10 000 mg/L TDS (Table 6). Salinity greater than this is considered harmful to all livestock [100], however sheep may tolerate salinity of up to 13 000 mg/L TDS for short periods of time [118].

As mentioned above, there is little information on drinking behaviour of insectivorous bats, however, they are known to drink from non-saline surface water bodies [119, 120] and tailings systems [4, 24, 30, 101]. There is some indication insectivorous bats may avoid drinking saline water if other sources are available [121].

Nevertheless, it seems very unlikely that any non-marine mammal can drink water with salinity equal to or greater than sea water.

Table 6. Tolerances of livestock to total dissolved solids (salinity) in drinking water[1]

	Total Dissolved Solids (mg/L)		
Livestock Species	No adverse affects expected	Minimal adverse affects[2]	Major adverse affects[3]
Beef cattle	0 to 4 000	4 000 to 5 000	5 000 to 10 000
Dairy cattle	0 to 2 400	2 400 to 4 000	4 000 to 7 000
Sheep	0 to 4 000	4 000 to 10 000	10 000 to 13 000[4]
Horses	0 to 4 000	4 000 to 6 000	6 000 to 7 000
Pigs	0 to 4 000	4 000 to 6 000	6 000 to 8 000
Poultry	0 to 2 000	2 000 to 3 000	3 000 to 4 000

[1] Adapted from ANZECC (1992).

[2] Animals may have initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production.

[3] Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually.

[4] Sheep feeding on lush green feed may tolerate up to 13 000 mg/L total dissolved solids without loss of condition or production.

With the exception of pelagic (marine) bird species, few birds can drink highly saline water. Marine birds have little or no access to fresh water and they all have specialised adaptations in the form of salt glands located in the nasal passages above the eyes that filter salt from the blood producing a highly concentrated sodium chloride solution of up to 50 000 mg/L TDS which is then expelled [122, 123]. This enables these birds to tolerate the ingestion of sea water (approximately 35 000 mg/L TDS) or food with a high salt content [123-125]. Functional salt glands are found in a number of avian orders (Table 7) including Sphenisciformes (penguins), Procellariiformes (albatrosses and petrels), pelecaniformes (pelicans, cormorants, frigatebirds), Anaseriformes (ducks, swans, geese), Falconiformes (eagles, hawks and falcons) and Charidiiformes (waders, terns, gulls) but not in Passeriformes (paserines or songbirds) [95, 122-128]. These glands are very effective and have been found in gulls to eliminate 90% of the salt ingested by drinking within 3 hours [122]. Two species of albatross could not survive in captivity unless artificial sea water was provided [129].

Table 7. Avian orders and families in which salt glands have been found within at least some species.

Order	Famliy	Presence of salt glands within the family	Australian species found to have salt glands	Habitats
Sphenisciformes (penguins)	Spheniscideae (penguins)	All species		Marine
Podicepediformes (grebes)	Podicepedidae (grebes)			Wetlands, marine
Procellariiformes (albatrosses and petrels)	Diomedeidae (albatrosses)	All species		Marine
	Procellariidae (petrels)	All species		Marine
	Hydrobatidae (storm-petrels)	All species		Marine
	Pelecanoididae (diving-petrels)	All species		Marine
Pelecaniformes (pelicans, cormorants, frigatebirds)	Phaethontidae (tropicbirds)	All species		Marine
	Pelecanidae (pelicans)	Probably all species	Australian Pelican	Wetlands, marine
	Sulidae (gannets and boobies)	All species		Marine
	Phalacrocoracidae (cormorants)	All or most species		Wetlands, marine
	Anhingidae (darters)			Wetlands, marine
	Fregatidae (frigatebirds)	All species		Marine
Ciconiiformes	Ardeidae (herons and egrets)	Some species		Wetlands, marine
	Ciconiidae (storks)			Wetlands
	Threskiornithidae (ibises and spoonbills)			Wetlands
Anaseriformes (ducks, swans, geese)	Anatidae (ducks, swans, geese)	Some species	Australian Shelduck, Chestnut Teal, Grey Teal, Pacific Black Duck	Wetlands, marine
Falconiformes (eagles, hawks and falcons)	Pandionidae (Osprey)	Unknown	Unknown	Wetlands, marine
	Accipitridae (hawks, eagles)	Some species	None known	Aerial, terrestrial, wetlands, marine

Order	Famliy	Presence of salt glands within the family	Australian species found to have salt glands	Habitats
	Falconidae (Falcons)	Some species	None known	Aerial, terrestrial, wetlands, marine
Charidiiformes (waders, terns, gulls)	Haematopididae (oystercatchers)	All species		Marine
	Recurvirostridae (avocets, stilts)	All species	Banded Stilt, Red-necked Avocet	Wetlands, marine
	Glareolidae (pratincoles)	All species	Australian Pratincole	Terrestrial
	Charadriidae (plovers)	All or most species	Inland Dotterel, Red-capped Plover	Wetlands, marine
	Scolopacidae (sandpipers, snipe)	All or most species	Red-necked Stint, Sharp-tailed Sandpiper	Wetlands, marine
	Stercorariidae (skuas)	All species		Marine
	Laridae (gulls and terns)	All or most species	Silver Gull	Terrestrial wetlands, marine

The effectiveness of the salt glands varies even within the same order. Birds of the order charadriiform (waders, terns and gulls) have generally well developed salt glands [125] however in one study Snowy Plovers *Charadrius alexandrinus* and Semipalmated Sandpipers *Calidris pusilla* failed to maintain body weight when given approx 17,500 mg/L NaCl (50% saline concentration of seawater) ad libitum and Killdeer *Charadrius vociferus* did even more poorly by rapidly losing weight on 12,000 mg/L [125]. In contrast Hughes (1970) kept more than half of a sample of Glaucus-winged Gull *Larus glaucescens* at constant weight when provided with 100% sea water [125]. Many ducks have salt glands however they have a varying ability to tolerate drinking saline water. In one experiment mallards were unable to tolerate water of much greater than 0.3 M NaCl (50% saline concentration of seawater) whereas Canvasback tolerated 0.45 M NaCl (75% saline concentration of seawater) and Barrows Goldeneye tolerated 0.55 M NaCl (92% saline concentration of seawater) [124]. Tolerance of drinking saline water varies even within species with development and size of salt glands being influenced by habitat [130]. In some species individuals living in marine habitats or salt lakes have been found to have more highly developed glands compared to individuals that live in fresh water habitats [122]. In one experiment domestic ducks of the white Peking variety were raised with various concentrations of sodium chloride (NaCl) added to their drinking water [123]. They were able to tolerate 10 000 mg/L TDS NaCl very well but 20 000 mg/L TDS NaCl and 30 000 mg/L TDS NaCl retarded the growth of the birds and could only be tolerated for shorter periods [123]. All ducks drinking salt solutions developed larger salt-secreting glands (nasal glands) than fresh water controls [123] and therefore developed a greater tolerance to drinking saline water.

A number of waterbirds and waders utilise saline and hypersaline habitats in Australia (Table 3) however none have been recorded drinking water of greater salinity than 35 000 mg/L TDS and some authors regard many species of waterbird as unable to drink saline water [131]. Black Swan *Cygnus atratus* is reported to be able to drink water up to 35 000 mg/L TDS [131], however two other characteristic saline species Australian Shelduck *Tadorna tadornoides* and Chestnut Teal *Anas castanea,* are restricted to drinking water with approximately 20 000 mg/L TDS [130] and 10 000 mg/L TDS [132] respectively. Chestnut Teal is said to have a poor ability to excrete salt [132] which suggests it requires fresh water even when utilizing saline habitats [126] and probably cant drink saline water to any great degree.

Salt glands have also been found in Australian Pratincole *Stiltia Isabella* and Common Sandpiper *Tringa hypoleucos* of a size that indicated that they could drink saline water but of a salinity 'somewhat less than seawater' [133]. Inland dotterel of arid Australia also has well developed salt glands interpreted as used for processing high salt content of plant material which are consumed for water needs [134]. However has been recorded to move to drink from stock tanks and claypans at dusk [95] and may be able to drink saline water of undetermined salinity.

In general, birds that lack salt glands have a low tolerance to salt because most avian kidneys cannot produce urine with a high salt content [123, 135]. Many birds without salt glands may be able to tolerate drinking water of up to 10 000 mg/L TDS NaCl, which is slightly above the concentration in the blood and within the capacity of the avian kidney to excrete [123]. However some terrestrial birds that live in arid environments or in close proximity to marine environments [123, 136, 137] can excrete salt by concentration of their urine via the interaction of kidney and cloaca [138] and are therefore able to drink saline water. The Australian Zebra Finch (*Taeniopygla castanotis*) and the American Savannah Sparrow (*Passerculus sandwichensis beldingi*) can tolerate salt solutions more concentrated than sea water [139, 140]. The Zebra Finch *Taeniopygia guttata* is a widespread Australian resident of semi-arid areas and it is reported that it is capable of drinking saline water that is 0.7 – 0.8 M NaCl (41 000 to 47 000 mg/L TDS) which is equivalent to 116 to 133% of sea water [139, 141]. Skadhauge and Bradshaw (1974) [141] measured an intake of 0.8 M NaCl water at 400 μl/day measured directly and approximately 200 μl/day calculated indirectly from the cloacal discharge of NaCl (in solution). These values are thus 20% and 10%, respectively, of the turnover of body water in the dehydrated state. The zebra finch seems dependent on water during its life as a common species in the arid interior of Australia [105, 106]. Most water holes in arid Australia are likely to be low in salts, even several months after the last rainfall [106]. However Zebra Finches have been observed to drink from a water hole at Mileura Station, Western Australia, with a Cl concentration of 309 meq/L [141].

The Zebra Finch appears to be exceptional in its adaptations to arid environments and saline tolerance and no other bird has been recorded as being as saline tolerant. Three species of quail found in arid and semi-arid habitats and two common doves of the Californian deserts, White-winged Dove *Zenaida asiatica* and Inca Dove *Scardafella inca*, could not withstand more than 50% seawater

[142, 143]. Some passerine families such as sparrows appear to be well adapted to drinking saline water. Apart from the above mentioned species, Black-throated Sparrow *Amphispiza bilineata* can drink water up to 23 000 mg/L [144] and Brewers Sparrow *Spizella breweri*, up to about 32 000 mg/L [145]. A study of different races of the Seaside Sparrow, *Ammospiza maritima*, found that drinking responses and capacities to concentrate urine were different and significantly correlated with the salinity of water available in each race's habitat [146]. Studies on osmoregulation and water economy of the Emu, Galah and Budgerigar indicate that these arid and semi-arid living species can concentrate salts in their urine and therefore have a degree of tolerance to salinity in their food and drinking water [147-149]. Laboratory experiments on captive Budgerigars found that when offered saline water of 0.2 M NaCl and 0.3 M NaCl as the only source of water some birds drank the solutions but lost weight and one bird died [147].

It is likely that when birds are presented with more than one option that they will choose the least saline water source to drink from however this was not confirmed in the literature.

General Drinking Behaviour in Birds

Water consumption is influenced by the size and age of the bird, environmental temperature, type and amount of food consumed [150]. Chickens consume 5.5%–20% of their body weight in water over 24 hours depending on whether they are growing, adult birds, laying hens, roosters or in what stage of egg production [150].

An extensive review of water consumption by wild birds revealed a range of 5-30% of body weight in 24 hours in the absence of temperature stress [151] (Table 8). However, with the exception of the Zebra Finch, (*Taenopygia guttata*) and the Budgerigar (*Melopsittacus undulates*) these birds are not adapted to arid conditions.

Many birds adapted to life in arid conditions rarely drink standing water, obtaining their water via metabolic processes through their food. Many arid zone birds are also adapted to their conditions by limiting metabolic water loss through reduced basal metabolic rate [152, 153]. Despite air temperatures often exceeding 40˚C, Smyth and Bartholomew (1966) [144] reported Black-throated Sparrows, *Amphispiza bilineata* making use of standing water only on the very driest days of the year. However, on a dry diet and in the absence of heat stress, the same species drank an average of 30.3% of their body weight in water per day in laboratory experiments.

Table 8. Mean body weight and water consumption of land birds. Adapted from Bartholomew and Cade (1963)

Latin name	Common name	Mean body weight (g)	Mean H_2O drunk % body wt./day	
			Ad libitum	Min.
Lophortyx californicus	California Quail	139.0	5.2	1.8
Zenaidura macroura	Mourning Dove	104.0	9.9	2.8
Melopsittacus undulates	Budgerigar	30.0	5.0	<1.0
Toxostoma dorsale	Crissal Thrasher	70.0	4.4	-
Passer domesticus	House Sparrow	17.3	32.9	-
Taeniopygia guttata	Zebra Finch	11.5	24.4	<1.0
Estrilda troglodytes	Black-rumped Waxbill	6.5	35.7	-
Pheucticus melanocephalus	Black-headed Grosbeak	37.0	10.3	-
Carpodacus mexicanus	House Finch	20.6	16.0	10.0
Pipilo fuscus	Canyon Towhee	43.7	15.8	-
Pipilo aberti	Albert’s Towhee	46.8	23.5	-
Passerculus sandwichensis brooksi	Savannah Sparrow	17.5	58.2	-
Passerculus s. beldingi	Savannah Sparrow	17.0	100.0	45.9
Passerculus s. rostratus	Savannah Sparrow	19.0	69.0	-
Junco hyemalis	Dark-eyed Junco	15.8	21.4	-
Zonotrichia atricapilla	Golden-crowned Sparrow	26.5	38.6	-
Zonotrichia albicollis	White-throated Sparrow	23.0	26.9	-
Passerella iliaca	Fox Sparrow	28.0	26.8	-
Melospiza melidia maxillaris	Song Sparrow	18.2	41.8	-
Melospiza m. samuelis	Song Sparrow	16.4	52.5	-
Melospiza m. cooperi	Song Sparrow	16.8	21.1	-

Detailed studies of the drinking behaviour of Australian arid zone bird species have been published [106, 154] suggested that species that are reliant on standing water for drinking on a daily basis may drink up to four times per day in excessively hot or dry conditions, however this was based on observations of only a single species. They also noted that at many locations, some species did not drink every day despite hot and dry conditions. Evans *et al.* (1985) [155] and [154] suggest that among Australian Estreldid finches, many individuals visit water bodies to drink only once per day and present evidence that *Heteromunia pectoralis* and *Erythrura gouldii*, Pictorella Mannikin and Gouldian Finch respectively, are able to imbibe most, if not all of their daily requirement in one drinking bout. Based on calculations using laboratory measured drinking rates and field recorded times, these species were estimated to be imbibing between 0.73 g and 1.17 g of water per drinking bout. A deficit of 0.97 g in the daily water budget of Zebra Finch, *T. guttata* was reported [154].

One study in the Australian desert classed 60% of the 118 species observed as water independent, in that they were either not observed drinking or only did so infrequently [106]. Granivorous species are the most dependent on water, and they are also the most abundant avian group in the arid parts of Australia in localities where surface water is available [106]. Nectivorous birds drink regularly, however, carnivorous and insectivorous birds are largely independent of water, and many small insectivorous birds appear never to drink [106]. A direct correlation is apparent between frequency of drinking and ambient temperature, almost all species that drink visit water more often on hot days than on cooler ones [106].

Water Consumption by Insectivorous Bats

Do bats require drinking water? The answer to this question may seem obvious given that bats have extremely high surface-to-volume ratios (due to the large surface area of membranous, vascularised wings), resulting in a high rate of water loss through evaporation, particularly during flight [156]. However, there are many bat species, as well as a range of other small mammals, that do not need to drink [123, 157-159]. Instead of drinking, these animals receive enough water in their food (i.e. preformed water) and/or produce enough water during biochemical processing of food molecules (i.e. metabolic water) that they do not have to drink [119]. For example, many bats that feed on fruit and nectar (Megachiroptera) ingest sufficient preformed water from these foods to maintain a positive water balance [107, 160].

In relation to insectivorous bats, laboratory studies have shown that these animals experience high levels of evaporative water loss (15-31% body mass) during diurnal roosting [161-165]. In order to compensate for these losses, replenishment of 20-40% of daily water reserves is achieved through drinking at water sources [166-169]. These results suggest insectivorous bats emerging from diurnal roosts, especially in hot, arid environments (such as the Eastern Goldfields region of Western Australia), would be motivated to drink at nearby surface water such as streams, rivers, lakes and tailings dams to replenish diurnal water losses [24, 28, 119, 170, 171]. Indeed, high levels of bat activity have been documented at surface waters located in xeric habitats [120, 171].

While there is evidence that foraging in the airspace above surface water is beneficial for some insectivorous bats [25, 119, 172-178], the specific behaviours employed by insectivorous bats when interacting with sources of surface water have received little attention [170]. Many studies present anecdotal evidence of insectivorous bats drinking surface water by swooping over a water source and lapping at the surface while in flight, a similar mode of drinking as that adopted by swallows, martins and swifts. However, published records presenting quantitative data on insectivorous bats drinking are rare [120, 171].

4.3.4 Ingestion (Foraging)

Foraging amongst supernatant and wet tailings represents a cyanide exposure pathway for wildlife [5] through inadvertent ingestion of cyanide-bearing solutions and slurries. Ingestion of solutions can occur regardless of whether the activity results in the successful acquisition of food. The amount of solution ingested and hence the dose of cyanide received is influenced by the presence or absence of food within the system and the foraging technique. Salinity also strongly influences ingestion rates as salt can cause dehydration and can even cause toxicity at high concentrations [123, 138, 179-183].

Foraging Techniques

All species have unique ecologies depending on habitats used, food type, bill length and shape, and many other factors. Foraging methods are correspondingly diverse however birds that feed in watery or muddy environments can be classed as either foraging by sight (visual inspection), filter feeding or by feeling for prey.

Species that hunt by visual inspection will only interact with the habitats if food is available. Species characterised as such that are commonly found within TSFs include Red-capped Plover *Charadrius ruficapillus*, Red-necked Stint *Calidris ruficollis* and Welcome Swallow *Hirundo neoxena* [109]. They feed on invertebrates usually on the surface of the supernatant, wet tailings and dry tailings by picking prey from these substrates. The presence of a range of live and dead invertebrates within the system therefore determines these species interaction with the TSF habitats. Absence of food will result in absence or very low level of interaction through foraging with TSF habitats.

Species that engage in filter or feel feeding, such as Grey Teal, Red-necked Avocet and Banded Stilt, need to access the supernatant and/or wet tailings and interact with these habitats to determine whether food is present. The lack of food within the tailings system does not therefore preclude these species from attempting to feed within the tailings storage facility as they need to test habitats to determine if food is present [109]. Some inadvertent ingestion of solution while attempting to feed may occur. Species that engage in this type of foraging behaviour tend to discern very quickly that prey is not present within TSFs [108].

Some species such as Grey Teal and Red-necked Stint have two or multiple foraging methods and may be filter feeders in certain situations and sight foragers in other situations.

The Avian Digestive Tract

The size of the digestive tract in birds varies with the size of the bird and its diet. Birds that eat coarse, fibrous foods (herbivores) have proportionately larger digestive tracts than granivores, which in turn have larger digestive tracts than carnivores [150]. See [184] for details of anatomical and histological variations in the digestive tracts within certain wild species. It has been measured the proventriculus and gizzard masses in adult Lesser black-backed gulls (*Larus fuscus*: body mass 799 ± 17 g) at 0·83 ± 0·03 g and 4.23 ± 0.21 g respectively [185]. However, gut morphology can be highly variable between individuals within species. [186] document changes of 10 – 100% in organ size in response to changing conditions in a wide range of bird groups.

The hydrogen ion concentration or pH of the digestive tract is dependent mainly on the amount of HCl secreted in the proventriculus and on the action of bile and pancreatic juice, which tends to neutralize the acid or increase pH in certain parts of the tract. The lowest pH occurs in the gizzard and the proventriculus [187] (Table 9).

Gastric juices may be collected from captive birds through various applications of catheters or syringes into the proventriculus or gizzard via the mouth or through an external opening [187]. More recently, probes have been developed specifically for monitoring gastric pH in wild animals [188]. The pH of mixed gastric juice collected from live domestic fowls, which tend to have an omnivorous diet, averages about 2.0 [187]. However, this may vary greatly depending on a number of factors. Measurements taken from wild *Pygoscelis* penguins during chick rearing ranged between pH 2.0 to almost neutral [188].

Factors affecting the amount of gastric secretion and its pH include the amount and type of food in the digestive tract, level of hydration of the animal and its level of excitement and nervous control [187]. The species and associated diet of the animal will also affect gastric pH and volume of gastric secretion (Table 9). Duke et al. (1975) [47] measured the undiluted gastric secretions of raptorial falconiformes and strigiformes on a similar diet between pH 1.3 – 1.8 and pH 2.2 – 2.5 respectively. The falconiformes varied in body weight from 0.68 kg (*Falco peregrinus*) to 3.3 kg (*Haliaetus leucocephalus*) and the strigiformes, 1.66 kg (*Bubo virginianus*) to 1.9 kg (*Nyctia scandiaca*). However, sufficient volume of gastric juices for preprandial (before meals) samples of 0.4 ml was much more difficult to obtain from the strigiformes than from the falconiformes suggesting gastric secretion is greater in falconiformes than in strigiformes regardless of body weight.

Table 9. Minimum pH in the digestive tracts of birds. Adapted from Sturkie (1976b)

	Proventriculus	Gizzard
Chicken	1.4 – 4.8	2.5 – 4.74
Pigeon	1 – 4.8	2
Pheasant	4.7	2
Duck	3.4	2.3
Turkey	4.7	2.2

Optimal reaction pH for digestive enzymes in Western Sandpipers (*Calidris mauri*) ranged between 3.1 and 6.9 although gut pH may be lower than this at times or in some digestive organs (Table 1). As migratory waders, these birds exhibited seasonal variation in digestive enzyme activities but not in digestive organ sizes [189] (Table 11).

Table 10. Optimal reaction pH for digestive enzymes in *Calidris mauri*. Adapted from Stein *et al.* (2005)

Digestive enzyme	Optimal reaction pH
Proventricular chitinase	3.1
Intestinal maltase	5.8
Intestinal amino-peptidase-N	6.9

Table 11. Wet mass of female western sandpipers *Calidris mauri* refuelling during migration. Adapted from Stein *et al.* (2005)

Variable	Spring Adults	Fall Adults	Fall Juveniles
Body mass (g)	26.0 ± 0.6	29.4 ± .7	27.5 ± .7
Digestive system (g)	2.38 ± 0.07	2.35 ± 0.05	2.58 ± 0.05
Proventriculus (mg)	101 ± 5	115 ± 4	84 ± 4
Gizzard (mg)	770 ± 27	726 ± 21	790 ± 22

HCL solution at pH 2 has been used to approximate the extractive conditions of the gastric fluid of the seed and fruit eating macaw parrot, Orange-winged Amazon (*Amazona amazona*) [190]. To estimate available minerals through geophagy, they added one gram of powered soil to 15 ml of the solution, agitated it at 38°C for one hour and then centrifuged.

Digestion in Insectivorous Bats

Digestion in Microchiroptera (insectivorous bats) follows the standard mammalian plan [191] . The stomach serves as a storage receptacle for large amounts of food ingested over a short period of time, for the destruction of bacteria by the stomach acid, and for the initial breakdown of proteins by the gastric enzymes pepsin and cathepsin [192, 193].

In Microchiroptera, as in other mammals, the gut consists of the small and large intestines [194]. As a general rule, the intestinal tract of insectivorous bats is no longer than four times the length of the body [191]. True enzymatic digestion occurs in the small intestinal epithelium [194], and fat is emulsified through the action of bile, making it available as a substrate for hydrophilic enzymes [160]. The large intestine is usually short, consisting only of a descending segment [195]. The large intestine and colon act mainly to reabsorb water and excrete the indigestible remains of food [196].

Microchiroptera digestion is characterised by rapid passage of food through the gastrointestinal tract and fast rates of absorption [192, 197-199]. The shortening of the intestine and rapid passage of food through the digestive system is likely related to the need to reduce weight during flight [200]. To exploit the full nutritional content of the food during its passage through the gut, the decreased time for digestion must be compensated for with an increased rate of enzymatic activity [160]. However, as there have been no systematic physiological studies into digestion in Microchiroptera, understanding of enzyme function within the digestive system is incomplete. There are no records documenting gastric pH for insectivorous bats, or the pH range under which optimal activity of digestive enzymes occurs.

Insectivorous bats forage by echolocation, sight and hearing and primarily feed on airborne insects, although some species can take prey from the surface of water, foliage or the ground [107]. The behaviour of insectivorous bats over TSFs has not been examined. However, their presence in the airspace above Fimiston II TSF has been documented through electronic monitoring of echolocation calls [201]. Echolocation call data provides quantitative evidence of the presence and activity patterns of insectivorous bats above a given water body, it does not however provide direct observations of behaviour such as drinking from the surface of open water. There are two logical hypotheses to explain the presence of insectivorous bats above open water bodies, including mine waste-derived water bodies such as TSFs:

- Access to surface water for drinking [25, 28, 29, 119, 120, 171]; and
- Foraging for emergent aquatic insects and other aerial invertebrates above the water's surface [175, 176, 178, 202, 203].

It is unknown whether species of insectivorous bats present in the Eastern Goldfields region forage by picking invertebrates from the surface of water or wet tailings slurries. If this type of foraging method is in fact employed, it may represent a cyanide exposure pathway similar to that documented for some bird species [109].

Foraging Activity and Presence of Prey

Foraging activity within all ecosystems such as natural and artificial wetlands is primarily influenced by presence and abundance of food. A number of studies on shorebirds have established correlations between the waders abundance and the density of prey [204] although a number of other variables such as habitat, competition for food resources, environmental factors and climate are also important [204]. Abiotic factors can also be important in determining abundance and have been found to be the biggest determinant of numbers for Red-capped Plovers in one study in Western Australia [204]. However this study also found that in two plots plover numbers were high when chironomid larvae were abundant but dropped to zero within two weeks of the disappearance of the food resource [204]. The relationship between foraging and long term presence of birds and food resources has been observed many times at hypersaline ephemeral lakes in Australia [92, 94]. In Australia hypersaline lakes are generally ephemeral in nature and once filled become progressively more saline and then dry out completely resulting in the complete loss of the aquatic food chain. Birds and other mobile animals must then move or face starvation.

Consequently sight foraging birds will not interact with systems if no food is available although they may be present to roost. Feel and filter feeders will only interact briefly with systems containing no food as they test these systems for presence of food however they too may roost within these systems [108].

The relationship between wildlife presence and abundance of food has been demonstrated in many ecosystems and many parts of the world. Anthropogenic acidification of wetlands through acid rain in Europe and North America has also been shown to cause the loss of a food chain at a number of sites with a consequent population reduction or total loss waterbird numbers [205].

At a study site in the Eastern Goldfields the presence of up to 100 Red-capped Plovers per day plus additional invertebrate feeding species such as Welcome Swallow and Red-necked Stint was correlated with the presence of live and dead invertebrates on wet and dry tailings and on the supernatant surface [109]. The seasonality of this food resource was unknown. Sampling revealed however that the TSF supernatant was devoid of aquatic macroinvertebrates and no successful foraging within the supernatant was observed [109]. Many species of callidrid waders such as sandpipers and stints forage by probing into muddy habitats, which resemble wet tailings. The only species recorded during this study was Red-necked Stint, which also forages by pecking at prey on the surface. No prey is expected to occur within the tailings due to its toxic nature to invertebrates.

Influences of Salinity on Solution Ingestion Rates

Many bird species utilise hypersaline environments in Australia [84] as indicated in Table 3. Species and guilds with salt glands (Table 7), as discussed above, are physiologically adapted to eliminating salt once ingested. However hypersaline environments can place such great stress on an animal's water balance that many species have either physical or behavioural adaptations to limit salt intake in the first place [206] [88]. Such physical adaptations include structures that remove excess water such as a thick tongue and bill lamellae that removes saltwater from prey before ingestion [206]. Alternatively behavioural adaptations include removing excess water through shaking prey before swallowing [88]. It is likely that as birds forage within hypersaline waters amounts ingested will be very small as animals seek to avoid dehydration caused by hypersaline water.

4.4 Influence of Salinity on Toxicity

4.4.1 Influence of Salinity and Non-Cyanide Toxicity

Hypersalinity does not automatically stop birds dying and mortality events have been recorded on hypersaline lakes due to salt toxicosis, toxicity from other contaminants such as selenium, natural mortality and botulism [130, 180-183, 207-209].

Salt toxicosis has been reported on a number of occasions in America [181], Australia [130] and Africa [210]. Hampton and Yamomoto (2002) [180] reported 354 grebes and ducks died from interaction with Searles Lake which contained water of over 600,00 mg/L salinity. Ruddy Ducks wintering on agricultural evaporation ponds with a concentration of only 39,000 mg/L of sodium have suffered from salt toxicosis [179] and in a number of waterfowl species, died from drinking water of 17 000 mg/L TDS [181]. Large-scale mortality events involving

Eared Grebes (*Podiceps nignicollis*) have been documented on hypersaline lakes of California for more than a century and attributed to adverse weather during migration and disease [211]. One particularly large mortality event involved the death of 150,000 Eared Grebes at the Salton Sea in 1992 [211] which is a high use lake for waterbirds and is approximately 44 000 mg/L TDS [212]. Australian Shelduck young have also been reported as dying from salt toxicosis due to ingestion of saline water before the full development of salt glands [130].

Salt toxicity can occur due to elevated sodium levels within the brain or salt encrustation of the feathers rendering birds unable to fly [179-181]. Additionally conjunctivitis, cataracts, myocardial and skeletal muscle degeneration, nephrosis, dehydration, bile stasis in the liver, and congestion in various organs have been described with salt toxicosis in waterfowl [181, 183, 209]. Salt toxicosis has been attributed to drought conditions or other factors such as inclement weather forcing birds to utilise hypersaline water bodies for which they were not adapted [179, 181]. The presence of food is likely to be the primary factor influencing bird use of hypersaline lakes and ponds [130, 179, 180, 213] and therefore is likely to play a primary role in mortality events from salt toxicosis. Death due to salt encrustation on feathers is understood to be related to environmental factors such as inclement weather and temperature causing wildfowl to use saline lakes in cold weather resulting in salt crystals growing on their plumage and causing incapacitation [181, 183].

Selenium toxicity has primarily been recorded in agricultural evaporation ponds in California [214-217]. Exposure is primarily through consumption of food rather than direct exposure to water [214, 217] and hence is dependant on the presence of food resources for at risk species. Salinity levels do not appear to influence selenium toxicity hence toxicity due to selenium occurs on hypersaline lakes and ponds [216, 217].

Natural background mortality in wildlife occurs on all water bodies including hypersaline lakes and ponds [218] and is influenced by many factors such as wildlife visitation rates. Botulism and other avian diseases are common and widespread and have been recorded on saline lakes [211, 219]. There may be a relationship between salinity and botulism in wildfowl for some strains of the disease [220]. Sublethal doses of botulism may kill some ducks drinking saline water because of impaired function of the salt gland caused by the disease [221].

4.4.2 Influence of Salinity on Cyanide Toxicity

Wether salinity influences the toxic effects of cyanide in an additive, less than additive, or greater than additive way is unknown and no literature was found regarding this subject.

5. Knowledge Gaps and Further Research

The exposure of insectivorous bats to mine waste solutions through foraging has not been determined. It is unlikely that insectivorous bats interact with and ingest aqueous and semi aqueous tailings solutions at the Fimiston II TSF, however, this requires further research.

6. References

1. International Cyanide Management Institute, *The international cyanide management code*. 2005, International Cyanide Management Institute. p. www.cyanidecode.org.
2. Environment Australia, *Cyanide Management: A Booklet in the Series on Best Practice Environmental Management in Mining Canberra, Environment Australia*. 2003, Canberra: Environment Australia.
3. Hagelstein, K. *The Ecotoxicological Properties of Cyanide*. in *Short Course Notes on Management of Cyanide Mining, 14-16 April, 1997*. 1997. Perth: ACMRR: Kenmore, Qld.
4. Henny, C.J., R.J. Hallock, and E.F. Hill, *Cyanide and Migratory Birds at Gold-Mines in Nevada, USA.* Ecotoxicology, 1994. **3**(1): p. 45-58.
5. Donato, D., *Bird Usage Patterns on Northern Territory Mining Water Tailings and their Management to Reduce Mortalities, Public Report*. 1999, Darwin, Northern Territory: Department of Mines and Energy. 179.
6. Sinclair, G., A. McMullen, and R. Peters. *A case study of bird mortality and cyanide management at Northparkes*. in *Short course notes on management of cyanide in mining*. 1997. Perth: Australian Centre for Minesite Rehabilitation Research.
7. Brooks, K. and J. McGlynn. *Cyanide in gold mining effluents: experiences in New South Wales*. in *Environmental Workshop*. 1987. Adelaide: Minerals Council of Australia, Dickson ACT, 1987.
8. Donato, D., *Draft; An Assessment of Wildlife Cyanosis Risks in the Residual Retention Area: Boddington Gold Mine*. 2007, Donato Environmental Services: Darwin.
9. Minerals Council of Australia, *Tailings storage facilities at Australia gold mines; Submission to the Senate Environment, Recreation, Communication and the Arts Reference Committee*. 1996, Minerals Council of Australia: Melbourne.
10. Staunton, P. and K. Jones. *Disposal of cyanide containing tailings*. in *Environmental Workshop*. 1989. Ballarat: Australian Mining Industry Council.
11. Botz, M., et al., *Cyanide: An overview of cyanide treatment and recovery methods.* Mining Environmental Management, 1995. **3**(2): p. 4-16.
12. Ou, B. and A. Zaidi, *Natural degeneration.* Mining Environmental Management, 1995. **June**: p. 5-6.
13. Franson, M.H., *Standard methods for the examination of water and wastewater*, Franson, Editor. 1992, American Public Health Association, American Water Works Association, Water Environment Federation: Washington, DC.
14. Minerals and Research Institute of Western Australia, *Cyanide waste management*, P. Lye, Editor. 2000, AMIRA: Perth.
15. Smith, A. and T. Mudder, *Chemistry and Treatment of Cyanidation Wastes*. 1991, London: Mining Journal Books.
16. Smith, A. and T. Mudder, *Cyanide; Dispelling the myth.* Mining Environmental Management, 1995. **June**: p. 4-5.
17. Schulz, R.S. *Basic chemistry and geochemistry*. in *Management of Cyanide in Mining*. 1997. Perth: ACMRR.

18. Environment Australia, *Cyanide Management: A Booklet in the Series on Best Practice Environmental Management in Mining*. 1998, Canberra: Environment Australia.
19. Donato, D. *Wildlife protection and practical approaches*. in *Cyanide management and use for the gold industry*. 2003. Parkes, NSW: ACMER.
20. Resource Assessment Commission, *Kakadu Conservation Zone Inquiry; Final report volume 2*, R.A. Commission, Editor. 1991, Australian Government Publishing Services: Canberra.
21. Northern Territory Bird Study Group, *Best Practice Guidelines; Reducing Impacts of Tailings Storage Facilities on Avian Wildlife in the Northern Territory of Australia*. 1998: Department of Mines & Energy, Darwin, Northern Territory.
22. Duffy, A.M., et al., *The efficacy of Anabat ultrasonic detectors and harp traps for surveying microchiropterans in south-eastern Australia.* Acta Chiropterologica, 2000. **2**(2): p. 127-144.
23. Clark, D.R., E.F. Hill, and P.F.P. Henry, *Comparative sensitivity of little brown bats (Myotis lucifugus) to acute dosages of sodium cyanide.* Bat Research News, 1991. **32**: p. 68.
24. Clark, D.R. and R.L. Hothem, *Mammal mortality at Arizona, California, and Nevada gold mines using cyanide extraction.* California Fish and Game, 1991. **77**(2): p. 61-69.
25. O'Shea, T.J., D.R. Clark, and T.P. Boyle, *Impacts of mine-related contaminants on bats*, in *Bat Conservation and Mining*, K.C.T. Vories, D. Alton. IL, Editor. 2001, Office of Surface Mining, U.S. Department of the Interior.: Alton, IL. p. 205-216.
26. Bassett, J.E. and E.H. Studier, *Methods for determining water balance in bats.*, in *Ecological and Behavioural Methods for the Study of Bats*, T.H. Kunz, Editor. 1988, Smithsonian Institution Press: Washington D.C. p. 373-386.
27. Smith, G.B., et al., *Ecology of a goldmining tailings facility in the Eastern Goldfields of Western Australia; A case study.* International Journal of Mining, Reclamation and Environment (In lit.), 2007.
28. Brown, P.E. and R.D. Berry. *Bats: habitat, impacts and mitigation.* in *Proceedings in Issues and Technology in the Management of Impacted Wildlife*. 1991. Snowmass, CO.: Thorne Ecological Institute.
29. Clark, D.R., *Where a drink of water may mean death: gold isn't the only legacy from mines.* California Fish and Game, 1991. **77**(3): p. 17-18.
30. Clark, D.R. and R.F. Shore, *Chiroptera*, in *Ecotoxicology of Wild Mammals*, R.F. Shore and B.A. Rattner, Editors. 2001, John Wiley & Sons Ltd.: London. p. 159-214.
31. Ryan, P. and R. Shanks, *Tailings Dams.* The Bird Observer, 1996. **July 1996**: p. 7-11.
32. Dames & Moore, *The Century Project : draft impact assessment study report*. 1994, Spring Hill, Qld.: Century Zinc. 3 v.
33. South Africa Chamber of Mines, *South African Guideline on Cyanide Management for Gold Mining*, G.P. Committee, Editor. 2001, Chamber of Mines of South Africa: Johannesburg.

34. The Mining Association of Canada, *A guideline to the management of tailings facilities*, The Mining Association of Canada, Editor. 1998, The Mining Association of Canada,: Ottawa.
35. Sadler, R., *Cyanide in gold processing wastewaters.* Water talk, 1989: p. 2-3.
36. Akcil, A., *First application of cyanidation process in Turkish gold mining and its environmental impacts.* Minerals Engineering, 2002. **15**(9): p. 695~699.
37. Akcil, A. and T. Mudder, *Microbial destruction of cyanide wastes in gold mining: process review.* Biotechnology Letters, 2003. **25**(6): p. 445~450.
38. Bernoth, L., et al., *Biotechnologies for remediation and pollution control in the mining industry.* Minerals & Metallurgical Processing, 2000. **17**(2): p. 105~111.
39. Carrillo-Pedroza, F.R., F. Nava-Alonso, and A. Uribe-Salas, *Cyanide oxidation by ozone in cyanidation tailings: Reaction kinetics.* Minerals Engineering, 2000. **13**(5): p. 541~548.
40. Stevenson, P.E., et al. *Recovery of Cyanide from mill tailings*. in *Short course notes on Management of Cyanide in Mining*. 1997. Perth: ACMRR.
41. Hallock, R.J. *Elimination of migratory bird mortality at gold and silver mines using cyanide extraction*. in *Nevada Wildlife/Mining Workshop*. 1990. Reno, Nevada: Nevada Mining Association.
42. Jeffress, W.R. *Waterfowl hazing techniques*. in *Nevada Wildlife/Mining Workshop*. 1990. Reno Nevada: Nevada Mining Association.
43. Department of Mineral Resources, *Bird deaths at Northparkes.* Minfo, 1996. **51**: p. 22-23.
44. Olsen, P. and M. Weston, *The State of Australia's Birds 2004, Water, Wetlands and Birds.* Wingspan, 2004. **14**(4): p. Supplement.
45. Reece, R. *Cyanide toxicity to birds*. in *Short course notes on Management of Cyanide Mining*. 1997. Perth: ACMRR.
46. Eisler, R., *Cyanide Hazards to Fish Wildlife and Invertebrates a Synoptic Review.* U S Fish and Wildlife Service Biological Report, 1991. **85**(123): p. 1-55.
47. Duke, G.E., Jegers, A. A., Loff, G. and Evanson, O. A., *Gastric digestion in some raptors.* Comparative Biochemistry and Physiology, 1975. **50A**: p. 649-656.
48. Kehoe, F.P. and C.D. Ankney, *Variation in digestive organ size among five species*

of diving ducks (Aythya spp.). . Can. J. Zool., 1985. **63**: p. 2339-2342.
49. Thouzeau, C., et al., *Adjustments of gastric pH, motility and temperature during long-term preservation of stomach contents in free-ranging incubating king penguins.* The Journal of Experimental Biology, 2004. **207**: p. 2715 - 2724.
50. Wiemeyer, S.T., et al., *Acute Oral Toxicity of Sodium Cyanide in Birds.* Journal of Wildlife Diseases, 1986. **22**(4): p. 538-46.
51. Ballantyne, B., *Toxicology of Cyanides*, in *Clinical and Experimental Toxicology of Cyanides*, B. Ballantyne and T.C. Marrs, Editors. 1987, Wright Publishers: Bristol, UK.

52. Donato, D.B., et al., *A critical review of the risk assessment of the effects of gold cyanide-bearing tailings solutions on wildlife.* Environment International, 2007. **33**: p. 974-984.
53. Seawright, A.A., *Metals, metalloids and other inorganic substances*. Animal Health in Australia Volume 2 (Second Edition) Chemical and Plant Poisons. 1989, Canberra, Australia: Australian Government Publishing Services.
54. Dey, P.M., et al., *Developmental lead exposure disturbs expression of synaptic neural cell adhesion molecules in herring gull brains.* Toxicology, 2000. **146**: p. 137-147.
55. Garcia-Arribas, O., et al., *Metallothionein as bioindicator of cadmium toxicity in rat liver[Deteccion de la exposicion al plomo mediante analisis de metalotioneina hepatica por electroforesis capilar].* Anales de la Real Academia de Farmacia, 1998. **64**(4): p. 599-614.
56. Damek-Poprawa, M. and K. Sawicka-Kapusta, *Damage to the liver, kidney and testis with reference to burden of heavy metals in yellow-necked mice from areas around steelworks and zinc smelters in Poland.* Toxicology, 2003. **186**(1-2): p. 1-10.
57. Mateo, R. and R. Guitart, *Heavy metals in livers of waterbirds from Spain.* Archives of Environmental Contamination and Toxicology, 2003. **44**(3): p. 398-404.
58. Scheuhammer, A.M. and D.M. Templeton, *Metallothionein production: similar responsiveness of avian liver and kidney to chronic cadmium administration.* Toxicology, 1990. **60**(1-2): p. 151-159.
59. Scheuhammer, A.M., et al., *Relationships between lake chemistry and calcium and trace metal concentrations of aquatic invertebrates eaten by breeding insectivorous waterfowl.* Environmental Pollution, 1997. **96**(2): p. 235-247.
60. Janssens, E., et al., *Breeding performanceof Great Tits (Parus major) along a gradient of heavy metal pollution.* Environmental Toxicology and Chemistry, 2003. **22**(5): p. 1140-1145.
61. ANZECC, *An introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. 2000, Australian and New Zealand Environment and Conservation Council.
62. Baron, L.A., et al., *Monitoring bioaccumulation of contaminants in the belted kingfisher (Ceryle alcyon).* Environmental Monitoring and Assessment, 1997. **47**(2): p. 153-165.
63. Pascoe, G.A., R.J. Blanchet, and G. Linder, *Food chain analysis of exposures and risks to wildlife at a metals-contaminated wetland.* Archives of Environmental Contamination and Toxicology, 1996. **30**(3): p. 306-318.
64. Plumlee, K.H., *Clinical Veterinary Toxicology*. 2004, St Louis, Missouri: Mosby. 210 p.
65. Dowsett, R., *Acid Ingestion (treatment guide)*, in *IPCS INTOX Databank*. 1998.
66. CCOHS, *Health Effects of Sulfuric Acid*, in *Canada's National Occupational Health and Safety Resource*. 1998.
67. ATSDR, *Toxicological Profile for Sulfur Trioxide and Sulfuric Acid*, in *U.S. Department of Health and Human Services, Public Health Services, Agency for Toxic Substances and Disease Registry*. 1998.

68. Yanez, L., et al., *Arsenic-cadmium interaction in rats: toxic effects in the heart and tissue metal shifts.* Toxicology, 1991. **67**(2): p. 227-234.
69. Eisler, R., *Cyanide*, in *Handbook of Chemical Risk Assessment: Health Hazards to Humans, Plants, and Animals.*, R. Eisler, Editor. 2000, Lewis Publishers. p. 903-952.
70. Alabaster, J.S., D.G. Shurben, and M.J. Mallett, *The acute lethal toxicity of mixtures of cyanide and ammonia to smolts of salmon, Salmo salar L. at low concentrations of dissolved oxygen.* Jour. Fish Biol., 1983. **22**: p. 215-222.
71. Leduc, G., *Cyanides in water: toxicological significance.*, in *Aquatic Toxicology*, L.J. Weber, Editor. 1984, Raven Press: New York. p. 153-224.
72. Leduc, G., R.C. Pierce, and I.R. McCracken, *The Effects of Cyanides on Aquatic Organisms with Emphasis upon Freshwater Fishes.* 1982, Natl. Res. Coun. Canada: Ottawa. p. 139.
73. Smith, L.L., et al., *Acute and Chronic Toxicity of HCN to Fish and Invertebrates.* 1979, U.S. Environ. Protection Agen. p. 129.
74. Towill, L.E., et al., *Reviews of the Environmental Effects of Pollutants.V. Cyanide.* 1978, U.S. Environ. Protection Agen. p. 191.
75. Doudoroff, P., *Some experiments on the toxicity of complex cyanides to fish.* Sewage Industr. Wastes, 1956. **28**: p. 1020-1040.
76. Furness, R.W., *Cadmium in birds*, in *Environmental contaminants in wildlife, Interpreting tissue concentrations. Society of Environmental Toxicology and Chemistry special publication.*, W.N. Beyer, G.H. Heinz, and A.W. Redmond-Norwood, Editors. 1996, CRC Press: Boca Raton, Florida. p. 389-404.
77. Cliplef, D.J. and G. Wobeser, *Observations on waterfowl carcasses during a botulism epizootic.* Journal of Wildlife Diseases, 1993. **29**: p. 8–14.
78. Linz, G., et al., *Estimating survival of bird carcasses in cattail marshes.* Wildlife Society Bulletin, 1991. **19**: p. 195–199.
79. Philibert, H., G. Wobeser, and R.G. Clark, *Counting dead birds: examination of methods.* J Wildl Dis., 1993. **29**(Apr (2)): p. 284-9.
80. Kostecke, R.M., G.M. Linz, and W.J. Bleier, *Survival Of Avian Carcasses And Photographic Evidence Of Predators And Scavengers.* J. Field Ornithol., 2001. **72**((3)): p. 439–447.
81. Williams, W.D., A.J. Boulton, and R.G. Taafe, *Salinity as a determinant of salt lake fauna: a question of scale.* Hydrobiologia, 1990. **197**: p. 257-266.
82. Pinder, A.M., et al., *Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity.* Hydrobiologia, 2005. **543**: p. 1-24.
83. Harper, D.M., et al., *Aquatic biodiversity and saline lakes: Lake Bogoria National Reserve, Kenya.* Hydrobiologia, 2003. **500**: p. 259–276.
84. Williams, W.D., *Salinity as a determinant of the structure of biological communities in salt lakes.* Hydrobiologia, 1998. **381**: p. 191-201.
85. Smith, G.B., *Bird assemblages and breeding extent at Sunrise Dam.* 2005, Donato Environmental Services: Darwin.
86. Geddes, M.C., et al., *On the chemistry and biota of some saline lakes in Western Australia.* Hydrobiologia : . 1981. **82**: p. 201-222.

87. Brock, M.A. and R.J. Shiel, *The composition of aquatic communities in saline wetlands in Western Australia.* Hydrobiologia, 1983. **105**: p. 77-84.
88. Goodsell, J.T., *Distribution of Waterbird Broods Relative to Wetland Salinity and pH in South-western Australia.* Australian Wildlife Research, 1990. **17**: p. 219-29.
89. Brock, M.A. and J.A.K. Lane, *The aquatic macrophyte flora of saline wetlands in Western Australia in relation to salinity and permanence.* Hydrobiologia, 1983. **105**: p. 63-76.
90. Hudson, P., *Sympatric distribution of an Australian salt lake wolf spider and scorpion.* Int. J. Salt Lake Res, 1997. **6**: p. 1–3.
91. De Deckker, P., *Australian salt lakes: their history, chemistry, and biota - a review.* Hydrobiologia, 1983. **105**: p. 231-244.
92. Kingsford, R.T., *Occurrence of high concentrations of waterbirds in arid Australia.* Journal of Arid Environments, 1995. **29**: p. 421-425.
93. Kingsford, R.T. and J.L. Porter, *Waterbirds Of Lake Eyre, Australia.* Biological Conservation, 1993. **65**: p. 141-151.
94. Williams, W.D., P. De Deckker, and R.J. Shiel, *The limnology of Lake Torrens, an episodic salt lake of central Australia, with particular reference to unique events in 1989.* Hydrobiologia, 1998. **384**: p. 101-110.
95. Marchant, S. and P.J. Higgins, *Handbook of Australian, New Zealand and Antarctic Birds*. Vol. 2: Raptores to Lapwings. 1993, Melbourne: Oxford University Press.
96. Roshier, D.A., et al., *Continental-scale interactions with temporary resources may explain the paradox of large populations of desert waterbirds in Australia.* Landscape Ecology, 2001. **16**: p. 547–556.
97. Timms, B.V., *The biology of the saline lakes of central and eastern inland of Australia: a review with special reference to their biogeographical affinities.* Hydrobiologia, 2007. **576**: p. 27–37.
98. Timms, B.V., *A comparison between saline and freshwater wetlands of Bloodwood Station, the Paroo, Australia, with special reference to their use by waterbirds.* International journal of salt lake research, 1997. **5**(4): p. 287 - 313.
99. Wilson, S. and G. Swan, *A complete Guide to the Reptiles of Australia*. 2003, Sydney: New Holland. 480.
100. Cunha, T.J., *Animal Feeding Nutrition: A Series Of Monographs.* 1989, New York, NY.: Academic Press, Inc.
101. Eisler, R., et al., *Sodium cyanide hazards to fish and other wildlife from gold mining operations.*, in *Environmental Impacts of Mining Activities: Emphasis on Mitigation and Remedial Measures.*, J.M. Azcue, Editor. 1999, Springer-Verlag: Berlin. p. 55-67.
102. Ma, Z., et al., *Are artificial wetlands good alternatives to natural wetlands for waterbirds? - A case study on Chongming Island, China.* Biodiversity and Conservation, 2004. **13**(2): p. 333-350.
103. Leach, G.J., *Effects of dam size on waterbirds at farm dams in South-east Queensland.* Corella, 1994. **18**(3): p. 77-82.
104. Roshier, D.A., A.I. Robertson, and R.T. Kingford, *Responses of waterbirds to flooding in an arid region of Australia and implications for conservation.* Biological Conservation, 2002. **106**: p. 399-411.

105. Davies, S.J.J.F., *Results of 40 hours' continuous watch at five waterpoints in an Australian desert.* Emu, 1972. **72**(1): p. 8-l 2.
106. Fisher, C.D., E. Lindgren, and W.K. Dawson, *Drinking patterns and behaviour of Australian desert birds in relation to their ecology and abundance.* Condor, 1972. **74**(111 - 136).
107. Churchill, S., *Australian Bats*. 1998, Melbourne: Reed New Holland.
108. Donato, D.B., et al., *Influences of gold mine tailings and hypersalinity on wildlife ingestion of solutions and cyanosis: a hypothesis and model.* International Journal of Mining, Reclamation and Environment, 2007. **In Press**.
109. Smith, G.B., et al., *Ecology of a goldmining tailings facility in the Eastern Goldfields of Western Australia; A case study.* International Journal of Mining, Reclamation and Environment (*in press.*), 2007.
110. Brunet, B., *Australian Insects: a natural history*. 2000, Sydney: New Holland Publishers.
111. Ehrlich, P.R., et al., *The Birdwatcher's Handbook: A guide to the natural history of the birds of Britain and Europe,*. 1994, Oxford: Oxford University Press.
112. Souren, A.W.M.G., *Living with cyanide*, in *The Geochemical News*. 2000. p. 16-26.
113. Simovic, L., et al. *Development of a model to describe the natural degradation of cyanide in gold milling effluents*. in *Cyanide and the Environment*. 1985. Tucson Arizona: Colorado State University.
114. John, C.D., *Residue and cyanide management at the Boddington Gold Mine.* 1988.
115. Longe, G.R. and F.W. Devries. *Some recent considerations on the natural degradation disappearance of cyanide*. in *Workshop of Economics and Practice of Heap Leaching in Gold Mining*. 1988. Cairns: Australasian Institute of Mining and Metallurgy.
116. Sadler, R., *The fate of cyanide in the gold processing industry.* Australian Science Magazine, 1990. **1**: p. 51-52.
117. Schmidt-Nielson, K., *Salt Glands*, in *Birds; Readings from Scientific American*, W. B., Editor. 1959, Scientific American: San Francisco. p. 186 - 191.
118. ANZECC/NHMRC, *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites.* 1992, Australian New Zealand Environment and Conservation Council / National Health and Medical research Council: Canberra.
119. Kurta, A., *Bats on the surface: the need for shelter, food, and water.*, in *Bat Conservation and Mining*, K.C. Vories and D. Throgmorton, Editors. 2001, Office of Surface Mining, U.S. Department of the Interior: Alton. IL. p. 197-204.
120. Adams, R.A. and J.A. Simmons, *Directionality of drinking passes by bats at water holes: is there cooperation?* Acta Chiropterologica, 2002. **4**(2): p. 195-99.
121. Codd, J., B. Clark, and K. Sanderson, *Drinking by the Common Bent-wing Bat Miniopterus schreibersii and Calcium in Cave Water.* Bat Research News (Adelaide, South Australia), 1999. **40**(1 (Spring)): p. 9-10.

122. del Hoyo, J., A. Elliott, and J. Sargatal, *Handbook of the Birds of the World*. Vol. 1. 1992, Barcelona: Lynx Edicions.
123. Schmidt-Nielsen, K. and Y.T. Kim, *The effect of salt intake on the size and function of the salt gland of ducks.* The Auk, 1964. **81**(April): p. 160-172.
124. Bennett, D.C. and M.R. Hughes, *Comparison of renal and salt gland function in three species of wild ducks.* J. Exp. Biol. Rev., 2003. **206**: p. 3273–3284.
125. Purdue, J.R. and H. Haines, *Salt Water Tolerance And Water Turnover In The Snowy Plover.* Auk, 1977. **94**((2): April-June): p. 248-255.
126. Marchant, S. and P.J. Higgins, *Handbook of Australian, New Zealand and Antarctic Birds*. Vol. 1: Ratites to Ducks. 1990, Melbourne: Oxford University Press.
127. Higgins, P.J. and S.J.J.F. Davies, *Handbook of Australian, New Zealand and Antarctic Birds*. Vol. 3: Snipe to Pigeons. 1996, Melbourne: Oxford University Press.
128. Cade, T.J. and L. Greenwald, *Nasal Salt Secretion in Falconiform Birds.* Condor, 1966. **68**((4): July-August): p. 338-350.
129. Frings, H. and M. Frings, *Observations on Salt Balance and Behavior of Laysan and Black-footed Albatrosses in Captivity.* Condor, 1959. **61**((5): September-October): p. 305-314.
130. Riggert, T.L., *The biology of the mountain duck on Rottnest Island, western Australia.* Wildlife Monographs, 1977. **52**: p. 1-67.
131. Halse, S.A., et al., *Wetland Characteristics and Waterbird Use of Wetlands in South-western Australia.* Wildlife Research, 1993. **20**: p. 103-26.
132. Baudinette, R.V., Norman F. I., and J. Roberts, *Salt Gland Secretion in Saline-Acclimated Chestnut Teal, and its Relevance to Release Programs.* Aust. J. Zool., 1982. **30**: p. 407-415.
133. Jesson, R.A. and G.L. Maclean, *Salt Glands in neonatal Australian Pratincole.* Emu, 1976. **76**(October): p. 227.
134. Maclean, G.L., *Field study of Australian Dotterel.* Emu, 1976. **76**(October): p. 207-215.
135. Harriman, A.E. and M.R. Kare, *Aversion to saline solutions in starlings, purple grackles, and herring gulls.* Physiol. Zool., 1966. **39**: p. 123–126.
136. Sabat, P., *Birds in marine and saline environments: living in dry habitats.* Revista Chilena de Historia Natural, 2000. **73**(3, Santiago set).
137. Sabat, P., J.M. Fariña, and M. Soto-Gamboa, *Terrestrial birds living on marine environments: does dietary composition of Cinclodes nigrofumosus (Passeriformes: Furnariidae) predict their osmotic load?* Revista Chilena de Historia Natural, 2003. **76**: p. 335-343.
138. Skadhauge, E., *A quantitative survey of salt and water excretion.* Comparative biochemistry and physiology. A, Comparative physiology, 1982. **71**(4): p. 481.
139. Oksche, A., et al., *The hypothalamo-hypophyseal neurosccretory system of the Zebra Finch, Tasniopygia castanotis.* Z. Zelljorsch., 1963. **58**: p. 846-914.
140. Poulson, T.L. and G.A. Bartholomew, *Salt Utilization in the House Finch.* Condor, 1962. **64**((4): July-August): p. 245-252.

141. Skadhauge, E. and S.D. Bradshaw, *Saline drinking and cloacal excretion of salt and water in the zebra finch.* American Journal Of Physiology, 1974. **227**(6, December): p. 1263-1267.
142. McNabb, F.M.A., *A comparative study of water balance in three species of quail-II. Utilization of saline drinking solutions.* Comparative Biochemistry and Physiology, 1969. **28**(3 , March): p. 1059-1074.
143. MacMillen, R.E. and C.H. Trost, *Water Economy And Salt Balance In White-Winged And Inca Doves.* Auk, 1966. **83**((3): July-September): p. 441-456.
144. Smyth, M. and G.A. Bartholomew, *The Water Economy of the Black-throated Sparrow and the Rock Wren.* Condor, 1966. **68**((5): September-October): p. 447-458.
145. Ohmart, R.D. and E.L. Smith, *Use Of Sodium Chloride Solutions By The Brewer's Sparrow And Tree Sparrow.* Auk:, 1970. **87**((2): April-June): p. 329-341.
146. Poulson, T.L., *Salt And Water Balance In Seaside And Sharp-Tailed Sparrows.* Auk, 1969. **86**(3, July-September): p. 473-489.
147. Cade, T.J. and J.A. Dybas, *Water Economy Of The Budgerygah.* Auk, 1962. **79**((3): July-September): p. 345-364.
148. Skadhauge, E., *Cloacal reabsorption of salt and water in the galah (Cacatua roseicapilla).* J Physiol Lond, 1974. **240**: p. 763-773.
149. Skadhauge, E., S.K. Maloney, and T.J. Dawson, *Osmotic adaptation of the emu (Dromaius novaehollandiae).* J Comp Physiol B, 1991. **161**: p. 173-178.
150. Sturkie, P.D., *Alimenary canal: Anatomy, Prehension, Deglutition, Feeding, Drinking, Passage of Ingesta, and Motility*, in *Avian Physiology*, P.D. Sturkie, Editor. 1976a, Springer-Verlag: New York. p. 185-195.
151. Bartholomew, G.A. and T.J. Cade, *The Water Economy of Land Birds.* Auk, 1963. **80**(4): p. 504-539.
152. Tieleman, B.I. and J.B. Williams, *The Adjustment of Avian Metabolic Rates and Water Fluxes to Desert Environments.* Physiological & Biochemical Zoology, 2000. **73**(4): p. 461.
153. Tieleman, B.I., J.B. Williams, and P. Bloomer, *Adaptation of Metabolism and Evaporative Water Loss along an Aridity Gradient.* Proceedings: Biological Sciences, 2003. **270**(1511): p. 207-214.
154. Evans, S.M., R. Neems, and C. Pagendam, *Drinking Skills in Estrildid Finches.* Emu, 1989. **89**: p. 177-181.
155. Evans, R.M. and K.J. Cash, *Early spring flights of American white pelicans: timing and functional role in attracting others to the breeding colony.* Condor, 1985. **87**(2).
156. Marom, S., et al., *Energy metabolism and evaporative water loss in the European free-tailed bat and Hemprich's long-eared bat (Michrochiroptera): species sympatric in the Negev Desert.* Physiological and Biochemical Zoology, 2006. **79**(5): p. 944-956.
157. Carpenter, R.E., *Structure and function of the kidney and the water balance of desert bats.* Physical Zoology, 1968. **42**: p. 288-302.
158. Geluso, K.N., *Urine concentrating ability and renal structure of insectivorous bats.* Journal of Mammalogy, 1968. **59**(2): p. 312-323.

159. Krausman, P.R., S.S. Rosenstock, and J.W. Cain, *Developed waters for wildlife: science, perception, values, and controversy.* Wildlife Society Bulletin, 2006. **34**(3): p. 563-569.
160. Neuweiler, G., *The Biology of Bats*. 2000, Oxford: Oxford University Press. 310.
161. O'Farrell, M.J., E.H. Studier, and W.G. Ewing, *Energy utilization and water requirements of captive Myotis thysanodes and Myotis lucifugus (Chiroptera).* Comparative Biochemistry and Physiology, 1971. **39A**: p. 549-552.
162. Studier, E.H. and M.J. O'Farrell, *Biology of Myotis thysanodes and M. lucifugus (Chiroptera: Vespertilionidae)-III. Metabolism, heart rate, breathing rate, evaporative water loss and general energetics.* Comparative Biochemistry and Physiology, 1976. **54A**: p. 423-432.
163. Studier, E.H., J.W. Procter, and D.J. Howell, *Diurnal body weight loss and tolerance of weight loss in five species of Myotis.* Journal of Mammalogy, 1970. **51**(2): p. 302-309.
164. Webb, P.I., *The comparative ecophysiology of water balance in microchiropteran bats.*, in *In Ecology, Evolution, and Behaviour of Bats.*, P.A. Racey and S.M. Swift, Editors. 1995, Clarendon Press: Oxford. p. 203-216.
165. Webb, P.I., J.R. Speakman, and P.A. Racey, *Evaporative water loss in two sympatric species of vespertilionid bat, Plecotus auritus and Myotis daubentoni: relation to foraging mode and implications for roost site selection.* Journal of Zoology (London), 1995. **235**: p. 269-278.
166. Adams, R.A., et al., *Calcium as a limiting resource to insectivorous bats: can water holes provide a supplemental mineral source?* Journal of Zoology (London), 2003. **260**: p. 189-194.
167. Kurta, A., et al., *Water balance of free-ranging little brown bats (Myotis lucifugus) during pregnancy and lactation.* Canadian Journal of Zoology, 1989. **67**: p. 2468-2472.
168. Kurta, A., T.H. Kunz, and K.A. Nagy, *Energetics and water flux of free-ranging big brown bats (Eptesicus fuscus) during pregnancy and lactation.* Journal of Mammalogy, 1990. **71**(1): p. 59-65.
169. McLean, J.A. and J.R. Speakman, *Energy budgets of lactating and non-reproductive brown long-eared bats (Plecotus auritus) suggest females use compensation in lactation.* Functional Ecology, 1999. **13**: p. 360-372.
170. Adams, R.A. and K.M. Thibault, *Temporal resource partitioning by bats at water holes.* Journal of Zoology (London), 2006. **270**: p. 466-472.
171. Tuttle, S.R., C.L. Chambers, and T.C. Theimer, *Potential effects of livestock water-trough modifications on bats in northern Arizona.* Wildlife Society Bulletin, 2006. **34**(3): p. 602-608.
172. Adams, R.A., *Consumption of water boatmen (Hemiptera: Corixidae) by little brown bats, Myotis lucifugus.* Bat Research News, 1993. **34**(2): p. 66-67.
173. Geluso, K., *Winter activity of bats over water and along flyways in New Mexico.* The Southwestern Naturalist, 2007. **52**(4): p. 482-492.
174. Meyer, C.F.J., M. Weinbeer, and E.K.V. Kalko, *Home-Range Size And Spacing Patterns Of Macrophyllum Macrophyllum (Phyllostomidae) Foraging Over Water.* Journal of Mammalogy, 2005. **86**(3): p. 587.

175. Park, K.J. and A. Christinacce, *Use of sewage treatment works as foraging sites by insectivorous bats.* Animal Conservation, 2006. **9**: p. 259-268.
176. Siemers, B.M., P. Stiltz, and H.-U. Schnitzler, *The acoustic advantage of hunting at low heights above water: behavioural experiments on the European 'trawling' bats Myotis capaccinii, M. dasycneme and M. daubentonii.* The Journal of Experimental Biology, 2001. **204**: p. 3843-3854.
177. Vahter, M., *Species-Differences in the Metabolism of Arsenic Compounds.* Applied Organometallic Chemistry, 1994. **8**(3): p. 175-182.
178. Vaughan, N., G. Jones, and S. Harris, *Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers.* Biological Conservation, 1996. **78**: p. 337-343.
179. Gordus, A.G., H.L. Shivaprasad, and P.K. Swift, *Salt toxicosis in ruddy ducks that winter on an agricultural evaporation basin in California.* J. Wildl. Dis, 2002. **38**(1): p. 124-131.
180. Hampton, S. and J. Yamamoto, *Assessment of Natural Resource Injuries to Birds at Searles Lake, 1998 to 2001.* 2002, California Department of Fish and Game.
181. Windingstad, R.M., F.X. Kartch, and R.K. Stroud, *Salt toxicosis in waterfowl in North Dakota.* Journal of Wildlife Diseases, 1987. **23**: p. 443-446.
182. Stolley, D.S. and C.U. Meteyer, *Peracute Sodium Toxicity in Free-ranging Black-bellied Whistling Duck Ducklings.* Journal of Wildlife Diseases, 2004. **40**((3)): p. 571–574.
183. Meteyer, C.U., et al., *Sodium toxicity and pathology associated with exposure of waterfowl to hypersaline playa lakes of southeast New Mexico.* Journal of Veterinary Diagnostic Investigations, 1997. **9**: p. 269-280.
184. Ziswiler, V. and D.S. Farner, *Digestion and digestive system*, in *Avian Biology*, D.S. Farner and J.R. King, Editors. 1972, Academic Press: London. p. 343.
185. Hilton, G.M., R.W. Furness, and D.C. Houston, *The effects of diet switching and mixing on digestion in seabirds.* Functional Ecology, 2000. **14**(2): p. 145-154.
186. Battley, P.F. and T. Piersma, *Adaptive Interplay Between Feeding Ecology and Features of the Digestive Tract in Birds*, in *Physiological and Ecological Adaptations to Feeding in Vertebrates*, J.M. Starck and T. Wang, Editors. 2005, Enfield: New Hampshire. p. 201-228.
187. Sturkie, P.D., *Secretion of Gastric and Pancreatic Juice, pH of Tract, Digestion in Alimentary Canal, Liver and Bile, and Absorption.*, in *Avian Physiology*, P.D. Sturkie, Editor. 1976b, Springer-Verlag: New York. p. 196-209.
188. Peters, G., *A new device for monitoring gastric pH in free-ranging animals.* American Journal of Physiology, 1997. **273**: p. 748-753.
189. Stein, R.W., et al., *Digestive Organ Sizes and Enzyme Activities of Refueling Western Sandpipers (Calidris mauri): Contrasting Effects of Season and Age.* Physiological & Biochemical Zoology, 2005. **78**(3): p. 434-446.

190. Gilardi, J.D., et al., *Biochemical functions of geophagy in parrots: detoxification of dietary toxins and cytoprotective effects.* Journal of Chemical Ecology, 1999. **25**(4): p. 897-922.
191. Rouk, C.S. and B.P. Glass, *Comparative gastric histology of five North and Central American bats.* Journal of Mammalogy, 1970. **51**(3): p. 455-471.
192. Dumont, E.R., *Salivary pH and buffering capacity in frugivorous and insectivorous bats.* Journal of Mammalogy, 1997. **78**(4): p. 1210-1219.
193. Forman, G.L., *Comparative morphological and histochemical studies of stomachs of selected American bats.* The University of Kansas Science Bulletin, 1972. **159**: p. 591-729.
194. Scillitani, G., et al., *Lectin histochemistry of gastrointestinal glycoconjugates in the greater horseshoe bat, Rhinolophus ferrumequinum (Schreber, 1774).* Acta Histochemica, 2007. **109**: p. 347-357.
195. Ishikawa, K., et al., *Anatomical study of the intestine of the insectfeeder bat, Myotis frater kaguae.* Journal of Anatomy, 1985. **142**: p. 141-150.
196. Okon, E., *Functional anatomy of the alimentary canal in the fruit bat, Eidolon helvum, and the insect bat, Tadarida nigeriae.* Acta Zoologica, 1977. **58**: p. 83-93.
197. Keegan, D.J., *Aspects of the assimilation of sugars by Rousettus aegypticus.* Comparative Biochemistry and Physiology. Part A. Physiology., 1977. **58**(4): p. 349-352.
198. Morris, S., A.L. Curtin, and M.B. Thompson, *Heterothermy, torpor, respiratory gas exchange, water balance and the effect of feeding in Gould's long-eared bat, Nyctophilus gouldi.* Journal of Experimental Biology, 1994. **197**: p. 309-335.
199. Tedmand, R.A. and L.S. Hall, *The morphology of the gastrointestinal tract and food transit time in fruit bats Pteropus alecto and P. poliocephalus (Megachiroptera).* Australian Journal of Zoology, 1985. **33**: p. 625-640.
200. Swartz, S.M., P.W. Freeman, and E.F. Stockwell, *Ecomorphology of bats: comparative and experimental approaches relating structural design to ecology*, in *Bat Ecology*, T.H. Kunz and M.B. Fenton, Editors. 2003, University of Chicago Press: Chicago. p. 257-300.
201. Donato, D.B. and S.R. Griffiths, *Wildlife Interactions with Tailings and Cyanosis Risks: Toward Compliance with the International Cyanide Management Code, Superpit*. 2006, Donato Environmental Services: Darwin.
202. Fukui, D., et al., *Effect of emergent aquatic insects on bat foraging in riparian forest.* Journal of Applied Ecology, 2006. **75**: p. 1252-1258.
203. Hayes, J.P., *Temporal variation in activity of bats and the design of echolocation-monitoring studies.* Journal of Mammalogy, 1997. **78**(2): p. 514-524.
204. Abensperg-Traun. M. and C.R. Dickman, *Distributional Ecology of Red-Capped Plover, Charadrius Ruficapillus (Temminck, 1822), on Western Australian Salt Lakes.* Journal of Biogeography, 1989. **16**(2): p. 151-157.
205. Diamond, A.W., *Impacts Of Acid Rain On Aquatic Birds.* Environmental Monitoring and Assessment, 1989. **12**: p. 245-254.

206. Mahoney, S.A. and J.R. Jehl, *Adaptations of migratory shorebirds to highly saline and alkaline lakes: Wilson's Phalarope and Ameriacn Avocet.* The Condor, 1985. **87**: p. 520-527.
207. Mitcham, S.A. and G. Wobeser, *Toxic Effects Of Natural Saline Waters On Mallard Ducklings.* Journal of Wildlife Diseases, 1988. **24**(1): p. 45-50.
208. Bollinger, T.K., P. Mineau, and M.L. Wickstrom, *Toxicity Of Sodium Chloride To House Sparrows (Passer Domesticus).* Journal of Wildlife Diseases, 2005. **41**(2): p. 363–370.
209. Wobeser, G. and J. Howard, *Mortality of waterfowl on a hypersaline wetland as a result of salt encrustation.* Journal of Wildlife Diseases, 1987. **23**: p. 127-134.
210. Johnson, G.A. and Donato D. *Avoidance of Wildlife Fatalities: Hard lessons from the African Sahel*. in *Global Sustainable Development Conference*. 2005. Alice Springs: Minerals Council of Australia.
211. Jehl, J.R., *Mass Mortality Events Of Eared Grebes In North America.* J. Field Ornithol., :, 1996. **67**((3)): p. 471-476.
212. Molina, K.C., *Population Status And Breeding Biology Of Black Skimmers At The Salton Sea, California.* Western Birds, 1996. **27**: p. 143-158.
213. Euliss, N.H.J., R.L. Jarvis, and D.S. Gilmer, *Feeding Ecology Of Waterfowl Wintering On Evaporation Ponds In California.* The Condor, 1991. **93**: p. 582-590.
214. Higashi, R.M., et al., *Remediation and Bioremediation of Selenium-Contaminated Waters*, in *Water Encyclopedia:Water Quality and Resource Development.*, J.H. Lehr and J. Keeley, Editors. 2005, Wiley,: Hoboken, NJ. p. 355-360.
215. Spallholz, J.E. and D.J. Hoffman, *Selenium toxicity: cause and effects in aquatic birds.* Aquat. Toxicol., 2002. **57**: p. 27-37.
216. Paveglio, E.L., K.M. Kilbride, and C.M. Bunck, *Selenium in aquatic birds from central California.* J. Wildl. Manage., 1997. **61**: p. 832-839.
217. Tanji, K., Davis D. Hanson C. Toto A. Higashi, R. Amrhein, C., *Evaporation ponds as a drainwater disposal management option.* Irrigation and Drainage Systems, 2002. **16**: p. 279~295.
218. Jehl, J.R., *Biology of the Eared Grebe and Wilson's Phalarope in the non breeding season: a study of adaptations to saline lakes.* Studies in Avian Biology, 1988. **No. 12**.
219. Galvin, J.W., et al., *An Outbreak Of Botulism In Wild Waterbirds In Southern Australia.* Journal of Wildlife Diseases, 1985. **21**((4)): p. 347-350.
220. Wobeser, G., *Effects Of Botulism On Ducks Drinking Saline Water.* Journal of Wildlife Diseases, 1988. **24**((2)): p. 240-245.
221. Cooch, F.G., *A Preliminary Study Of The Survival Value Of A Functional Salt Gland In Prairie Anatidae.* Auk, 1964. **81**((3): July-September): p. 380-393.

Appendix 2: Chemistry survey

Methodology

Systematic on-site monitoring and study of the BGS TSF commenced in June 2006 with the ACMER P58 study and continued in 2007 and 2008 with the M398 study. The monitoring recommendations of M398 were implemented and have been ongoing.

DES conducted intensive chemistry monitoring in May 2006 (ACMER P58), August 2007, January and May 2008 (M398) and April, May, June, July and August 2010 (this current work).

Routine on-site chemistry monitoring

On-site chemistry monitoring of the TSF in a manner consistent with current monitoring commenced in 2006 when BGS became participants in the ACMER P58 study, with regular chemistry samples taken from 17 April 2007. At the time BGS staff were advised on where to sample in the tailings system for WAD cyanide, pH, salinity and copper. The sample sites are the discharge spigot and the supernatant solution at the decant pump station of each active TSF cell.

Field sampling protocols were advised, in a manner consistent with the Code, which included but are not limited to:

- on-site filtering and pH preservation of samples (Noller and Schulz 1995);
- collecting in specific opaque bottles and labelling accordingly; and
- providing samples to the on-site laboratory, with duplicate and blank samples transported to a NATA-registered laboratory.

The sampling frequency regime varied according to Code requirements of the time and other matters but was generally daily. The data was collated onto spreadsheets for dissemination and analysis. This data has been used during ACMER P58 and M398 and is available to DES for this study. No data has been omitted. This routine monitoring is ongoing. The on-site dataset for this report considers data collected between 17 April 2007 and 18 August 2010.

Samples were analysed on site. Free cyanide analysis is conducted using the titration silver nitrate colourmetric method. WAD cyanide is assayed using picric acid method. Duplicate samples were sent to ALS for analysis of WAD, total and free cyanides by Discrete Analyser using procedures published by USEPA (US EPA 1998) and APHA (APHA 2005). A regular program of splitting spigot samples for duplicate ALS analysis was conducted from 16 February 2009 to 21 January 2010. Samples were split for two-way and three-way analysis at on-site, ALS and CCWA laboratories at other times. The number of samples taken and analysed by on-site, ALS and CCWA laboratories is given in Table 1.

Table 1. Number of samples analysed for each chemistry parameter by on-site, ALS and CCWA laboratories from on-site monitoring for saline and hypersaline conditions at the TSF between 17 April 2007 and 18 August 2010. Samples taken by DES are not included

	Spigot				Decant			
Laboratory	WAD cyanide	pH	TDS	Copper	WAD cyanide	pH	TDS	Copper
Saline (17 April 2007 to 7 May 2010)								
On site	372	279	325	296	384	0	0	340
ALS	50	52	52	50	0	0	0	
CCWA	55	2	23		0	0	0	
Hypersaline (8 May to 18 August 2010)								
On site	76	72	74	78	84	70	62	60
ALS	2	2	2		2	2	2	
CCWA	2	2	2		2	2	2	

Additional chemistry sampling (mostly pH and free cyanide) regularly occurs at various points in the mill for process purposes. Pertinent to this work, the addition of cyanide is measured automatically at leach tank 0 and free cyanide is measured every four hours in leach tank 0 and CIP tank 6 (Figure 1). BGS has commissioned an automated WAD cyanide analyser to be located in the mill that will be installed in coming months. This will automatically control cyanide addition to leach tank 0. An automated salinity analyser has also been commissioned and will be installed just before the tailings hopper (Figure 1) to measure salinity of the final tailings exiting the mill and will control the addition of hypersaline water to meet the objective of tailings discharge at above 50 000 mg/L TDS. This will also be installed in coming months.

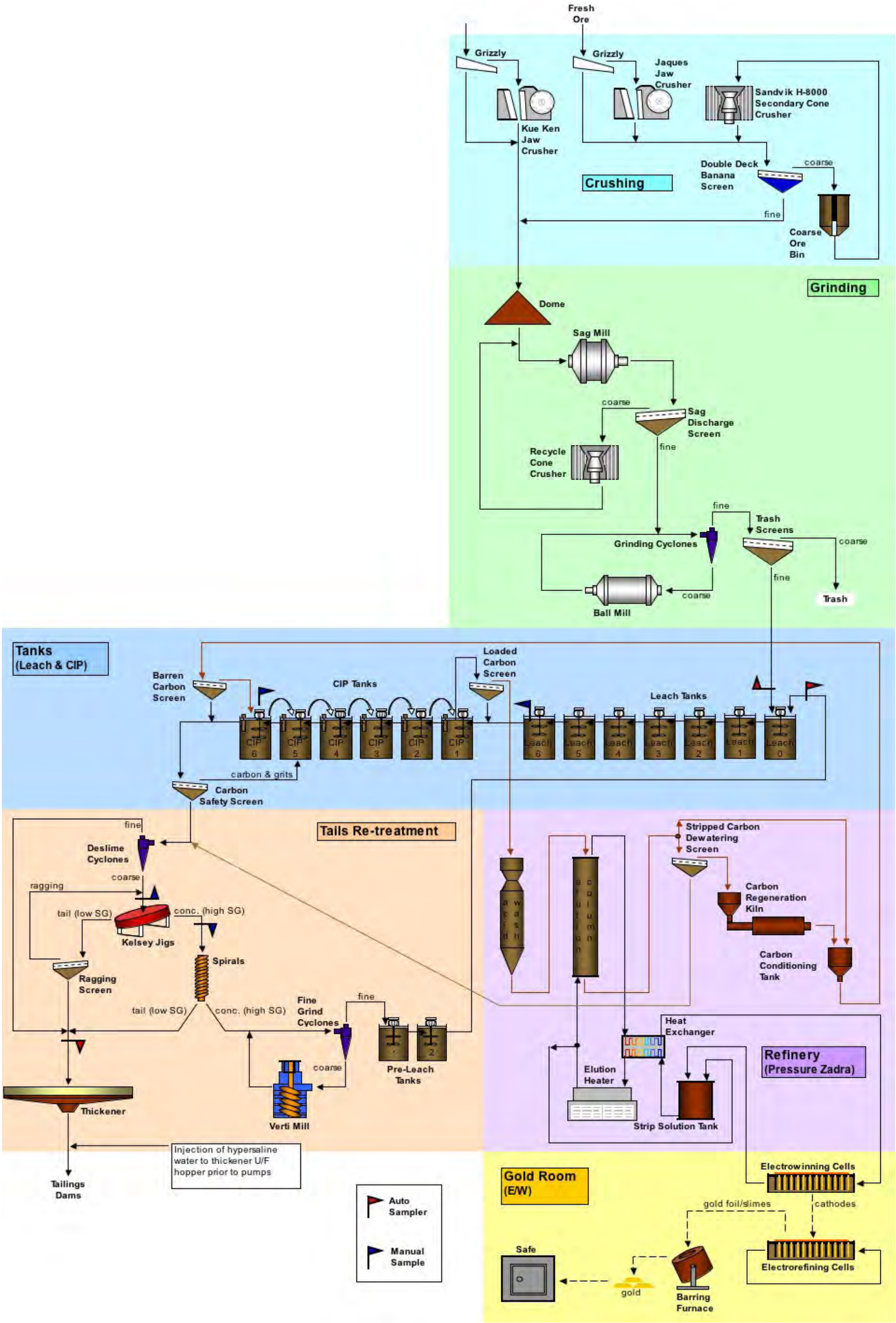


Figure 1. Mill flow sheet showing automated (red flags) and manual (blue flags) chemistry sampling points

Intensive chemistry sampling and analysis methodology (DES)

Intensive sampling by DES was conducted primarily during the M398 study and the current project however some more limited sampling (of spigots, the supernatant and time trials) was also conducted during ACMER P58.

Sampling protocol

A summary of chemistry sampling conducted on each site visit from May 2006 to August 2010 is provided in Table 2. Chemistry sampling activities are described below. For a full list of samples see Appendix 4. All sampling protocol was conducted in a Code-compliant manner and was consistent for each study.

Table 2. Summary of samples taken for each site visit including total number of samples taken, the number of samples analysed by on-site, ALS and CCWA laboratories and number of samples by sampling activity. Samples may serve two or more purposes and therefore be counted in more than one category

Mill process plant sampling

Plant samples were taken to capture plant chemistry conditions at the time of TSF sampling. Some plant samples were taken on most site visits however the most extensive plant sampling was conducted during the M398 project. Samples were taken from a number of points including leach feed, leach tank 0, leach tank 6, CIP 6, thickener underflow, thickener overflow, process pond and deslimes C+1.

HCN gas logging (M398)

HCN gas logging was conducted at various points within the mill and at the spigot to assess cyanide loss throughout the circuit via HCN gas volatilisation. HCN gas concentration and temperature data was collected using calibrated and certified GasBadge Pro units, which logged at 20 or 60-second intervals. The GasBadge Pro units were located at strategic points in the mill processing plant, at the spigot and were carried by the researchers. The latter yielded overall ambient TSF and plant data, as well as data relating to specific conditions of HCN (g) and temperature prevailing at individual sampling points.

Regular spigot and supernatant sampling

Spigots and the supernatant were sampled at least once a day to assess chemistry conditions at the time of wildlife observations and to compare with on-site daily chemistry sampling.

Alternative water body sampling

Water samples were taken from a number of alternative water bodies including the seepage trench, haul road lakes, haul road borrow pit, goanna pit and Winditch Pit and analysed for cyanides, various metals, TDS and other physical paramaters. This allows for comparison with the tailings solutions in terms of toxicity, salinity and wildlife use.

Spatial sampling of the tailings discharge zone

Sampling of the TDZ was limited to areas accessible from adjacent walls and the decant finger due to inability to walk on tailings in active cells except during M398 when the radio controlled boat (RCB) was used to sample the tailings plume. Spatial sampling of the TDZ was primarily conducted through spigot-to-supernatant sampling using spigots set up to discharge next to or close to the decant wall ('lucky spigots') and sampled with extended poles from the embankment. Additional sampling of spigot pools was conducted using sampling poles and from within the tailings plume using a RCB in the M398 project.

Spatial sampling of the supernatant

Spatial sampling throughout the supernatant was conducted in M398 using the RCB. Onboard monitoring included pH, ORP, salinity, depth and position (using GPS), and 17 samples were collected. Some of these intensive-sampling surveys were conducted during the hot conditions of January and February 2008 and during presumed peak bird migratory season of March and April 2008.

Continuation of supernatant at various points either side of the decant wall was conducted in May 2008 and June, July and August 2010.

Temporal (time) sampling from a discharge spigot

Spigot discharge sampling on an hourly basis was conducted during P58, M398 and this project to varying extents on all site visits.

Cyanide speciation

Cyanide speciation analysis was conducted through direct validation of metals by ICP-AES and ICP-MS and with metals as cyanide complexes by ion chromatography (IC).

Laboratory cyanide degradation test work

First-order cyanide degradation rate constants were obtained for several synthetic solutions as well as spigot and supernatant filtrate solutions. The test work of stirred vat tests were carried out at an accredited metallurgical test work laboratory (SGS Lakefield Oretest in Perth). The synthetic solutions were comprised of NaCN.

Cyanide and pH levels recorded through the 48-hour tests on four synthetic solutions of increasing salinity were tested.

Special projects investigation (M398)

Four specific questions were investigated under the auspices of the M398 study. These are described below as special project one to four.

Special Project 1 (Remobilisation of cyanide from wet and dry tailings)

Dry and wet (consolidated) solid tailings samples were collected in January 2008 from the top 10 to 20 mm of tailings surface within the TSF, placed in a small plastic container and kept in the dark and refrigerated until analysis. An aliquot of the solids was extracted with deionised water, pressure filtered and the filtrate analysed for WAD cyanide and total cyanide to simulate the maximum amount of cyanide that could be solubilised by rain water coming in contact with the dry TSF surface. Similarly an aliquot of the solid was extracted with dilute sodium hydroxide, NaOH solution (0.05 M) to determine the amount of cyanide stored in the solid.

Special Project 2 (Prepared sampling preservation technique)

Determining the preferred sample preservation of saline and hypersaline cyanide solutions for transport to service laboratories was considered necessary after initial chemistry sampling carried out in phase 1 of the M398 project. Spigot and supernatant samples were taken in January 2008 and split into sub-samples and subjected to cyanide analysis after undergoing different stabilisation procedures.

Special Project 3 (Simulation of cyanide liberation under avian digestive conditions)

Avian wildlife produce different amounts of gastric juices according to quantities of food or water consumed. Tests were designed to mimic intake of different quantities of test solution into gastric juices of different strength (stomach acidity is species dependent) and to determine the amount of cyanide that could be liberated and potentially adsorbed by the wildlife. Spigot and supernatant samples were taken in January 2008 and split into sub-samples.

They were then subjected to WAD cyanide analysis after dilution with acid solutions of various pH values and at different volume ratios.

Special Project 4 (Copper analysis techniques for tailings solutions)

Copper was identified in Phase 1 as a significant component of the WAD cyanide and is well known as a stabilising agent for WAD cyanide in TSF supernatant waters. Control of copper levels in tailings and supernatant waters is therefore important, hence, the advantage of accessing a simple assay method for the analysis of copper in site laboratories was mooted. A tailings sample was taken in January 2008 and split into sub-samples and subjected to copper analysis by ICPAES/MS and by flame AAS.

Analytical protocol

The NATA-registered ALS chemical laboratory was used in May, June, July and August 2010 (current study). During the M398 study of 2007 and 2008 the Chemistry Centre of Western Australia (CCWA) was used for analysis of chemistry sampling of the BGS tailings system. Three-way splits were conducted in July and August 2010 with samples analysed on site (using the Picric method) and splits provided to the ALS and CCWA laboratories.

BGS charter flights and commercial courier services were used to minimise delays between packaging and receiving at the laboratories. All samples from this exercise were received at the respective laboratory within 24 hours of dispatch. The samples were received in-tact, chilled and uncompromised at the CCWA and ALS chemical laboratories.

The chemistry sampling analysis included the critical parameters of:

- salinity (as mg/L TDS);
- free, WAD and total cyanide concentration;
- pH; and
- copper.

Other analyses conducted were for a suite of 20 metals, thiocyanate, cyanates, alkalinity, nitrates, nitrites, total nitrogen and major cations and anions.

All samples were pressure-filtered using site facilities and preserved as required by the previously established procedures based on the Code guidelines.

Quality assurance and quality control was conducted through:

- two-way or three-way splits of chemistry samples for analysis on site and at an off-site laboratory;
- internal analysis of quality control results from commercial laboratories; blind testing of laboratories; and
- duplicate sampling for laboratory analysis.

Chemistry data analysis

All consultant-collected data from ACMER P58, M398 and in this current study are included. No data is omitted.

Analysis has been conducted using Microsoft ExcelÒ, including statistical analysis and creation of graphs. In the determination histograms the 80th and 95th percentiles are also calculated using the Microsoft ExcelÒ, which computes percentiles using the following formula.

Percentile (x) = (Rank (x) - 1) / (n - 1) where n is the number of data points. If x does not match one of the values, then the percentage rank function interpolates.

Chemistry results – routine in house

The on-site chemistry dataset considered for this report is between 17 April 2007 and 18 August 2010. A total of 489 spigot samples and 468 supernatant samples are included in the analysis for this period. As typical with most operations, BGS experienced regular and unscheduled mill shutdowns, process disruptions and changes, which greatly influenced chemical parameters at times, especially cyanide concentrations at spigot discharge. As a consequence, when considering the WAD cyanide spigot concentrations for BGS, those values below 10 were removed from the analysis. Raw on-site data is used for the following analysis. Error in the data is demonstrated by comparison with ALS data in the QA and QC section for cyanide in particular, however the error is variable, dependant on many factors. Consequently it is not possible to apply a uniform adjustment factor here for the whole range of cyanide data.

Chemistry data

A summary of BGS on-site cyanide analyses is presented in Table 3 for the saline and hypersaline conditions in the TSF. Average cyanide concentrations, as measured on-site, were similar for the saline and hypersaline periods (Table 3) although considerable variability is evident throughout both periods (figures 2 and 3). Spigot sampling during the saline period recorded a maximum of 150 mg/L WAD cyanide and 71.2% of readings were above 50 mg/L. A maximum of 90 mg/L WAD cyanide was recorded in spigot samples during the hypersaline conditions with 78.9% of reading being over 50 mg/L. The mean WAD cyanide concentration in the supernatant was slightly higher in the saline period. The maximum reading was substantially higher in the saline period and 21 readings (5.5%) were above 50 mg/L in this period. Of importance is that the supernatant WAD cyanide concentration is substantially less than that at spigot discharge, and below 50 mg/L in all determinations as a hypersaline system. This illustrates consistent degradation of cyanides within the TSF.

The variability in the discharge concentrations of WAD cyanide at BGS (figures 7 and 8) is similar to that experienced elsewhere such as Sunrise Dam Gold Mine (SDGM) (Donato and Smith 2007). This variability is partly due to analysis error (see QA and QC section) but also due to numerous process plant metallurgical parameters, ore body characteristics, changes in ore body, variable cyanide dosage rates and environmental factors.

Confidence in the accuracy of this dataset is not high (see QA and QC section) and this dataset cannot be used to determine operating parameters.

Table 3. Summary of WAD cyanide analysis from on-site sampling conducted when the TSF was saline and hypersaline

	N=	Average (± S.D)	Max. (min.)	Samples/ days (%) over 50 mg/L
Saline (9 January 2008 to 7 May 2010)				
Supernatant	384	19.7 ± 15.5	73.8	21 (5.5%)
Spigot	372	60.8 ± 22.5	150	265 (71.2%)
Hypersaline (8 May to 18 August 2010)				
Supernatant	84	15.0 ± 7.9	29.5	0
Spigot	76	61.6 ± 13.8	90	60 (78.9%)

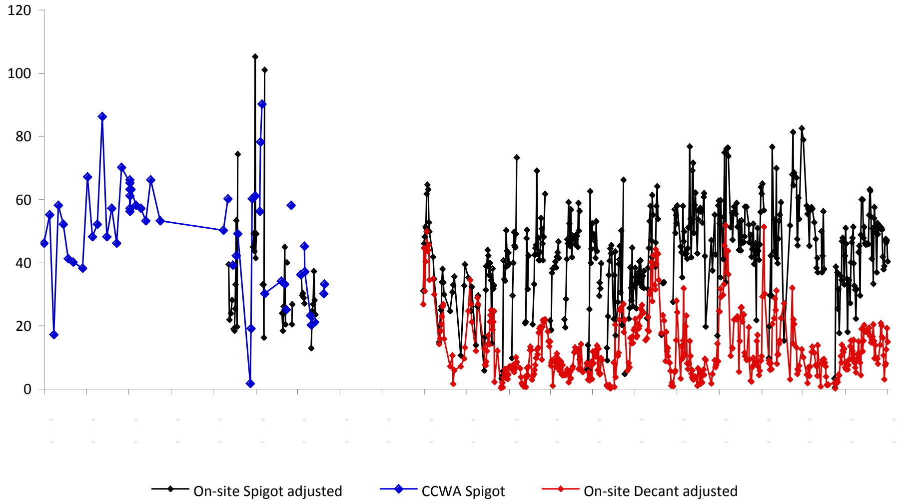


Figure 2. CCWA and BGS WAD cyanide concentrations (mg/L) at spigot discharge (n = 61 and 448) and in the supernatant (n = 468) between 17 April 2007 and 18 August 2010

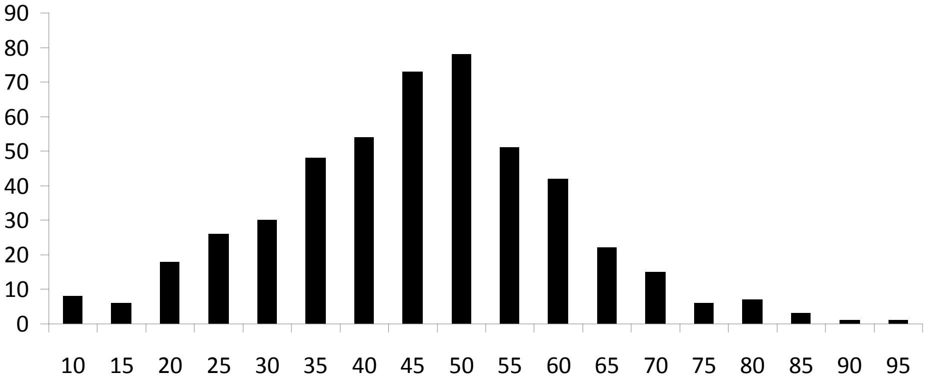


Figure 3. BGS distribution of WAD cyanide at spigot discharge (n = 448) in number of samples (y-axis) for each bin range of 5 mg/L WAD cyanide (x-axis)

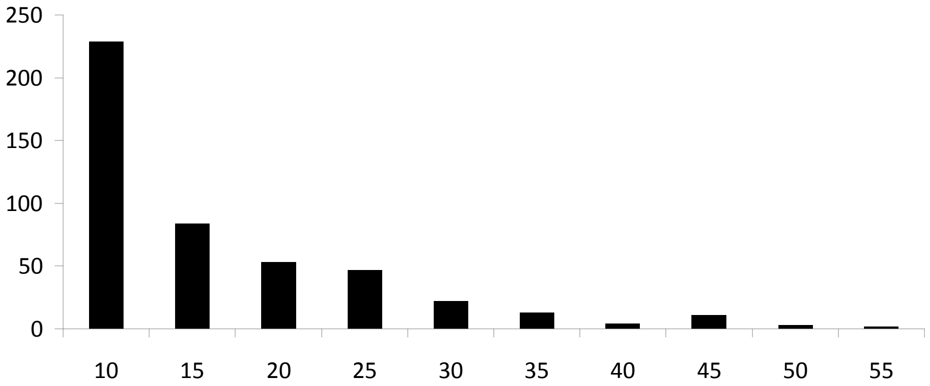


Figure 4. BGS distribution of WAD cyanide at supernatant (n = 468) in number of samples (y-axis) for each bin range of 5 mg/L WAD cyanide (x-axis)

Salinity (TDS) from on-site data at the spigot and in the supernatant is illustrated in Figure 5. It is obvious when the hypersaline tailings wash circuit was introduced (7 May 2010) salinity increased in the tailings system although variability is evident (Figure 5 and Table 4). Since early June 2010 salinity concentrations have generally stabilised at between 50 000 and 65 000 TDS at both spigot discharge and in the supernatant (Figure 5) although 22 (29.7%) spigot samples were recorded at below 50 000 TDS.

The pH mean at spigot was 9.1 ± 0.8 when the TSF was saline but dropped to 8.8 at the spigot and in the supernatant once it was hypersaline (Table 4). These values are typical for a saline tailings system. The pH was quite variable at times at both the spigot and in the supernatant (Figure 6) ranging between 6.9 and 10.6 at the spigot and 7.2 and 9.6 in the supernatant. Variability in the supernatant is expected when tailings discharge is switched between cells and water quality takes time to stabilise. Mill shutdowns and a variety of operational conditions will affect discharge pH. The pH value at discharge is expected to decrease under continued hypersaline conditions.

Mean copper concentrations at BGS were 18.4 ± 12.7 mg/L at the spigot and 11.8 ± 8.8 mg/L in the supernatant. There is great variability in the copper concentrations at different times illustrating that the copper levels differ considerably in the different ore bodies (Figure 7).

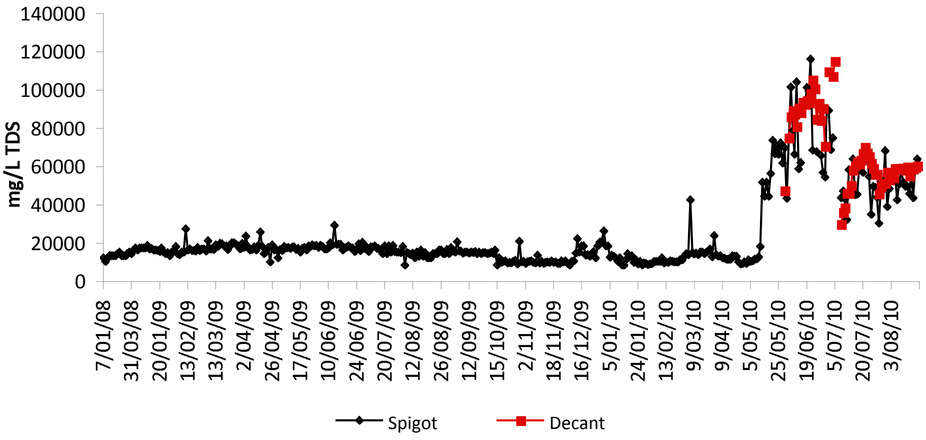


Figure 5. Salinity (TDS) at spigot discharge (n = 400) and in the supernatant (n = 62) between 7 January 2008 and 18 August 2010

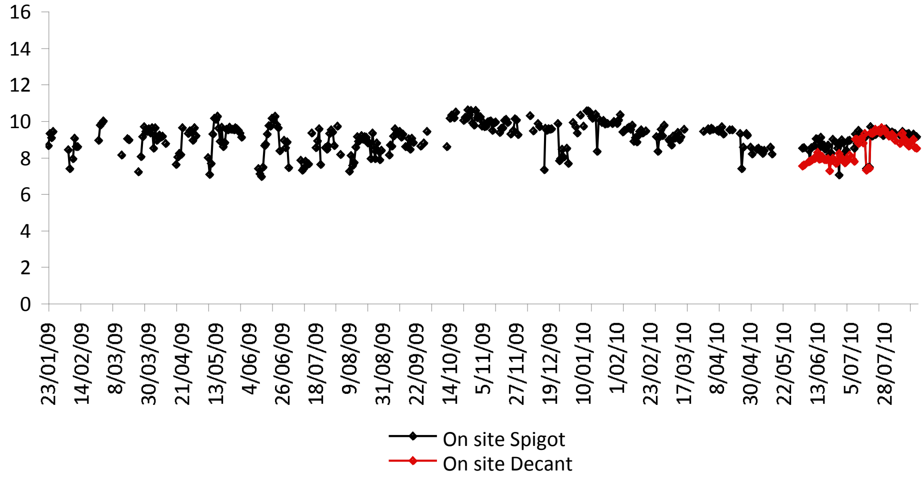


Figure 6. pH at spigot discharge (n = 351) and in the supernatant (n = 69) between 23 January 2009 and 18 August 2010

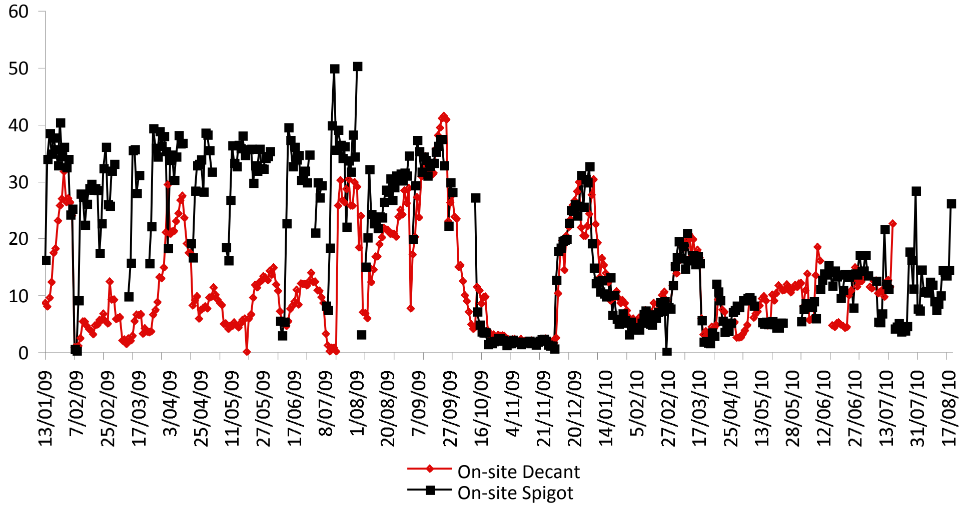


Figure 7. Copper concentrations at spigot discharge (n = 400) and in the supernatant (n = 375) between 13 January 2008 and 18 August 2010

Table 4. Summary of pH, salinity (TDS) and copper analysis from on-site sampling conducted when the TSF was saline and hypersaline

	pH		TDS		Copper	
	N=	Average	N=	Average	N=	Average
Saline (9 January 2008 to 7 May 2010)						
Supernatant	0	-	0	-	340	12.1 ± 9.4
Spigot	279	9.1 ± 0.8	326	14 490 ± 3 901	296	20.5 ± 13.2
Hypersaline (8 May to 18 August 2010)						
Supernatant	70	8.8 ± 0.7	62	68 261 ± 19 936	60	10.0 ± 3.7
Spigot	72	8.8 ± 0.6	74	61 086 ± 18 097	78	10.4 ± 5.0

Chemistry results – consultant data

Mill process plant sampling and HCN gas logging

The major contribution to reduction in WAD cyanide in the mill process was the carbon-in-leach (CIL) circuit, with the strongest effect being observed for the highest salinity water, as shown in Table 5.

Table 5. Influence of salinity (as TDS) on WAD cyanide reduction in four CIL circuits

			WAD cyanide reduction in CIL (%)			
Mine site	Circuit	TDS (mg/L)	Aug 2007	Jan 2008	Jun 2008	Average
BKB	Calcine CIP	195 000	57	27	52	45
BKB	Float tailings CIP	195 000	55	84		70
GSI	CIP	50 000	44	35	46	42
BGS	CIP	16 000	21	41	45	36

Some measure of the seasonality of cyanide degradation across each of the three sites can be gleaned from Figure 8. While no distinct seasonality trend can be established from the limited dataset, it is clear that cyanide loss, primarily by HCN volatilisation, occurs throughout the process plant circuit through to the TSF. On average, about 16% cyanide loss also occurs in the tailings slurry pipeline.

Limited sampling conducted on 19 August 2010 under hypersaline conditions in the mill produced results consistent with the findings above. Cyanide losses of 44%, 40% and 53% for total cyanide, WAD cyanide and free cyanide, respectively, were measured from leach tank 0 to the final tailings hopper (Figure 9). These results are drawn from one sample at each location and should be treated with caution.

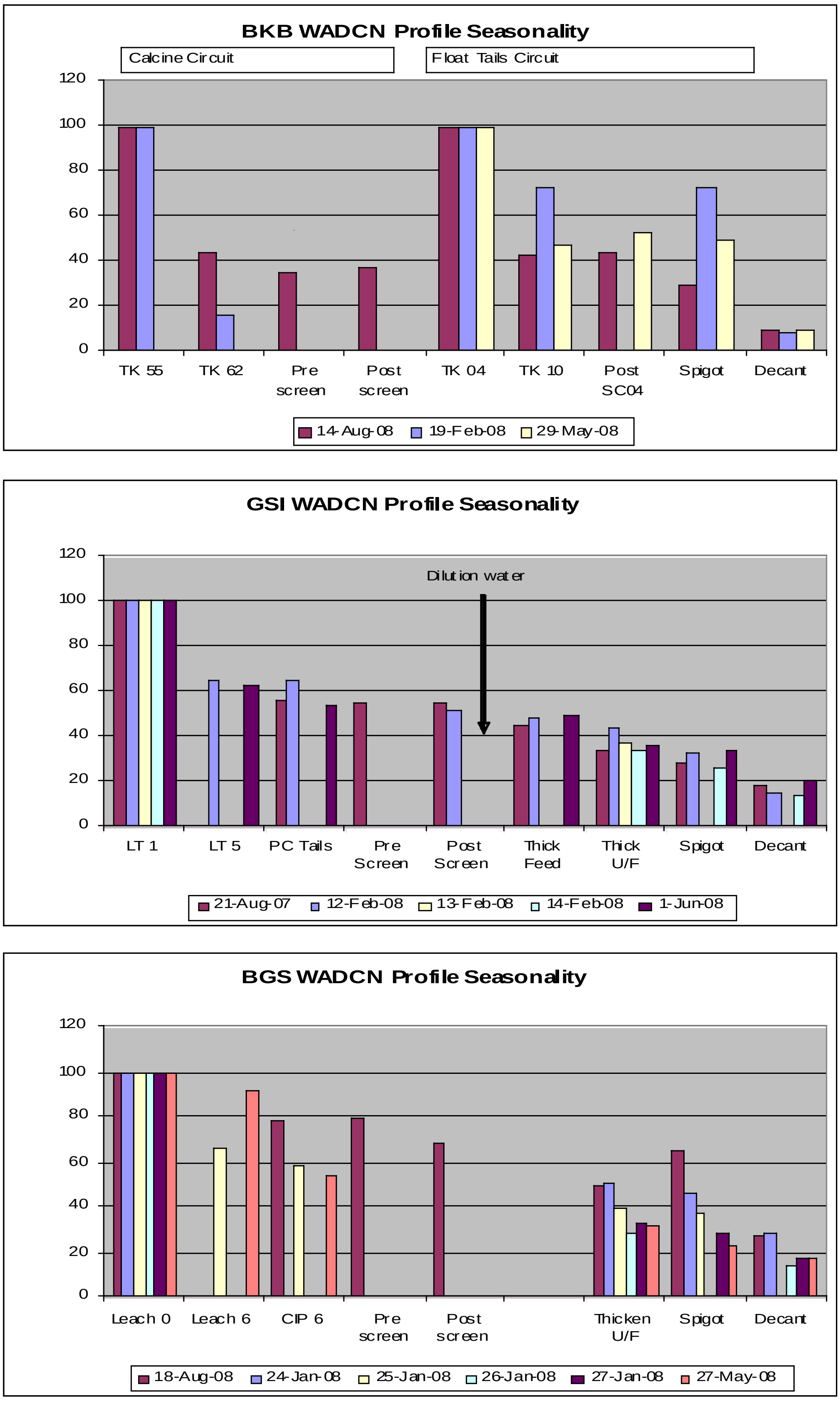


Figure 8. WAD cyanide degradation profiles from the three sites in the M398 project normalised to primary cyanide addition point for (a) BKB, (b) GSI and (c) BGS

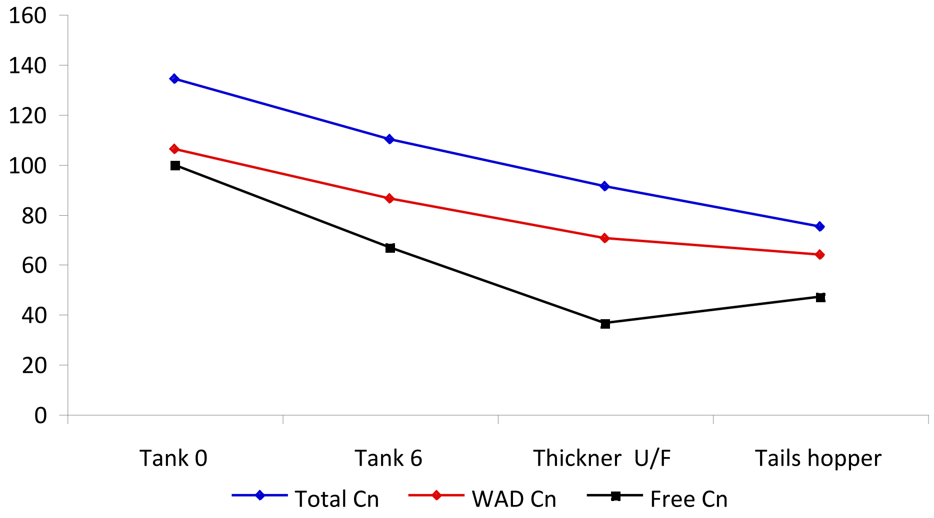


Figure 9. Free, WAD and total cyanide measured at four points within the BGS plant at 15:00 on 19 August 2010

Volatilisation of HCN was identified in phase 1 and phase 2 of M398 at all saline sites, with the strongest effect being observed for the highest salinity water. HCN volatilisation is well known to account for the majority of the cyanide degradation occurring in TSF systems (Simovic, Snodgrass, Murphy and Schmidt 1985; Adams 1990; Adams 1990).

The results from the M398 project are summarised in Table 6 for the two hypersaline sites (BKB and GSI) and the two saline sites (BD and BGS).

Table 6. Summary of HCN gas levels at the four plant and TSF locations, BKB, GSI, BD and BGS

The two hypersaline sites share both lower operating pH ranges and higher gaseous HCN emissions compared with the two saline sites. These results are consistent with the assertion that HCN volatilisation is an important source of cyanide loss to the tailings system.

Spigot and supernatant sampling

Averages for spigot discharge and supernatant chemistry data are given for samples collected by DES under saline and hypersaline conditions at the TSF in tables 7 and 8. Results are also presented for each site visit in Table 9. All results are from analysis conducted by ALS.

WAD cyanide averaged just over 50 mg/L at the spigot during samples taken under hypersaline conditions (Table 7) with a recorded maximum of 90.5 mg/L. Free cyanide averaged just below 50 mg/L but had a maximum of 93.1, which indicates a level of analytical error, as free cyanide is a subset of WAD cyanide. Average supernatant cyanide concentrations were substantially lower than at the spigot (Table 7). WAD cyanide in the supernatant was well below 50 mg/L in all samples.

Under saline conditions WAD cyanide was higher within the supernatant compared to under hypersaline conditions (Table 8).

Variability in cyanides at the spigot and in the supernatant is indicated by the standard deviations but also in figures 10 and 11, which show variability between site visit averages. This variability at the spigot is consistent with on-site data from a more complete dataset and is likely to be due to many factors within the mill. Cyanide concentrations in the supernatant can be influenced by many factors other than just spigot discharge concentrations such as supernatant size, the pattern of TSF cell activity, environmental conditions and rainfall events.

Table 7. Summary of chemistry data from DES sampling under hypersaline conditions at the BGS TSF between 8 May and 21 August 2010

	WAD cyanide	Free cyanide	Total cyanide	pH	TDS	Copper
Supernatant						
N=	22	22	22	14	14	22
Average (± SD)	10.5 ± 6.0	9.7 ± 5.7	19.5 ± 12.4	8.7 ± 0.1	61 464 ± 14 406	3.9 ± 1.8
Maximum (minimum)	21.3	18.3	41.1		(33 200)	
Spigot						
N =	79	79	79	46	46	75
Average (± SD)	53.4 ± 19.5	48.6 ± 20.2	65.3 ± 23.8	9.2 ± 0.1	61 595 ± 11 540	4.4 ± 4.5
Maximum (minimum)	90.5	93.1	111	9.5	(35 600)	20.7

Table 8. Summary of chemistry data from DES sampling under saline conditions at the BGS TSF between June 2006 and 7 May 2010

	WAD cyanide	Free cyanide	Total cyanide	pH	TDS	Copper
Supernatant						
N=	41	25	24	25	27	25
Average (± SD)	24.9 ± 7.6	9.4 ± 3.3	52.4 ± 23.7	8.0 ± 0.3	20 518 ± 2 578	15.0 ± 5.1
Maximum	37	15	110	8.6	33 000	22
Spigot						
N =	37	21	22	22	17	21
Average (± SD)	40.9 ± 13.9	30.6 ± 12.8	94.0 ± 19.3	9.1 ± 0.5	14 656 ± 1 215	8.3 ± 3.1
Maximum	66	49	130	10.1	17 000	14

Table 9. Summary of DES chemistry sampling incorporating data from all site visits between May 2006 and August 2010. Averages are given for each of the primary chemistry parameters measured during each site visit.

Project	Sampling month	Ore Campaign		No. of samples	WAD cyanide (mg/L)	Free cyanide (mg/L)	Total cyanide (mg/L)	pH	TDS (mg/L)	Copper (mg/L)
P58	May-06	Wallaby	Spigot	13	29.2 ± 1.1				24 333 ± 7 505	
			Super	13	30.5 ± 1.6				17 000	
M398	Aug-07	Wallaby	Spigot	10	59.5 ± 5.3	41.7 ± 4.8	83.3 ± 7.9	9.4 ± 0.2	15 000 ± 471	8.1 ± 4.3
			Super	2	27.5 ± 0.71	9 ± 0	53.5 ± 10.6	8.1 ± 0	20 500 ± 707	9.0 ± 4.0
	Jan-08	Wallaby	Spigot	11	40.6 ± 10.0	20.5 ± 8.4	106.8 ± 17.5	8.9 ± 0.6	13 333 ± 516	8.5 ± 1.5
			Super	14	22.8 ± 6.1	6.8 ± 1.4	67.1 ± 22.0	7.9 ± 0.4	19 846 ± 800	12.3 ± 2.2
	May-08	Wallaby	Spigot	1	31		59	9.2	16 800	
			Super	9	23.7 ± 1.1	12.7 ± 2	31.1 ± 3.8	8.1 ± 0.1	20 222 ± 441	21 ± 0.5
Current Project	Apr- May 10	Crescent	Spigot	4	55.0 ± 4.3				14 875 ± 4 393	8.9 ± 1.7
			Super	1	15				11 640	6.3
	May-10	Crescent	Spigot	19	41.1 ± 4.0	38.4 ± 3.9	43.9 ± 4.9	9.0 ± 0.1	68 300 ± 9 687	1.0 ± 0.8
			Super	2	7.9 ± 1.1	6.3 ± 0.2	9.2 ± 1.3	8.7 ± 0.05	48 850 ± 6 434	2.7 ± 3.6
	Jun-10	Wallaby	Spigot	22	32.4 ± 8.3	27.1 ± 6.2	48.1 ± 18.3			4.3 ± 3.1
			Super	7	4.0 ± 0.6	3.2 ± 0.5	5.4 ± 1.1			2.9 ± 1.0
	Jul-10	Crescent	Spigot	23	70.0 ± 7.7	71.7 ± 11.0	86.1 ± 13.7	9.2 ± 0.1	58 680 ± 9 786	3.4 ± 1.2
			Super	10	12.7 ± 3.2	12.6 ± 3.1	27.5 ± 7.0	8.7 ± 0.1	69 380 ± 5 316	4.2 ± 1.2
	Aug-10	Crescent	Spigot	15	74.3 ± 9.0	57.8 ± 12.8	86.0 ± 8.1	9.3 ± 0.1	51 728 ± 11 389	11.8 ± 5.6
			Super	3	20.4 ± 1.0	17.6 ± 0.7	32.6 ± 1.1	8.4 ± 0.01	34 500 ± 1 838	6.5 ± 0.7

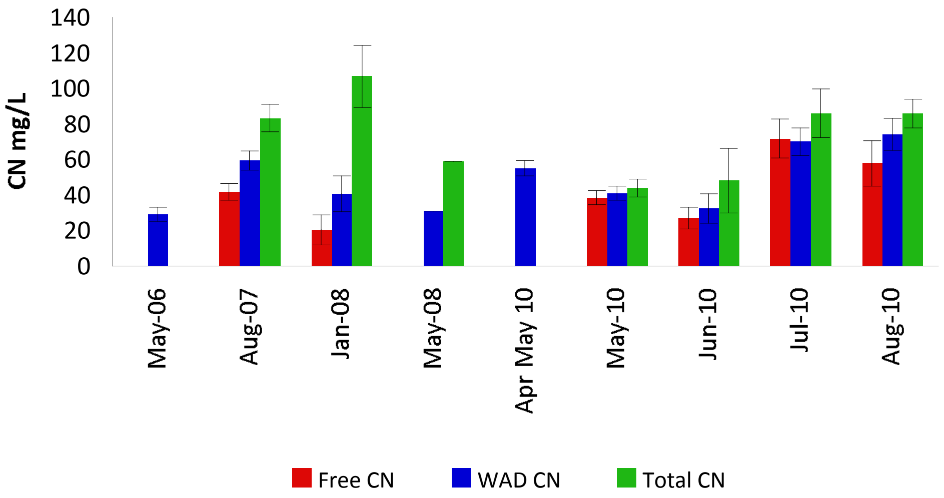


Figure 10. Averages for free, WAD and total cyanide (mg/L) at the spigot from samples taken by DES during each site visit between May 2006 and August 2010

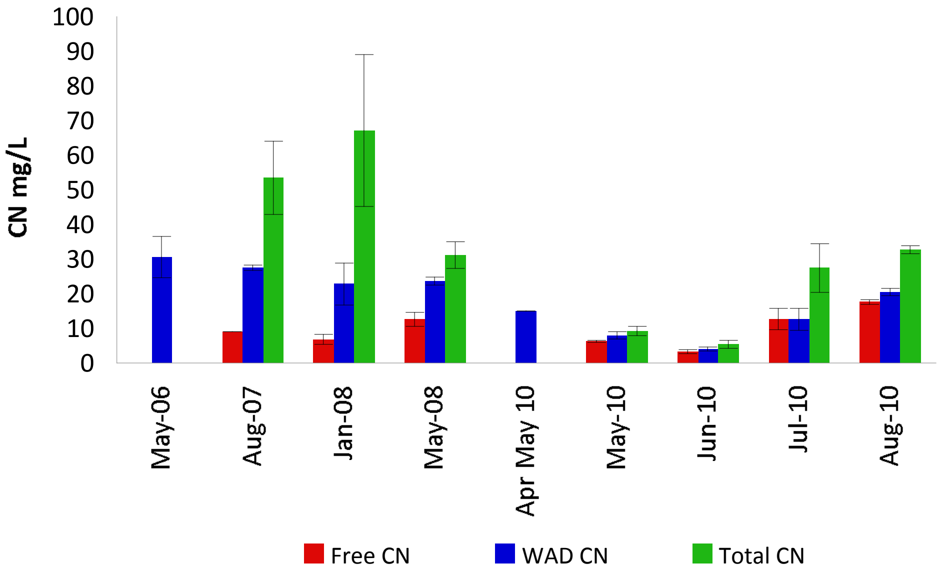


Figure 11. Averages for free, WAD and total cyanide (mg/L) at the supernatant from samples taken by DES during each site visit between May 2006 and August 2010

Average salinity (TDS) at spigot was approximately 61 000 mg/L TDS under hypersaline conditions (tables 7 and 9) but was variable with seven spigot samples (15.2%) under 50 000 mg/L. The average salinity of the supernatant was similar under hypersaline conditions (tables 7 and 9) and three samples (21.4%) returned a value of less than 50 000 mg/L TDS. Variability of salinity averages is illustrated for each site visit in Figure 12. Consistent with on-site data, salinity was generally between 10 000 and 25 000 TDS at both the spigot and in the supernatant before the hypersaline circuit was introduced, which is clearly seen in the data (Figure 12). The averages for August 2010 were lower than for June and July however the spigot discharge still averaged over 50 000 mg/L TDS although the supernatant was less than this (Figure 12).

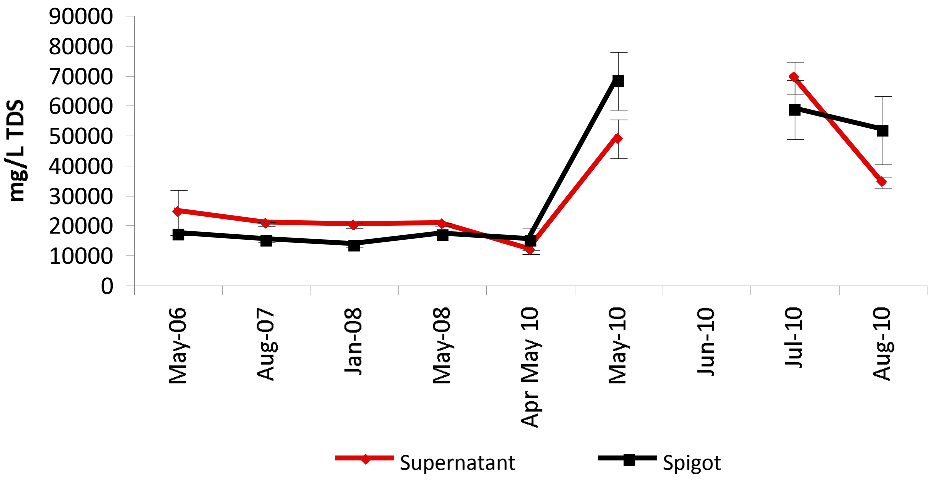


Figure 12. Average concentrations of salinity (mg/L TDS) at the spigot and supernatant from samples taken by DES during each site visit between May 2006 and August 2010

Averages measured for pH during DES sampling were higher in the hypersaline datasets at both the spigot and supernatant compared to the saline datasets (tables 7 and 8). Averages measured for pH during DES sampling have been quite consistent at the spigot between site visits, generally between 9 and 9.5 (Figure 13). Variability has reduced substantially (indicated by the size of the error bars) in 2010 compared to previous years (Figure 13). In the supernatant, pH was consistent at about 8.1 to 8.2 under saline conditions from August 2007 to May 2008, and between 8.4 and 8.8 under hypersaline conditions in 2010 (Figure 13). This is expected for the spigot sampling as a higher pH is required to keep cyanide stable in hypersaline solutions. The reasons for a substantially higher pH of the supernatant under hypersaline conditions is not immediately evident.

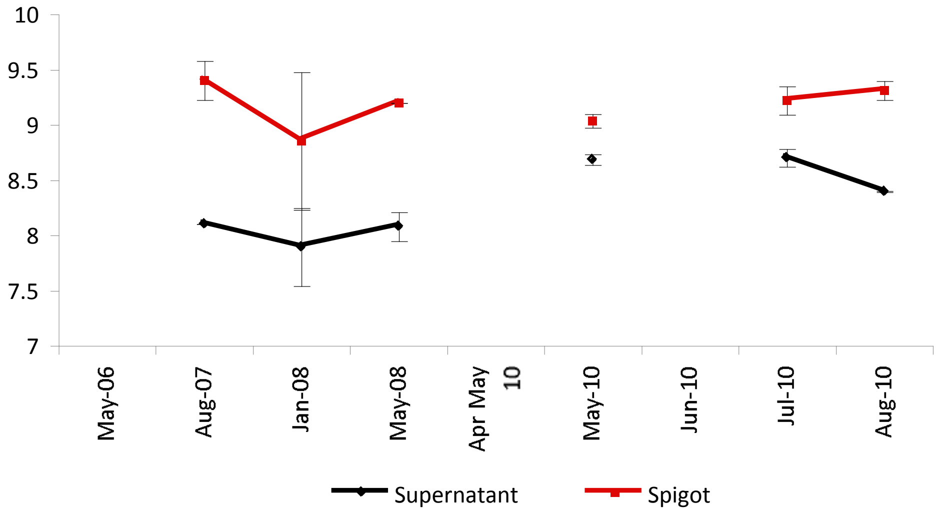


Figure 13. Averages for pH at the spigot and supernatant from samples taken by DES during each site visit between May 2006 and August 2010

Copper concentration averages measured during DES sampling were below 10 mg/L at the spigot and in the supernatant under hypersaline conditions (Figure 14). Average copper concentrations were higher in the saline dataset with a large increase in the supernatant in May 2008 (Figure 14).

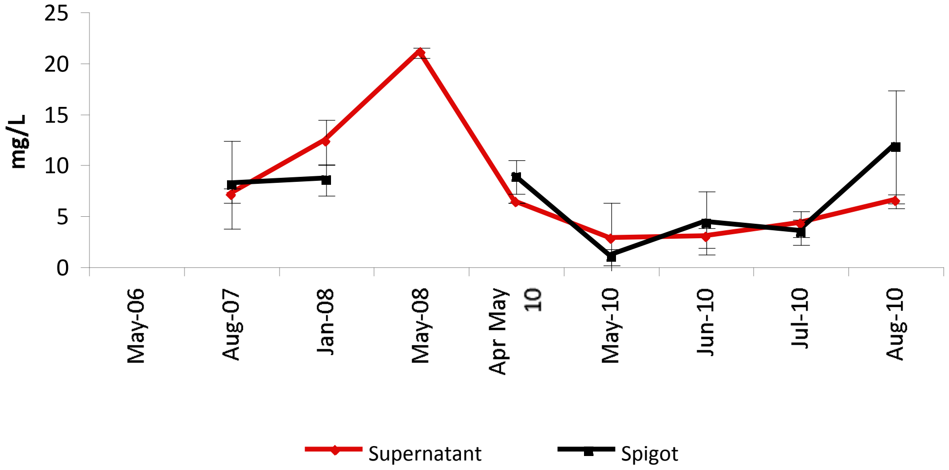


Figure 14. Average concentrations of copper (mg/L) at the spigot and supernatant from samples taken by DES during each site visit between May 2006 and August 2010

Spigot discharge time trials over one day

Hourly spigot time trials were conducted by DES on most site visits to assess variability on a temporal scale. Some variability in WAD cyanide discharge concentrations at the spigot is evident on all days they were conducted (Figure 15). Within a 12-hour period cyanide concentration can vary as much as 15 mg/L (30%) as evident in sampling on 12 May 2010. Of note is that the variability is not random but sequential, with the previous sample influencing the subsequent sample concentration.

Such variability can be caused by many factors in the mill circuit and is likely to reflect actual variability at spigot discharge as well as some level of analytical error.

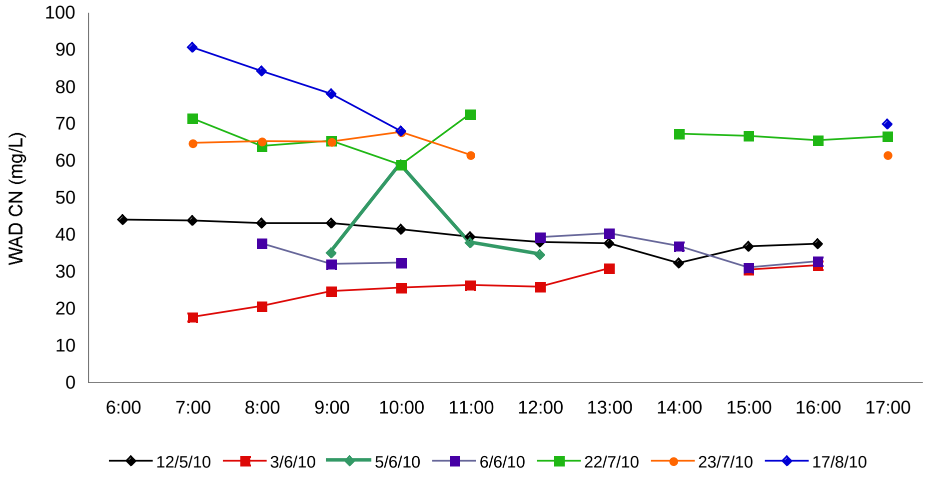


Figure 15. WAD cyanide concentration at the spigot according to time within each sample day for seven days between May and August 2010

One time trial (during P58) was conducted at the supernatant (from the same location) as well as at the spigot (Figure 16). While variability in the spigot is again evident, the supernatant WAD cyanide indicates that substantial variability is inherent in the sampling, transport and analysis process. The variability in WAD cyanide concentrations observed at the supernatant in Figure 16 is likely to reflect analytical error and cyanide loss due to handling rather than actual cyanide variability in the supernatant, which would be unlikely over such a short time frame. Sampling was conducted away from the spigot plume and the water volume of the supernatant is too large to be influenced to such a degree by variability at the spigot over a matter of hours.

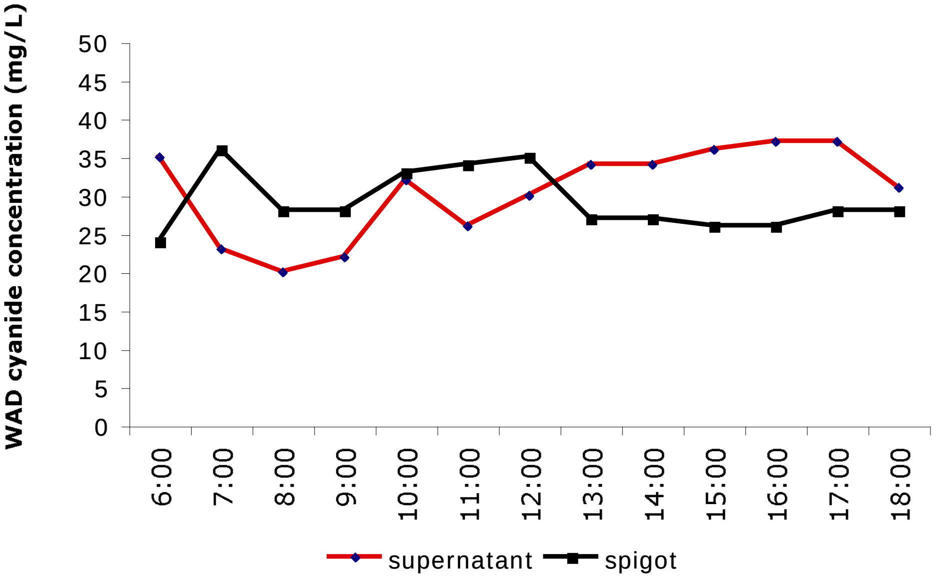


Figure 16. WAD cyanide concentration at the spigot and in the supernatant (from the same location) according to time on 18 May 2006

Spatial sampling of the tailings discharge zone

Lucky spigot is the terminology when a spigot immediately contiguous to a decant wall is turned on and the tailings stream flows parallel to the wall within sampling pole distance to the supernatant.

Lucky spigot sampling was conducted under saline and hypersaline conditions. Results from saline lucky spigots conducted in M398 were not consistent with one conducted on 19 August 2007, which showed little cyanide degradation throughout the profile (Figure 17). This is due to pH (9.4 to 9.6) stabilisation, being above the critical pH 9.1. The supernatant was 8.1. In contrast, sampling conducted on 24 January 2008 showed definite cyanide degradation (Figure 18) at pH levels of between 9.2 at the spigot and 8.8 in the plume. The supernatant was again measured at pH 8.1 and had much lower cyanide concentrations. The copper levels measured in both profiles were low and indicate that copper was not a primary reason for WAD cyanide resilience throughout both lucky spigot profiles (figures 17 and 18).

Lucky spigots conducted on hypersaline tailings from May to July 2010 showed mixed results in terms of WAD cyanide degradation (Figure 19). Sampling conducted on four days showed some limited degradation before tailings reached the supernatant. In the profile from 24 July 2010 at 7:00, no cyanide degradation was observed at all within the plume (Figure 19). Similar pH was measured throughout the plume for all of these profiles at between 9 and 9.2, which is at the threshold for pH stabilisation and may account for the variable results.

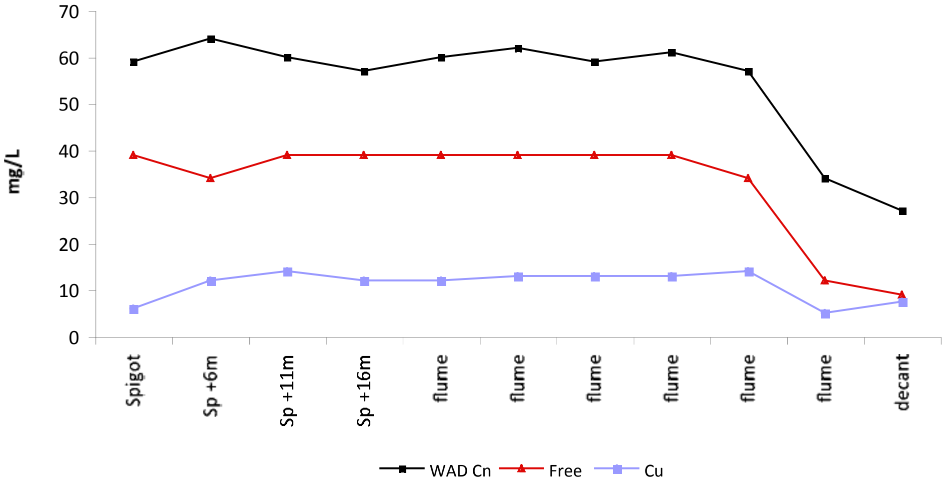


Figure 17. Cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile under saline conditions at BGS on 19 August 2007 during the M398 project

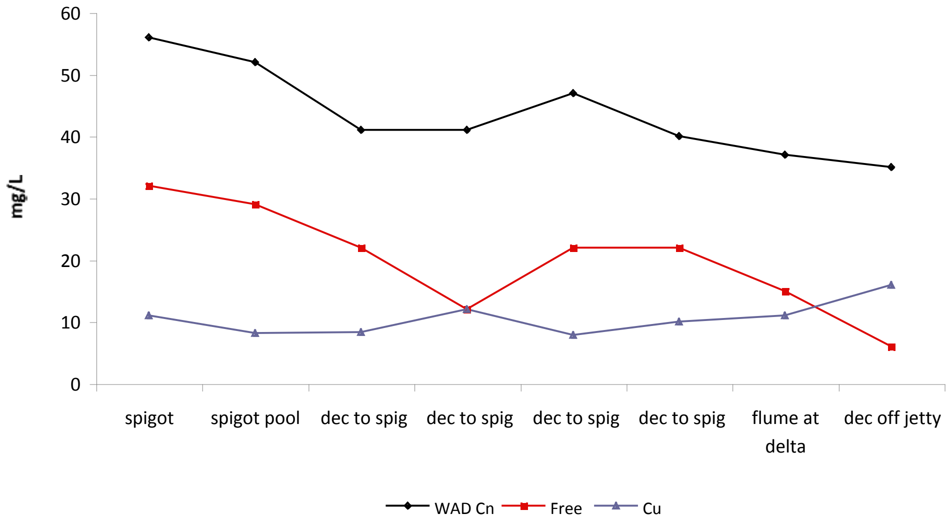


Figure 18. Cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile under saline conditions at BGS on 24 January 2008 during the M398 project

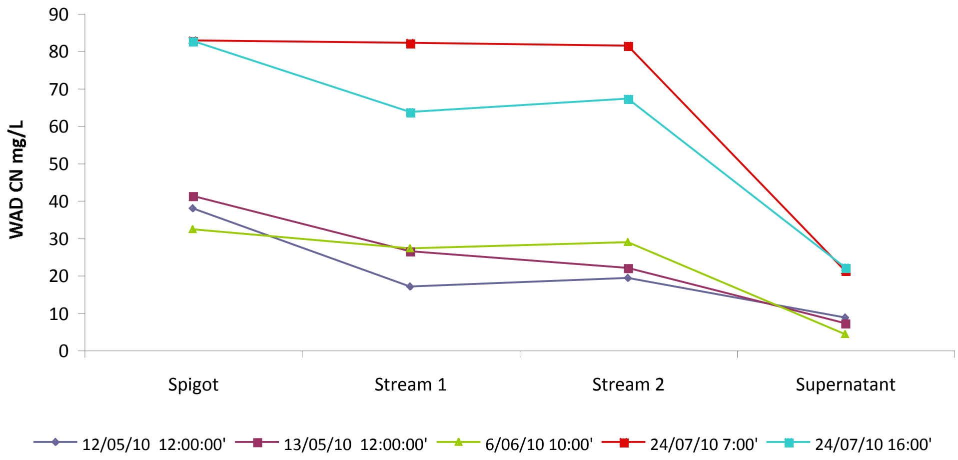


Figure 19. WAD Cyanide levels (mg/L) of a lucky spigot plume (spigot-to-supernatant) profile at BGS on five occasions (four days) under hypersaline conditions from May to July 2010. Locations for in-stream samples (stream 1 and 2) vary between lucky spigots depending on access.

Comparable data for GSI and BKB is presented in figures 20 and 21 under hypersaline conditions. During the M398 project, reduction in WAD cyanide in the spigot to supernatant plume during the summer sampling exercise in January/February 2008 was up to 8% and 55% for the saline (BGS and BD) and hypersaline (BKB and GSI) conditions, respectively.

Figures 20 and 21 demonstrate that substantial amounts of WAD and free cyanide were lost between the spigot and the supernatant, primarily very soon after discharge. Relatively little loss occurs from the tailings stream (plume) until contact with the supernatant (figures 20 and 21). At GSI the decline of free cyanide concentrations was rapid and complete, with little measurable free cyanide left, approximately half way to the supernatant under turbulent flow conditions (Figure 20). This loss corresponded with an increase in salinity (TDS). For WAD cyanide concentrations the loss was also initially rapid but then ceased as WAD cyanide stabilised to the level measured in the supernatant (Figure 20). The final WAD cyanide concentration was deduced to be strongly related to copper levels in the tailings. Similar trends were observed for BKB although concentrations were higher (Figure 21).

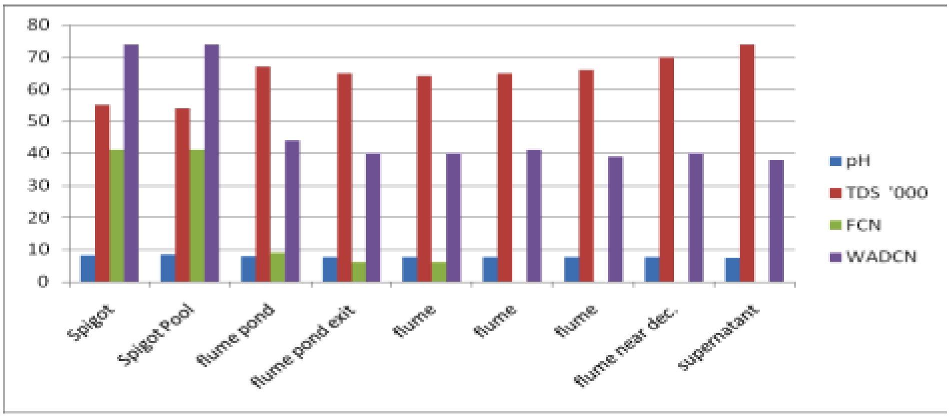


Figure 20. Cyanide levels (mg/L) in a hypersaline lucky spigot plume (spigot-to-supernatant) profile sampled at GSI in January 2008 during the M398 project

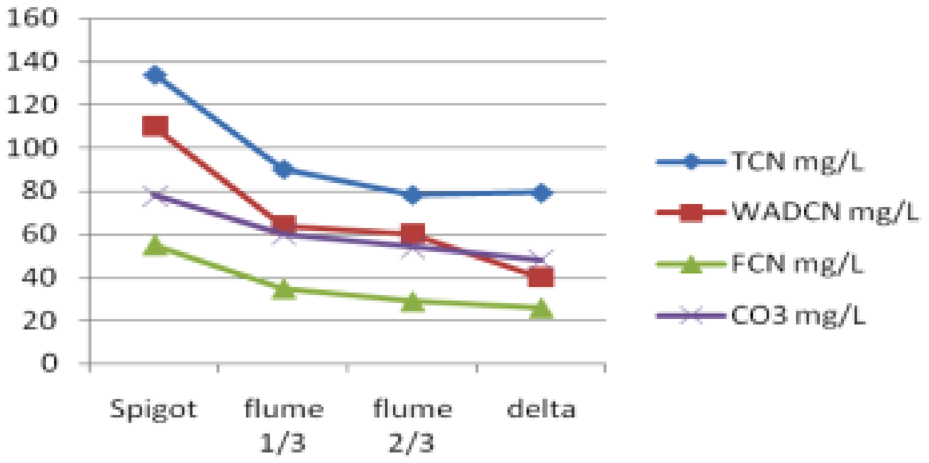


Figure 21. Cyanide levels (mg/L) in hypersaline lucky spigot plume (spigot-to-supernatant) profiled at BKB in Febuary 2008 during the M398 project

In both cases illustrated above, the initial cyanide loss primarily represents rapid breakdown of free cyanide under conditions where it is not pH stabilised (generally below pH 9.1). In contrast at BGS under hypersaline conditions during the current project the pH of the tailings at the spigot is at or just above 9.1 and hence cyanide loss is not as immediate as the tailings exits the spigot. The pH of the tailings rapidly drops on contact with the supernatant and a combined effect of rapid breakdown of free cyanide and dilution renders the supernatant at substantially lower cyanide concentrations. This is facilitated by the low copper concentrations.

Temporal sampling of a spigot pool was also conducted over a ten-hour period on 23 July 2010 soon after the spigot was turned off to document cyanide degradation. No cyanide degradation was evident after the first hour of sampling however the samples taken at 9:00 and 10:00 showed substantial degradation (25% and 36%, respectively). When the next sample was taken at 17:00, 85% of the WAD cyanide had been lost. Interestingly, the pH for the first four samples was between 9.1 and 9.3, hence cyanide loss over the first three hours was not pH related. The pH of the 17:00 sample was 7.8.

WAD and free cyanide concentrations were very similar and tracked each other over the ten-hour period (Figure 22) indicating that most of the WAD cyanide was composed of free cyanide. Salinity showed a noticeable increase after ten hours, probably due to evapo-concentration. Copper concentrations were low at less than 6 mg/L for all samples.

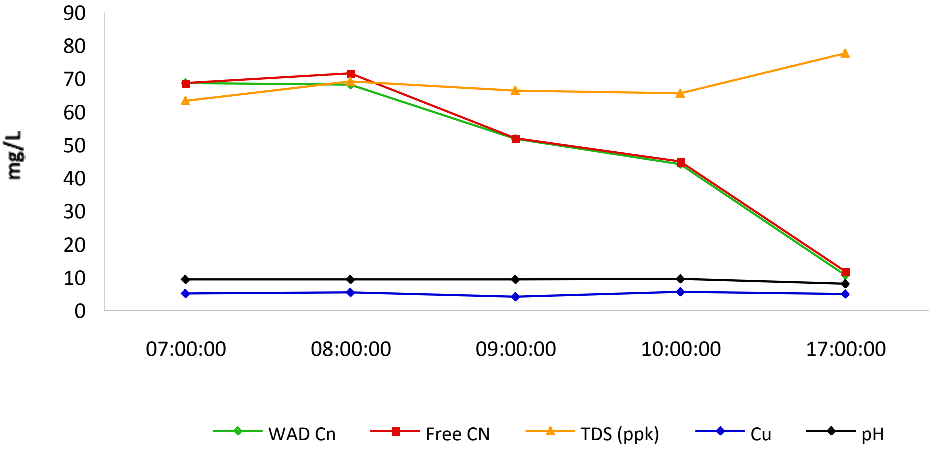


Figure 22. Cyanide levels (mg/L) measured at a spigot pool under hypersaline conditions at BGS on 23 July 2010

Spatial sampling of the supernatant

Spatial sampling of the supernatant with a RCB found that the supernatant is well mixed with no hot spots of elevated concentrations of cyanides. This was expected considering the lack of WAD cyanide stabilisers (copper and pH above 9.1) and environmental conditions (wind) mixing the solution. The supernatant was found to be shallow, less than 1 m deep. This mixing effect is expected to assist in maintaining a relatively high rate of cyanide degradation via the volatilisation and dilution mechanism.

Spatial sampling of the supernatant was conducted at various points around the decant finger on 22 and 23 July 2010 with four samples for each run. Results showed some variability in WAD cyanide concentrations but little variation in pH. Some of this variation may have been due to analytical error (Figure 23).

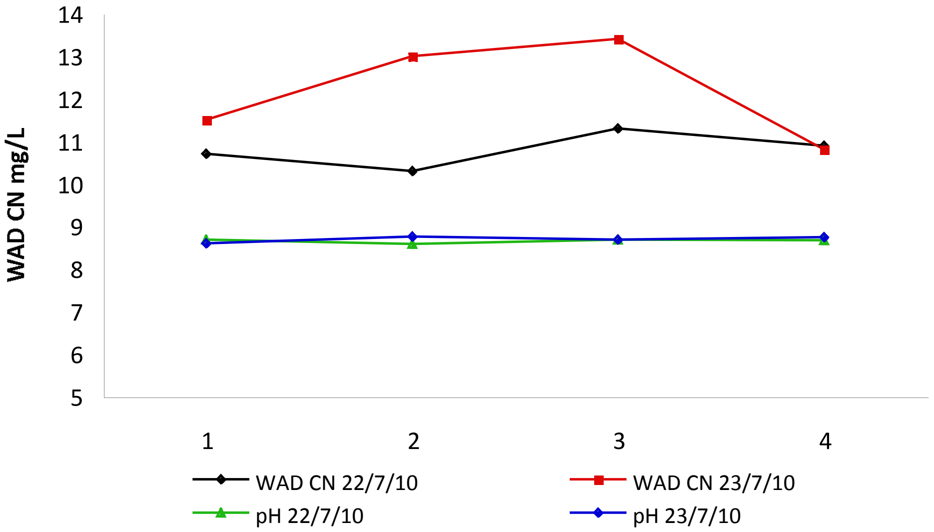


Figure 23. WAD cyanide levels (mg/L) and pH measured in the supernatant under hypersaline conditions at BGS on 22 and 23 July 2010

Cyanide speciation and metals

Cyanide-metalo speciation of some samples by ion chromatography (IC) was conducted during January 2008 (in the M398 study). Speciation for selected samples including one from July 2010 are provided in Table 10. All metalo-cyanide complexes are in very low concentrations, even within the plant sample, with the exception of copper and iron 2+ cyanides, which were between 8 and 17 mg/L for copper cyanide and 4 and 31 mg/L for iron cyanide (Table 10).

Table 10. Typical cyanide speciation values for selected samples taken in January 2008 and a single sample taken in July 2010, all values are in mg/L

Cyanide species	Analysis method Code	Limit of Reporting	25/1/08 11:30 BGS 21 CIP tank 6	24/1/08 16:58 BGS 17 Spigot	24/1/08 16:21 BGS10 Flume	27/1/08 9:39 BGS 52 Spigot	27/1/08 10:17 BGS 55 Delta	17/8/10 7:00 1 Spigot
TCN	iCNT1WTAA	0.01	200	170	150	140	140	93
TCN-SCN	iCNT4WTAA	0.01	150	130	110	110	81	92
WADCN	iCNW1WAAA	0.01	89	56	37	33	24	
FCN	iCNF1WATI	5	61	32	15	17	<13	62
Ag_CN	iCNSP1WSLC	0.5	<2	<2	<2	<2	<2	<2.0
Au_CN	iCNSP1WSLC	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co_CN	iCNSP1WSLC	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr_CN	iCNSP1WSLC	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cu_CN	iCNSP1WSLC	0.1	19	12	13	14	17	8
Fe2+_CN	iCNSP1WSLC	0.1	27	17	19	31	15	3.5
Fe3+_CN	iCNSP1WSLC	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ni_CN	iCNSP1WSLC	0.2	2	1.5	1.1	1.8	3	<0.2
SCN	iCO1WCDA	0.1	110	75	79	84	130	2.6
OCN	iCNO1WAIC	0.1	41	27	29	27	50	34

Typical metal analysis for spigot and supernatant samples taken on 22 July 2010 and analysed at the ALS laboratory is provided in Table 11. Again, all metals are in low concentrations except for copper (approximately 4 mg/L) and iron (between 5.8 and 7.1 mg/L), which is consistent with cyanide speciation results. Copper cyanides are included in WAD cyanide analysis. Iron cyanides are strong acid dissociable (SAD) and hence not considered toxic to wildlife and not included in WAD cyanide analysis.

Table 11. Representative samples showing typical metal concentrations (mg/L) at the spigot and in the supernatant. Samples were taken on 22 July 2010 under hypersaline conditions

	Analysis method	Reporting limit	15:00 spigot 12	15:00 supernatant 10
ED045G: Chloride Discrete analyser			22/7/10	22/7/10
Chloride	16887-00-6	1	30400	31 900
ED093F: Dissolved Major Cations				
Calcium	7440-70-2	1	1940	1 980
Magnesium	7439-95-4	1	639	664
Sodium	7440-23-5	1	21600	22 400
Potassium	7440-09-7	1	627	656
EG020F: Dissolved Metals by ICP-MS				
Aluminium	7429-90-5	0.01	<0.10	<0.10
Arsenic	7440-38-2	0.001	0.046	0.029
Beryllium	7440-41-7	0.001	<0.010	<0.010
Cadmium	7440-43-9	0.000	0.011	0.015
Chromium	7440-47-3	0.001	<0.010	<0.010
Copper	7440-50-8	0.001	4.58	4.13
Cobalt	7440-48-4	0.001	0.221	0.244
Nickel	7440-02-0	0.001	0.367	0.358
Lead	7439-92-1	0.001	<0.010	<0.010
Zinc	7440-66-6	0.005	0.249	0.134
Manganese	7439-96-5	0.001	<0.010	<0.010
Selenium	7782-49-2	0.01	<0.10	<0.10
Boron	7440-42-8	0.05	0.21	0.22
Iron	7439-89-6	0.05	7.13	5.81

Laboratory cyanide degradation test work

Degradation test work conducted for WAD cyanide in tailings solutions in July 2010 demonstrated that WAD cyanide degradation at the spigot was rapid at first with 77% being lost over the first four hours (Figure 24). The degradation then slowed considerably but did continue over the next 44 hours to the end of the trial.

A slow rate of degradation was evident in the supernatant sample for the first two hours but then the WAD cyanide concentration appeared to rise (Figure 24). The value given at the four-hour mark is questionable and may relate to analysis error. If the value is disregarded then degradation is fairly constant to the 24-hour point in the trial (Figure 24). Copper concentrations are an important stabilising factor for cyanide in the tailings environment. They are low in both spigot and supernatant samples (Table 12). The pH levels in both spigot and supernatant samples arrive at a similar point of 8.1 to 8.2 (Table 12), which is consistent with supernatant sampling results. The initial pH value given for the supernatant (9.6) is clearly not correct.

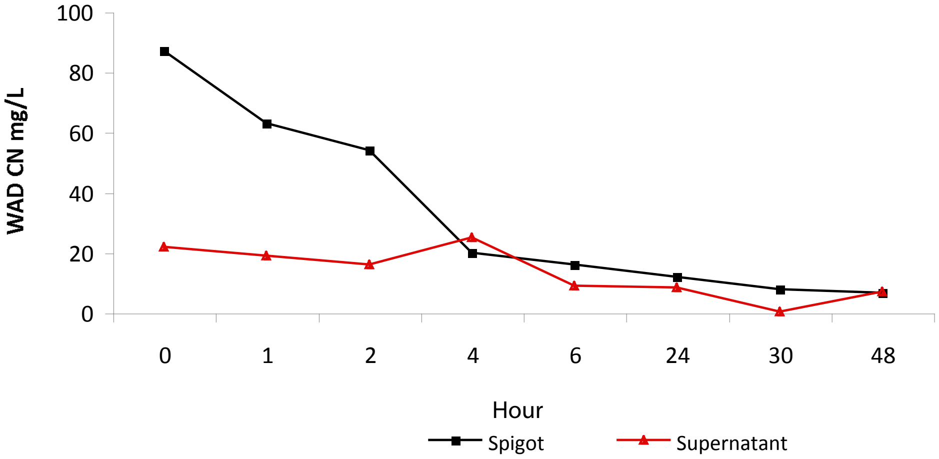


Figure 24. Cyanide degradation test chart of time versus cyanide concentration in mg/L for spigot and supernatant samples tested

Table 12. Summary of results from full analysis of BGS spigot and supernatant solutions at the beginning and end of the degradation trial

	Spigot		Supernatant	
	0 hour	48 hour	0 hour	48 hour
Free cyanide	56	< 5	9	< 5
WAD cyanide	87	6.6	22	7.1
Total cyanide	93	29	40	30
pH	9.6	8.2	9.6	8.1
Salinity (TDS)	54 000	57 000	59 000	64 000
copper	4.9	< 0.002	1.1	< 0.002

The above work builds on more in-depth degradation testing and analysis conducted during M398. The results and findings from the M398 laboratory cyanide degradation test work are replicated in full below.

First-order cyanide degradation rate constants were obtained for several synthetic solutions as well as spigot and supernatant filtrate solutions from the three sites under investigation in this study, via stirred vat tests carried out at an accredited metallurgical test work laboratory (SGS Lakefield Oretest in Perth). Solutions were made up with NaCN in a matrix with the approximate composition of concentrated seawater.

Cyanide and pH levels recorded through the 48-hour tests on four synthetic solutions of increasing salinity are illustrated in Figure 25. Cyanide levels decreased in all cases but at much faster rates as the salinity increased. The pH values were observed to initially increase somewhat (due to the loss of hydrocyanic acid, HCN, by volatilisation – equations 1 and 2), followed by a steady drop in pH value over a longer period (due to absorption of carbon dioxide, forming carbonic acid – equations 3 to 5):

$$\mathrm{CN^{-}\ (aq) + H_2O = HCN\ (aq) + OH^{-}\ (aq)} \quad (1)$$

$$\mathrm{HCN\ (aq) = HCN\ (g)} \quad (2)$$

$$\mathrm{CO_2\ (g) = CO_2\ (aq)} \quad (3)$$

$$\mathrm{CO_2\ (aq) + H_2O = H_2CO_3\ (aq)} \quad (4)$$

$$\mathrm{H_2CO_3\ (aq) = H^{+}\ (aq) + HCO_3^{-}\ (aq)} \quad (5)$$

First-order kinetics of cyanide loss reactions have been well established by several studies [29-32] and the results are therefore to be expected.

The pertinent volatilisation rate equation is expressed by equation 6:

$$-(d[HCN]/dt) = kv\,[HCN] \qquad (6)$$

where [HCN] is the concentration of dissolved HCN in the solution, and kv is the first-order rate constant.

Integration and rearrangement yields equation 7:

$$\ln[HCN] = \ln[HCN]_o - kv\,t \qquad (7)$$

When the pH value of the solution is sufficiently below the hydrocyanic acid pKa value, the majority of the free cyanide exists in the form of HCN and free cyanide can be substituted for HCN in equation 7. The pH of 90% HCN occurs at about 8.0 for fresh solutions and 8.5 for solutions of TDS ~200 000 mg/L. Values of kv under the various test conditions were determined from plots of ln[CN] against t.

HCN volatilisation is well known to account for the majority of the cyanide degradation occurring in TSF systems [29-32]. Equation 7 can thus provide a simple predictive model for determining the cyanide degradation expected in a system given a certain initial cyanide concentration and retention time.

First-order rate constant data calculated from the test work results is summarised in Tables 13 and 14. Coefficients of correlation (R2), excluding the supernatant solutions, which showed very low degradation rates, averaged ~0.95. The effect of salinity (expressed as TDS) on the rate of cyanide loss is illustrated in Figure 26, which shows an increase in cyanide volatilisation rate as salinity approaches the 50 g/L hypersaline barrier, beyond which the rate essentially plateaus. This effect is consistent with the pH buffering effect, resulting in lower pH values at higher salinities.

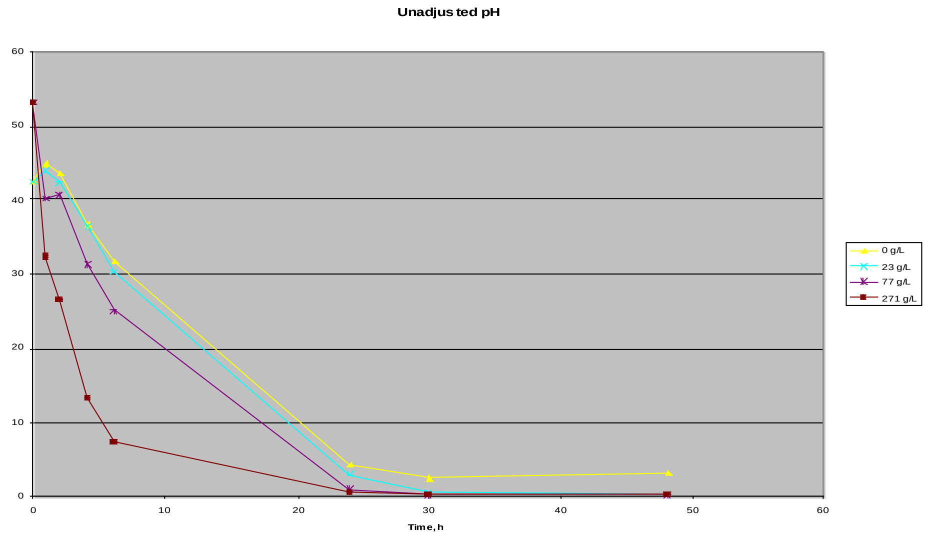


Figure 25. Effect of salinity on (a) cyanide degradation and (b) pH value, from synthetic solutions of TDS (i) 0 mg/L; (ii) 23 mg/L; (iii) 77 mg/L; and (iv) 271 mg/L

In contrast, holding the pH value constant at ~8.5 produces the reverse effect, i.e. a decrease in cyanide volatilisation rate as salinity approaches the 50 mg/L hypersaline barrier, beyond which the rate again plateaus.

The effect of copper is to decrease volatilisation rates to levels similar to those observed for plant spigot solutions, most likely an effect of ligand exchange of the fourth CN– ion between Cu(CN)43–.

Table 13. Kinetics of cyanide loss from synthetic solutions of various salinities

	k1 (h-1)		
TDS (g/L)	NaCN	NaCN (pH 8.5)	copper/cyanide
0	0.0994	0.4088	0.0325
23	0.1414	0.2844	0.0446
77	0.1745	0.2478	0.0416
271	0.1693	0.2615	0.0588

Table 14. Kinetics of cyanide loss from plant solutions of various salinities

	Spigot	Supernatant		
	TDS (g/L)	k1 (h-1)	TDS (g/L)	k1 (h-1)
BGS	16	0.0344	20	0.0273
GSI	51	0.0509	56	0.0115
BKB	230	0.0792	230	0.0129

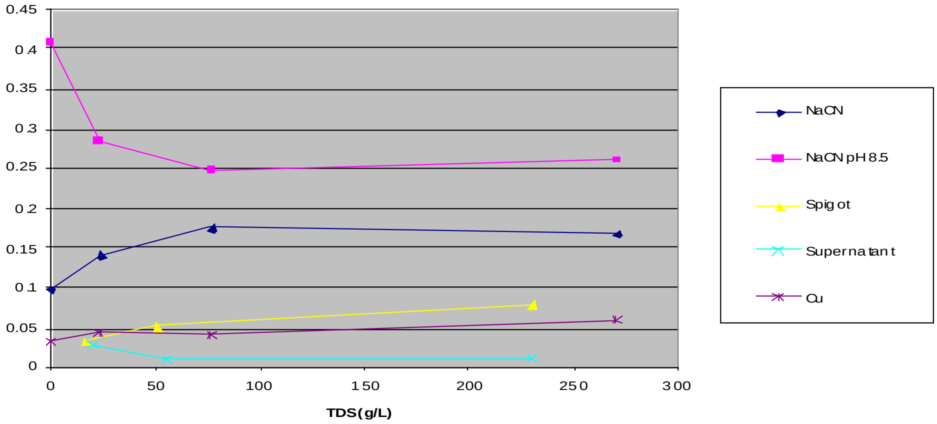


Figure 26. Effect of salinity on first-order rate constant for cyanide loss from solution in a stirred vat (500 mL, 50 rpm, 20 oC)

Outcomes of the above results are as follows:

Increasing cyanide degradation rates occur in well-mixed solutions exposed to the atmosphere at increasing salinities.

Ultimately high cyanide losses are achieved in TSF supernatant systems at sufficiently long retention times, regardless of salinity, due to the pH drop arising from atmospheric carbon dioxide absorption (depending on initial pH value).

Adjustment of pH value of the synthetic solutions to the ~8.5 levels found in the plant solutions proved problematic because cyanide started volatilising immediately and was lost at a very rapid rate. Adjustment to higher levels caused precipitation of metal hydroxides such as magnesium, resulting in a non-comparable system.

Plant solution degradation tests on both spigot and supernatant solutions were carried out for all three sites. The data illustrated the rapid loss of free cyanide in the first hour or two, with residual WAD cyanide stabilising at levels similar to that of the respective supernatant solutions, with copper-bound cyanide showing resistance to further degradation. The hypersaline sites showed faster kinetics, as expected.

Synthetic copper cyanide degradation tests at different salinities exemplified the stabilising effect of copper on WAD cyanide, with cyanide degradation halting after about 24 hours in all cases, with WAD cyanide to copper ratios remaining at ~0.8 from 24 hours through to 120 hours (see Figure 27), consistent with the stable Cu(CN)32– remaining in solution for lengthy periods, as found previously [32].

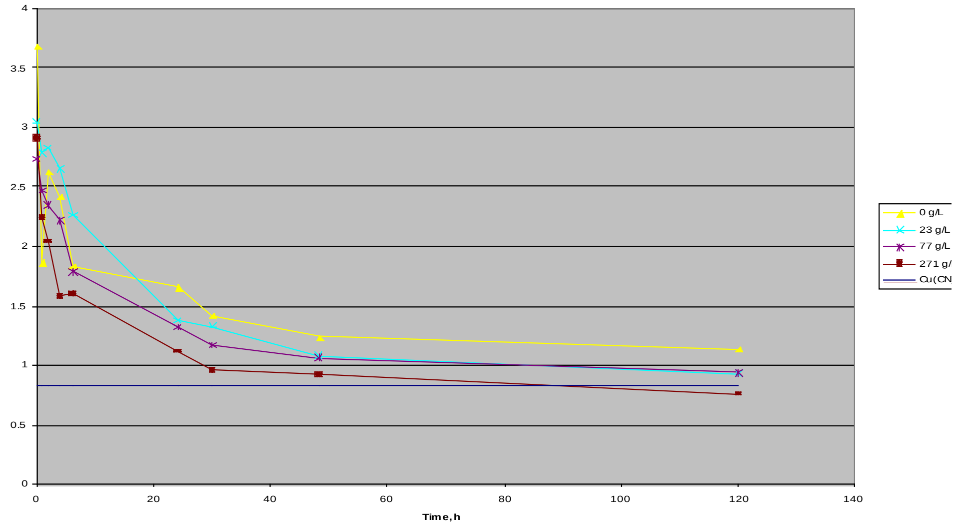


Figure 27. Effect of copper on the WAD cyanide to copper mass ratio, from synthetic solutions of TDS (i) 0 mg/L; (ii) 23 mg/L; (iii) 77 mg/L; and (iv) 271 mg/L. Theoretical value corresponding to Cu(CN)32– is included.

Special projects investigation (M398)

The following are findings from the four special project investigations conducted during M398.

Special Project 1

Avian wildlife should not be adversely affected by moving over dry beaches because the residual free cyanide levels are negligible and the residual WAD cyanide levels are also very low. This was clearly demonstrated by the low cyanide values determined by de-ionised water leaching (representing the influence of exposure to rain water). The alkaline leach provided an indication of the maximum WAD cyanide solubility from the dry beach. The values of recovered WAD cyanide were also low. As expected, the wet beaches showed slightly higher residual WAD cyanide levels, but they too are considered to be very low. Subsequent samples were taken in August 2010 however results were not available at the time of report finalisation.

Special Project 2

The preservation of samples sent to laboratories can potentially affect the integrity of the results. High sodium hydroxide additions may cause some reductions in the levels of WAD cyanide, metal-cyanide complexes and metals. This has been noted particularly for highly saline samples containing significant amounts of magnesium. The pH of the solution to be preserved will not rise above a pH value of 10 by the addition of sodium hydroxide pellets unless almost all of the magnesium has been precipitated as magnesium hydroxide. The magnesium hydroxide precipitate may trap metal-cyanide complexes or metal ions from solution, resulting in low results. Total cyanide results may also be adversely affected as high additions of sodium hydroxide can reduce the acidity of the digest solution, causing incomplete liberation of the cyanide ions for subsequent quantification.

Special Project 3

Some interesting and potentially useful data was obtained for the evaluation of any protective mechanisms and exposure levels for avian wildlife. Avian wildlife produce different amounts of gastric juices according to quantities of food or water consumed. Tests were designed to mimic intake of different quantities of test solution into gastric juices of different strength (stomach acidity is species dependent) and to determine the amount of cyanide that could be liberated and potentially adsorbed by the wildlife. These results were recalculated into absolute micrograms per actual test volumes. Allowing for representative weights of some avian species and the reported literature values of toxicity data for the respective species enabled the estimation of potential volumes of harmful solution and trigger cyanide concentrations. Solutions with a higher alkaline buffering capacity resulted in higher tolerance levels for the consumption of solutions with a higher WAD cyanide concentration. However, comparing the special project 3 results for BGS with those for GSI and BKB show higher free cyanide released in the latter two cases at the same pH values, so an interpretation is that the beneficial buffering effect, while present, is outweighed by increased HCN volatilisation at high salinity.

Special Project 4

Copper was identified as a significant component of the WAD cyanide and is well known as a stabilising agent for WAD cyanide in TSF supernatant waters. Control of copper levels in tailings and supernatant waters is therefore important, hence, the advantage of accessing a simple assay method for the analysis of copper in on-site laboratories was mooted. It was found that copper could feasibly be analysed on site by flame AAS by direct aspiration into the flame. While higher salinities caused a slight reduction of the results, a ten-fold dilution with the lower salinity standard diluent solution gave results close to reference values for the test solution obtained by digestion and aspiration into an ICP-AES instrument. At sites where copper levels are relatively high or where fluctuations due to re-circulating load balances or ore mineralogy are expected, provision of copper monitoring data via on-site AAS should be considered.

Alternative water body sampling

Alternative water bodies have been sampled on occasion by DES for cyanides and physical chemistry. Results are given in Table 15 and show that cyanides are either below detection levels or very low (< 1 mg/L) at all water bodies. Analysis of cyanides is difficult at such low levels and values given should be treated with caution, hence it is unlikely that WAD cyanide levels are higher at the haul road lakes than at the seepage trench.

Occasional on-site sampling results for TDS and pH are given in Table 16 and show that Granny, Goanna and Keringal pits are all very hypersaline at > 200 000 mg/L TDS, that Winditch Pit is saline and Jubilee Pit is quite fresh. Interestingly the hypersaline pits have a noticeably lower pH than the other two pits (Table 16).

Table 15. Chemistry results for DES sampling of alternative water bodies conducted during this and previous projects

		Analysis	WAD cyanide	Free cyanide	Total cyanide	pH	TDS
TSF seepage drain	21/05/2006	CCWA	0.03				42 500
TSF seepage drain	25/07/2010	ALS	0.277	0.204	0.931	7.83	25 400
Winditch Pit	26/05/2008	CCWA	0.02	< 0.01	< 5	7.2	12 000
Goanna Pit	26/05/2008	CCWA	<0.01	<0.01	<5	7.1	290 000
Haul road lakes	2/05/2010	On-site	0.8				1 540

Table 16. Averages for TDS and pH from occasional on-site monitoring at old on-site pits, conducted between 11 November 2006 and 30 July 2010.

	N=	TDS	N	pH
Winditch Pit	18	8 896 ± 3 775	6	7.9 ± 0.4
Goanna Pit	23	297 227 ± 27 803	6	7.4 ± 0.2
Granny pit	6	230 000 ± 20 000	6	7.2 ± 0.2
Keringal Pit	6	268 333 ± 4 083	6	7.4 ± 0.2
Jubilee Pit	1	2 000	1	8.4

Quality assurance and quality control of chemistry data

Comparison of on-site and ALS chemistry analysis

The on-site picric acid WAD cyanide analysis results are compared with the NATA registered ALS laboratory Discrete Analyser instrument method (Figure 28). Duplicate spigot samples from 16 February 2009 to 21 January 2010 were used in comparative analysis. The on-site laboratory picric acid method provided results higher than the ALS results. The mean value for the on-site laboratory was 61.2 mg/L compared to the ALS assay of 42.9 mg/L (n = 46). The mean difference is 18.3 ± 6.1 (95% C.I.). This represents an overestimation of 30% ± 9.9%. The correlation between the two laboratories for WAD cyanide analysis is close (R2 = 0.54). Of interest is that the strong correlation represents a consistent overestimatation by the on-site laboratory of approximately 30% for the period of these samples, which may relate to over-aggressive acidic digestion of samples.

This relationship is not held up for comparisons of ALS and on-site data collected in May, July and August 2010 under hypersaline conditions (Table 17, Figure 29). In May 2010 on-site WAD cyanide analyses averaged 47.5% ± 21.9% higher than ALS results and but ranged between 18.9% and 112.4% difference. In July 2010 on-site analysis was very close to that of ALS results (Figure 29) with only 1.3% ± 6.9% difference on average (Table 17). This is understood to be due to additional QA and QC measures employed in the laboratory for this time period (such as making of new standards, etc). In August 2010 the average difference between on-site and ALS results was 15.9% ± 8.0% but this time with on-site results being lower (Table 17). Since January 2010 there has been no obvious relationship between on-site and ALS results for WAD cyanide analysis.

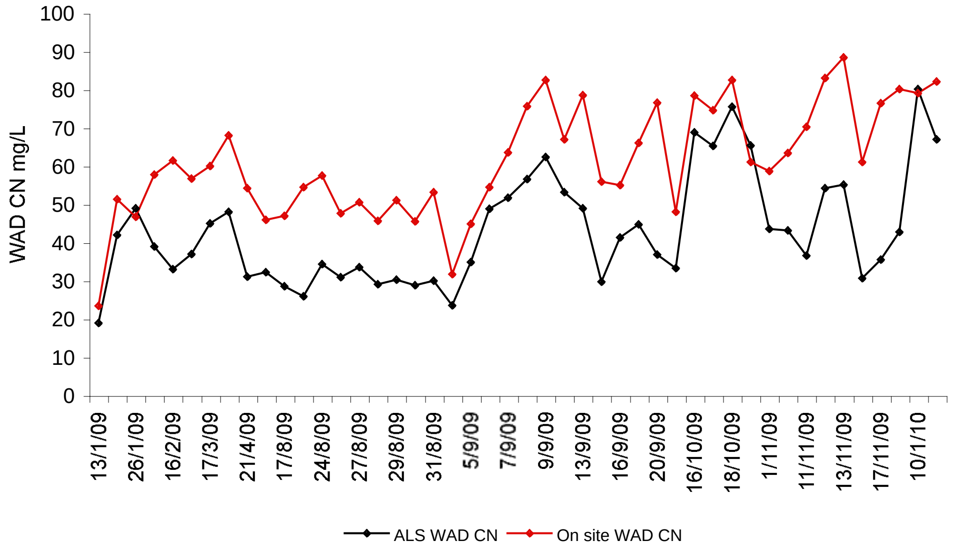


Figure 28. ALS and on-site laboratory WAD cyanide analysis between 13 January 2009 and 24 January 2010

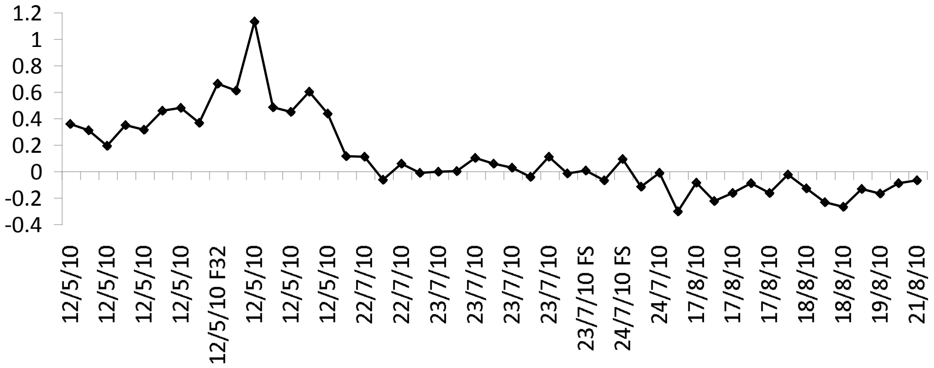


Figure 29. Per cent difference of on-site WAD cyanide analysis from ALS analysis for samples taken in May, July and August 2010

Table 17. Average per cent variance of on-site WAD cyanide analysis, from ALS analysis for three site visits. Positive averages indicate higher analysis values and negative averages indicate lower analysis values. The number of samples compared, standard deviation, minimum variation and maximum variation are also shown for each site visit.

	Number of samples compared	Average	Standard deviation	Minimum	Maximum
May 2010	15	47.5%	21.9%	18.9%	112.4%
Jul 2010	18	1.3%	6.9%	-0.1%	-12.1%
Aug 2010	14	-15.9%	8.0%	-3.2%	30.8%

Samples were split between ALS and on-site laboratories and analysed for salinity (TDS) in May and August 2010 (Figure 6). ALS analysis results were consistently higher than on-site results (Figure 6) by between 5% and 45% with an average of 22% ± 10.4% difference.

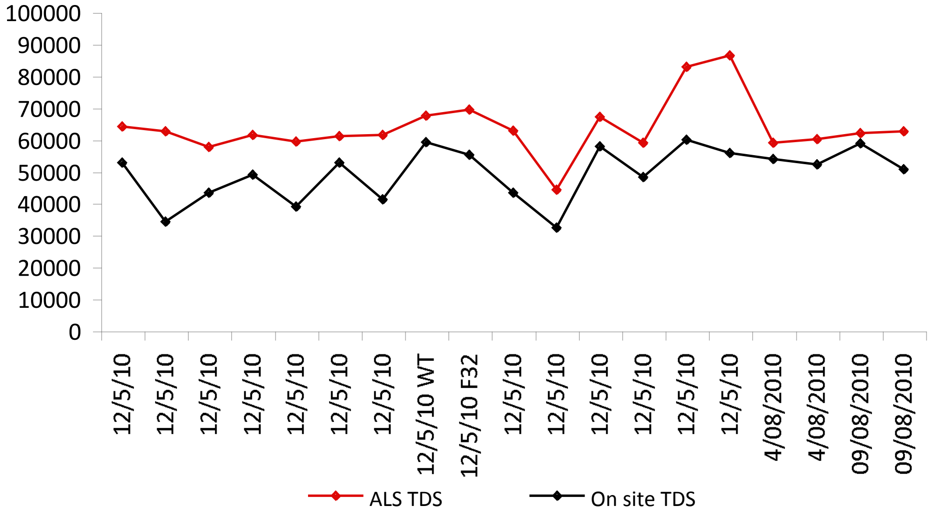


Figure 30. Results from on-site and ALS salinity (TDS) analyses for samples taken in May and August 2010

Comparison of off-site laboratory results

QA and QC for DES chemistry sampling included three-way splits of chemistry samples for analysis on site, at ALS and CCWA laboratories in Perth. QA and QC testing commissioned by BGS included three-way splits of spigot and supernatant sampling on 4 and 9 August 2010. Sampling results for WAD cyanide, pH, TDS and copper from three-way splits are presented in figures 31 to 33.

The percentage difference of CCWA and on-site results from ALS results is presented in Figure 34. Interestingly CCWA and ALS WAD cyanide results differed by more than 10% in ten samples and in three samples the difference was 50 to 60%. For 12 results they were within 10% of the ALS result (Figure 34). CCWA analysis for TDS was very close to ALS results, generally within 5% (figures 31, 32, 33 and 34) although one CCWA TDS result differed from ALS by 12%. On-site copper results differed substantially in terms of per cent from ALS results however concentrations were low, which may have affected accuracy (Figure 33).

Comparison of total WAD and free cyanide values given for specific samples analysed at off-site laboratories revealed some inaccuracies with free cyanide values given as slightly higher than WAD cyanide values on some occasions.

One spigot sample (10:30, spigot 12 taken on 18/8/10) was split and both samples were sent to CCWA for analysis. Results of 65 and 73 mg/L WAD cyanide were returned, an error of about 11 to 12%.

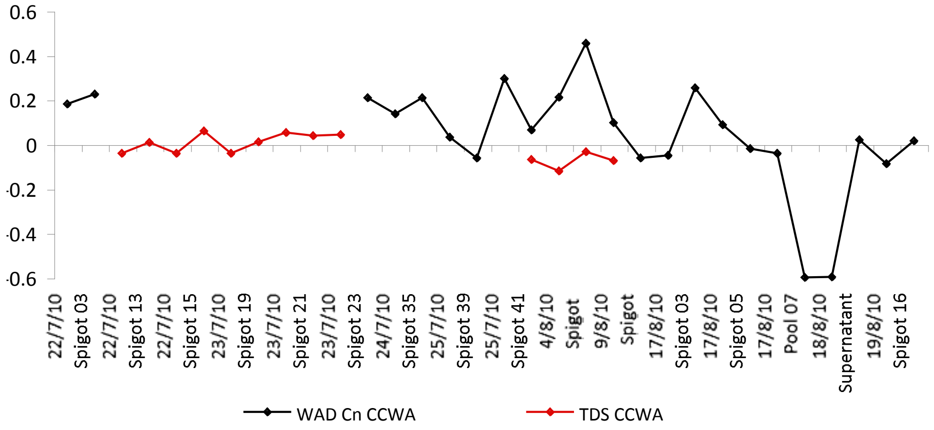


Figure 31. Results from chemistry samples taken by DES in July and August 2010 and split for WAD cyanide analysis by on-site, ALS and CCWA laboratories

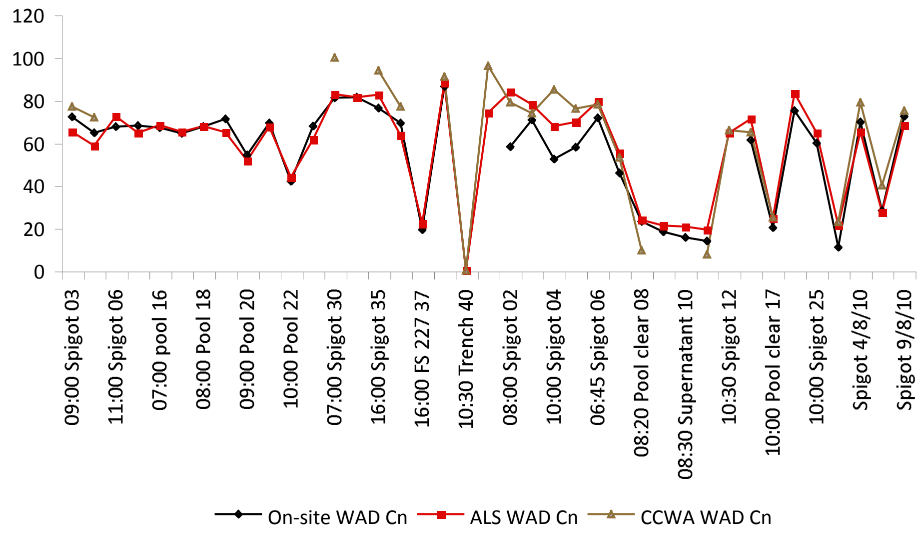


Figure 32. Results from chemistry samples taken by DES in July and August 2010 and split for pH and copper analysis by ALS, on-site (copper only), and CCWA laboratories (pH only)

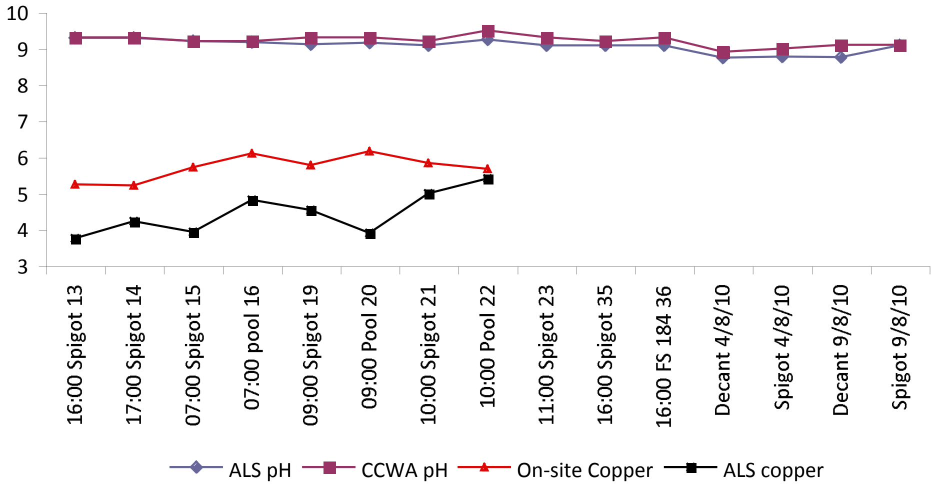


Figure 33. Results from chemistry samples taken by DES in July and August 2010 and split for TDS analysis by ALS and CCWA laboratories

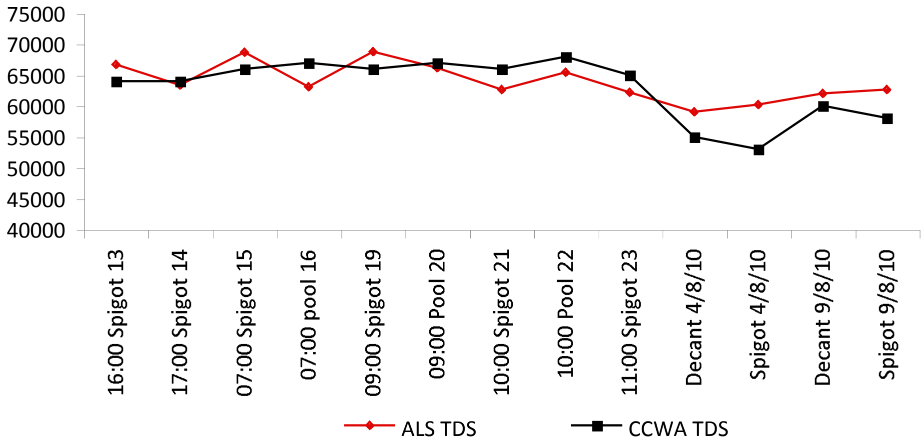


Figure 34. Per cent difference of CCWA results from ALS results for WAD cyanide and TDS in samples taken during July and August 2010

Quality assurance and quality control of chemistry sampling during M398

During the M398 project consultants carried out blind checks by the National Measurements Institute (NMI) laboratory on the selected laboratory, CCWA. In addition the consultants sent a number of blind samples to CCWA. In the initial phase of the project approximately 15% of the total analytical sample load was allocated to QA samples. This proportion of QA was kept for phase 2 of the program but the number of check samples sent to NMI was reduced in the January/February sampling period and completely stopped in the May/June sampling period due to a lack of accuracy of results (particularly in cyanide analyses) and efficiency of the NMI laboratory (excessively long delays to complete the assays). The number of blind check samples was correspondingly increased in the phase 2 sampling periods. An example of the analytical variation between the laboratories is shown in Table 18.

Table 18. Comparison of two samples assayed by CCWA and NMI

	Sample id.	BGS 41	BGS 41	BGS 42	BGS 42	BGS 53	BGS 53	BGS 57	BGS 57
	Laboratory	CCWA	CN balance	NMI QC 41	CN balance	CCWA	CN balance	NMI QC 53	CN balance
		Assay	Calculated	Assay	Calculated	Assay	Calculated	Assay	Calculated
EC	mS/m	n/a		n/a		2 650		2 520	
TDS	mg/L	n/a		n/a		18 000		17 900	
Cyanides									
FCN	mg/L	<5	21	19	19	9	9	15	15
WADCN	mg/L	26	24.3	27	41.3	26	20.6	20	37.3
TCN	mg/L	65	50.4	44	67.4	120	102.4	44	147.4
Metals									
Cu	mg/L	15	18.4	n/a (15)2	18.4	7.6	9.3	15	18.4
Ni	mg/L	2.2	3.9	n/a (2.2)2	3.9	1.3	2.3	2.2	3.9
Co	mg/L	0.33	0.86	n/a (0.33)2	0.86	0.21	0.56	1.4	3.7
Fe	mg/L	9	25.2	n/a (9)2	25.2	29	81.2	38	106.4

As outlined in Table 18, the determined WAD cyanide results of both laboratories are in reasonable agreement. The WAD cyanide balance calculation based on respective assays of free cyanide and the cyanide complexes of copper and nickel indicate some significant deviation for the NMI results. The consultant reviewed the internal QC of the laboratories and was satisfied with the results but decided to supplement the QCs with blind (to CCWA) duplication of samples registered in the same batch but out of sequential order with the sample duplicated. Results were generally good and are provided for selected analytes (TDS, WAD cyanide, copper and iron) in the provided spreadsheet. Two of the duplicated samples included the metal cyanide complexes and their comparison was excellent. To further enhance the QA, CCWA were required to carry out analytical checks on designated samples (blind to CCWA) for total and WAD cyanides by alternative procedures, i.e. by APHA methods (normal procedures use SFAA methods as per ASTM) and also check recoveries at two different added concentrations. The comparison is provided in Table 19.

Table 19. Comparison of methodologies and recoveries

Method	SFAA mg/L	APHA mg/L	APHA Recovery %	APHA Recovery %
WADCN	120	97		
	120	88		
TCN	190	160		
	190	190		
	42	44	106	104
	32	38	117	112

The results are generally within acceptable limits except for two sets of WAD cyanide for the hypersaline sites, one each for BKB (66.5 ± 32.5 mg/L) and GSI (56.5 ± 22.5 mg/L), which are difficult to explain. Apart from the two cited examples, the salinity, or more correctly the matrix, appears to affect both methods to some degree and both methods provide comparable results.

References

Adams, M. D., 1990. The chemistry of cyanide in the extraction of gold. 1. Kinetics of cyanide loss in the presence and absence of activated carbon. J. S. Afr. Inst. Min. Metall. 90(2): 37-44.

Adams, M. D., 1990. The chemistry of cyanide in the extraction of gold. 2. Mechanisms of cyanide loss in the carbon-in-pulp process. J. S. Afr. Inst. Min. Metall. 90(3): 67-73.

APHA, 2005. Standard methods for the examination of water and wastewater, 4500-Cyanide, 21th edition. Washington D.C., APHA.

Donato, D. B. G. B. Smith, 2007. Summary of Findings: ACMER Project 58, Sunrise Dam Gold Mine Sponsor's Report, Anglogold Ashanti Australia. Donato Environmental Services, Darwin.

Noller, B. N. R. S. Schulz, 1995. The effects of cyanide preservation procedures on analytical results. 4th Environmental Chemistry Conference, Darwin, Northern Territory Australia, Environmental Chemistry.

Simovic, L., W. J. Snodgrass, K. L. Murphy J. W. Schmidt, 1985. Development of a model to describe the natural degradation of cyanide in gold milling effluents. Cyanide and the Environment, Tucson Arizona, Colorado State University.

US EPA, 1998. Cyanide - Water Quality Standards Criteria Summaries: A compilation of State/Federal Criteria. Office of Water.

Appendix 3: Wildlife survey

Wildlife survey and analysis methodology

The aim of this methodology is to document wildlife ecology, wildlife deaths and exposure pathways to mine waste solutions in order to explore and assess potential protective mechanisms associated with hypersalinity.

Data presented in this report is sourced from on-site monitoring results (BGS) and data collected over a number of site visits by Donato Environmental Services (DES). All data is considered in its entirety with no omissions. The methodology describes all the data collected, including under the ACMER P58 and M398 projects.

Routine on-site monitoring regime by trained mine staff

On-site wildlife monitoring of tailings dams

Within the TSF, only the operating cells and the surrounding ground water interception trench (seepage trench) were monitored regularly (i.e. the cells that were being discharged into). However non-active cells were also surveyed from time to time. All habitats within the TSF were carefully surveyed to determine presence of both alive and dead animals. All observations were conducted using binoculars with 8x or greater magnification.

On-site personnel conducted wildlife monitoring at the BGS TSF on a total of 1 023 days (71.8%) between 16 June 2006 and 7 May 2010, when the TSF was saline. The TSF was monitored on 70 days (68.0% of a potential 103 days) between 8 May and 18 August 2010 as a hypersaline system.

TSF active cells were monitored for a period of 15 to 20 minutes, mostly commencing within three hours of sunrise. This time frame was chosen to maximise biodiversity detection. Morning surveys would also be expected to detect resultant carcasses of waterbirds that are active nocturnally before they were entombed by subsequent tailings deposit or scavenged. The seepage trench was monitored on 478 days. It is monitored by driving slowly along the trench and looking for wildlife. Occasional stops are made to look for wildlife or when wildlife is observed. This survey takes approximately 15 minutes.

Some on-site personnel that conducted on-site wildlife monitoring received specialised training from DES during the ACMER P58, M398 and this current study. Training aimed to aid on-site observers in detecting the presence of wildlife, identifying it and recording its habitat use. Special attention was focused on waders from the families *Scolopacidae* and *Charadriidae*, which can be difficult to observe and identify. Wading birds are regular visitors to gold mine TSFs and can be resident within these systems (Smith, Donato, Gillespie et al. 2007) however they are often under-reported or not detected (Donato 1999; ACMER Project 58 unpublished data 2007). Training was conducted through presentation and field activities.

Wildlife, if not identified to species level, was grouped according to guilds, which were ducks, herons and egrets, other waterbirds, waders, parrots and pigeons, bush birds, raptors, martins and swallows, and corvids. While most observations were recorded to species level, analysis of on-site wildlife data is primarily at the guild level due to the difficulties in identifying many species.

The following data was also recorded:

- observer's name;
- date of survey and start and finish times;
- wildlife guild and or species observed and the number of individuals present (alive and dead);
- habitats within the TSF used by each guild and or species; and
- behaviour of each guild and or species.

Habitat categories used by on-site monitoring are defined in Table 1.

Table 1. TSF habitat data categories

Data category	Definition
Supernatant	Open water within the tailings paddock
Wet tailings	Wet mine waste slurry
Dry tailings	Dry mine waste slurry
Beach/wet tailings	Beach interface between the supernatant and wet tailings
Beach/dry tailings	Beach interface between the supernatant and dry tailings
Infrastructure	Infrastructure, such as poles, scaffolding and pump stations
Aerial	Only for wildlife flying over the TSF
Walls	Outer paddock walls and the decant key wall

Intensive diurnal wildlife monitoring

Particular attention was given to wildlife use of the TDZ as this is the area where WAD cyanide concentrations are highest. A TDZ is defined as the area between active (or very recently active) discharging spigots and the supernatant including the tailings plume, where the tailings entering the supernatant is still concentrated. The TDZ includes spigot pools, wet (fresh) tailings, flowing tailings stream, wet tailings beaches, clear pools and plume habitats. Habitats within the TDZ are categorised into finer resolution than for the rest of the TSF to gain a greater understanding of the risk presented to wildlife from TDZ habitats. Data analyses have been carried out for the TDZ and the rest of the TSF separately or combined where appropriate to gain a greater understanding of risks to wildlife of cyanide within the TSF. The TDZ moved to different parts of the TSF on a rotational basis for operational reasons.

Monitoring was also conducted at a number of alternative water bodies, primarily at Goanna Pit (hypersaline), Winditch Pit (brackish), the haul road lakes (fresh) and the dewatering trench surrounding the TSF (hypersaline) although other on-site water bodies were also visited. Alternative water bodies surveyed during this and previous projects are listed and broadly categorised in Table 2. Data collection methodologies employed at alternative water bodies are the same as those used at the TSF.

DES-collected data relating to wildlife presence, abundance, habitat use and behaviour including carcass presence detection trials of carcass replicates. The intensive diurnal wildlife surveys were conducted at the TSF over a total of 56 days since 2006. Of these, 34 monitoring days were conducted on the TSF as a saline system (< 20 000 ppm TDS), and 22 monitoring days during this project as a hypersaline system (Table 2). Alternative water bodies were observed on a varying number of days accordingly (see Table 2).

Table 2. Number of days monitored and 20-minute surveys performed for the TSF and alternative water bodies during this and previous projects. Wetland description, size and salinity for the TSF and alternative wetlands are also given.

Location	Wetland descriptors	Salinity	Wetland Size	Number of days (% of days) observed by on-site monitoring	Number of days observed by consultants	Number of 20 minute surveys*
TSF						
TSF (Saline) – 15/6/06 to 7/5/10	Paddock cells, shallow bowl	>50 000	5 – 10 ha	1023 (71.9%)	34	119
TSF (Hypersaline) – 8/5/10 to 21/8/10	Paddock cells, shallow bowl	>20 000	5 – 10 ha	70 (68.0%)	22	113
Alternative fresh water bodies						
Sewage ponds	Multi-celled shallow dam	<5 000	<1 ha		10	6
Ti-tree dam	Single-celled stock dam	<2 000	<1 ha		4	3
Haul road lakes	Shallow borrow pit	<2 000	5 – 10 ha		17	17
Phoenix Pit	Water-filled pit	<2 000	10+ ha		5	3
Jubilee Pit	Water-filled pit	3 600	10+ ha		2	2
Alternative saline water bodies						
Winditch Pit	Water-filled pit	12 000	10+ ha		12	11
Haul road borrow pit	Shallow borrow pit		5 – 10 ha		5	5
Sediment dam	Single-celled dam		<1 ha		1	1
Seepage trench	Trench	27 000	Linear	478	23	17
Alternative hypersaline water bodies						
Saline wash (duckpond)	Shallow wash	63 000	<1 ha		23	35
Lake Carey-hypersaline discharge	Shallow wash	>100 000	1 – 5 ha		3	3
Goanna Pit	Water-filled pit	220 000	10+ ha		12	11
Granny's Pit	Water-filled pit	210 000	10+ ha		8	4
Keringal Pit	Water-filled pit	220 000	10+ ha		2	2

* Observations of alternative waterbodies during ACMER P58 were conducted as opportunistic observations and not 20 minute surveys

DES collected a number of different types of data to document wildlife ecology and exposure pathways to mine waste solutions. The wildlife data collection can be categorised as follows:

- intensive diurnal observations of birds and terrestrial mammals recording presence, abundance, habitat use and behavior including carcass presence and abundance;
- carcass replication detection trials;
- diurnal and nocturnal acoustic recordings of wildlife (excluding bats);
- infrared camera trap observations;
- nocturnal recordings for bats;
- aquatic macroinvertebrate (dip net) sampling; and
- aerial and terrestrial macroinvertebrates (malaise trap and pan trap) sampling.

Intensive diurnal observations

All wildlife observations conducted by DES used binoculars with 8x magnification and a 20 to 60x magnification telescope. The telescope was moved to a variety of locations within the TSF and was generally used within two hours of sunrise to minimise the effects of heat shimmer and wind. Only active TSF cells (those containing bioavalable cyanide) were monitored on all trips.

Four methods were used to collect wildlife behaviour and habitat data:

- daily total compilations;
- 20-minute intensive surveys;
- wildlife behaviour and habitat use surveys; and
- interaction surveys of wildlife using cyanide-bearing habitats including foraging rates of individuals over a one-minute period (where appropriate).

Habitat and behaviour data categories used by DES for all methods are defined in Table 3 and are broadly similar to those used for on-site monitoring with a few additions.

Monitoring for carcasses was specifically carried out each day using a telescope and binoculars.

Table 3. Behaviour and habitat data categories used for intensive diurnal wildlife monitoring

Data category	Definition
Foraging	Searching for food, irrelevant of observation of food source consumed or success of feeding action
Resting	Not engaged in any activity or engaged in comfort activities such as preening
Locomotion	Moving from one location to another
Nesting	Used for Red-capped Plovers observed sitting on a nest within the TSF
Drinking	Only for observations where wildlife was actually observed drinking
Bathing	Wildlife engaged in active bathing behaviour in the supernatant
Patrolling	Hunting/searching behaviour typical of raptors and corvids
Supernatant	Open water
Flowing stream	Stream of tailings flowing in a channel from the spigot to the supernatant
Beach/dry tailings	The interface between supernatant and adjacent dry tailings
Beach/wet tailings	The interface between supernatant and adjacent wet tailings
Dry tailings/wet tailings interface	The interface between dry tailings and adjacent wet tailings
Dry tailings	Dry consolidated tailings
Wet tailings	Wet unconsolidated tailings
Infrastructure	Any infrastructure present in the survey area such as pipes, decant towers, causeways, etc.
Aerial	Only for wildlife flying over the water bodies

continued

Data category	Definition
Aerial over supernatant	Used for flying birds foraging or patrolling very low over the supernatant (< 1 m) with an obvious interest or interaction with the supernatant
Aerial over wet tailings	Used for flying birds foraging or patrolling very low over wet tailings (< 1 m) with an obvious interest or interaction with the wet tailings
Aerial over dry tailings	Used for flying birds foraging or patrolling very low over dry tailings (< 1 m) with an obvious interest or interaction with the dry tailings

Daily totals

A record of all wildlife visitations to the TSF for a given day was recorded. A visitation is regarded as an individual that visits the TSF on a given day. Repeated visits to the TSF by an individual on the same day (where known) are treated as a single visitation. Attempts to avoid double counting the same individuals were made.

20-minute intensive surveys

During observation sessions all wildlife present, entering and leaving the tailings system during a 20-minute period was recorded, with care taken to avoid double counting. The following data was recorded for each observation:

- time;
- species;
- number of individuals; and
- relevant comments and notes.

Monitoring for carcasses was specifically carried out each observation day using a telescope and binoculars.

Habitat and behaviour surveys

A snapshot observation of the habitat and behaviour of all birds present in the active cell was periodically conducted. The number of wildlife engaged in a behaviour and the habitat it was using was recorded. This provides an understanding of habitat preferences and behaviour in those habitats.

Interaction surveys of wildlife using cyanide-bearing habitats including foraging rates of individuals over a one-minute period

Wildlife interactions with cyanide-bearing habitats were the focus of intensive observations and wildlife was watched closely when it was using such habitats. When wildlife was interacting orally with cyanide-bearing habitats (foraging or drinking) data was recorded on time, habitat used, any visible signs of distress or effect and the number and manner of discrete oral interactions (pecks, head ducks, probes, etc.) over a one-minute period for individual randomly selected birds. Relevant notes such as proximity to active spigots, etc. were also taken. Where flocks of birds were interacting with cyanide-bearing habitats the number of birds and the type of interaction was recorded.

A summary of the survey effort by DES for intensive wildlife observations is presented in Table 4.

Table 4. Summary of survey effort for intensive diurnal wildlife observation methods at the TSF used in this and previous projects. Site visit dates and seasonality are also given.

Site visit dates	Project	Season	Days observed	20-minute surveys	Habitat and Behaviour surveys	1 minute/ interaction surveys	Balloon test conducted
Saline system			34	119	406	122	3
18-22/05/2006	ACMER P58	Autumn	5		57		
11-14/9/2006	ACMER P58	Spring	4		28		
18-19/08/2007	MERIWA M398	Winter	2		3		
18-28/01/2008	MERIWA M398	Summer	11	62	90	49	X
25-27/04/2008	MERIWA M398	Autumn	3	13	25	12	X
25-28/05/2008	MERIWA M398	Autumn	4	12	9	9	X
29/4 – 3/5/2010	Current Project	Autumn	5	32	194	52	
Hypersaline system			22	113	306	271	2
11-14/05/2010	Current Project	Autumn	4	21	37	35	
2-7/06/2010	Current Project	Winter	6	26	32	20	X
21-26/07/2010	Current Project	Winter	6	36	146	154	X
16-21/08/2010	Current Project	Winter	6	30	91	62	X
Total			56	232	712	393	5

Carcass replication trials using balloons

Blue, black and/or grey balloons were half-filled with water and set within the TSF by DES and on-site staff. Balloons were filled with approximately 300 to 400 ml of water and inflated with a minimal amount of air then tied with a knot to replicate carcasses. Grey balloons filled with smaller amounts of water replicated Red-capped Plover carcasses to some degree. Some balloons were almost completely filled with water to replicate carcasses of larger waders or small ducks. They were then set in the TSF, either thrown into the supernatant or placed in various habitats and situations throughout the TDZ, to test observer detectability (Lawrence, Painter and Little 2007). Balloons had a residence time of generally between two to four days when they either popped or deflated, giving opportunity for trial replication.

On-site personnel charged with conducting wildlife observations were informed of the balloon trial upon the commencement of the program but not on the days the trials were conducted. They were instructed to record the number of balloons detected on the wildlife data sheet. Mine personnel were not told of when and how many balloons had been deployed, nor were they informed on the number once they had documented the presence of balloons.

The number and colour of balloons observed by on-site mine staff was recorded. Efficiency of observing and recording of balloons was determined by the number of balloons detected.

DES observers were also not told when or how many balloons were set and similarly recorded the number of balloons detected. Notes were taken on whether balloons were easy or difficult to detect and their final rest location.

Balloon trials were conducted once per site visit as indicated in Table 4.

Infrared camera trap monitoring methodology

Two Reconyx RC60 infrared cameras were used to document wildlife presence at the TSF active cell and at haul road lakes (Table 5).

At the TSF active cell the cameras were positioned to cover wet tailings, dry tailings and along the interface (beach) of wet tailings or dry tailings and the supernatant. At the haul road lakes the cameras were positioned to view most of the water body, an internal mudflat and a wider angle view to include the lake margin. They were programmed to take a photo every 15 minutes. Also the infrared and motion detection options were set to very sensitive with a trigger response time of 0.1 second, resulting in three consecutive frames per second. Whether cameras were triggered to take photos or not was dependant on the size of wildlife, speed of movement, direction of movement and the distance from the camera. The matrix of the animal size and how close it must be to trigger off the camera is not known. The photographs were viewed to document species presence and habitat use. Temporal abundance was used to document high visitation times. Data from the Reconyx RC55 is recorded onto 4GB compact flash cards.

Table 5. Number of trap days/nights that cameras were set at BGS TSF and haul road lakes from 2 June 2010 to 20 August 2010

Water body/cell	No. of days camera trap set	Total no. of hours camera trap set
TSF	30	108.45
Haul road lakes	8	187.25

Diurnal and nocturnal acoustic monitoring of wildlife methodology

Two Songmeters were used to document wildlife presence through the recording of wildlife calls (and other distinctive animal noises) at the TSF and haul road lakes. Songmeters record sounds within the range of 20 to 20 000 Hz, which is auditable to humans. The Songmeter at the TSF was located on the decant finger. The distance over which wildlife calls and sounds can be recorded is not known and is likely to vary according to the species' actual call or sound, wind direction and extent of background noise. The Songmeter located at the haul road lakes was placed close to the water/wet mud beach. The daily program for recording was structured to target wildlife active at dawn, during early to mid morning, late afternoon and dusk. Recording times were set to commence at 04:00 for three hours and 17:00 for three hours during the April-May site visit however only the first 20-minute period of each hour, was analysed for consistency with other survey periods (Table 6). On all subsequent site visits the Songmeter was set to record for 20-minute periods at 06:00, 07:00, 08:00, 09:00, 10:00, 16:00, and 17:00. Twenty-minute surveys were divided into four five-minute sub-surveys, and species recorded were marked as present, giving four potential presences per survey. The recording rate of species per five-minute sub-survey was determined.

Table 6. Summary of daily recording regime and number of recording hours for Songmeters used at the TSF and the haul road lakes during the current project

	Recording period per survey (hours)	Recording schedule (time start)	Total recording hours
TSF			19:20*
4/29/2010	0:20	17:00	
30/4 – 2/5/2010	0:20	4:00, 5:00, 6:00, 17:00, 18:00, 19:00	
7/21/2010	0:20	17:00	0:20
7/22/2010	0:20	6:00, 7:00, 8:00, 9:00	1:20
7/26/2010	0:20	16:00, 17:00	0:40
27-31/7/2010	0:20	6:00, 7:00, 8:00, 9:00, 10:00, 16:00, 17:00	9:20
8/1/2010	0:20	6:00, 7:00, 8:00, 9:00	1:20
16-20/8/10	0:20	18:00, 19:00, 20:00, 21:00, 22:00, 4:00	7:40
8/21/2010	0:20	4:00	0:20
Haul road lakes			18:00
4/29/2010	0:20	17:00, 18:00, 19:00	1:00
30/4 – 2/5/2010	0:20	4:00, 5:00, 6:00, 17:00, 18:00, 19:00	6:00
7/21/2010	0:20	17:00	0:20
22-25/07/2010	0:20	6:00, 7:00, 8:00, 9:00, 10:00, 16:00, 17:00	9:20
7/26/2010	0:20	6:00, 7:00, 8:00, 9:00	1:20

* Six 20-minute surveys could not be analysed due to windy conditions

Nocturnal bat monitoring methodology

All bats belong to the order Chiroptera and they are split into two main groups (suborders): microchiroptera (insectivorous bats) and megachiroptera (typically fruit bats). This work deals solely with insectivorous bats. Insectivorous bats, although not blind, rely on echolocation to navigate and hunt for food and emit high frequency calls, mostly beyond the limits of human hearing.

Insectivorous bats include the familiar small bats that eat insects, roost in crevices and hollows and use echolocation for navigation and hunting. Insectivorous bats mainly eat moths and beetles but most are opportunistic and will take a broad range of insects, particularly mosquitoes and midges. Most microchiroptera concentrate on aerial foraging, catching and eating insects on the wing and can remain airborne for hours at a time (Churchill 1998). They are capable of finding their way in complete darkness.

Sound waves emitted for navigation are referred to as cruise calls and are relatively regular-shaped pulses that insectivorous bats emit as they navigate through the landscape (Pennay, Law and Reinhold 2004). When bats are hunting for food, and not just flying past or cruising, the calls are made more frequently and are referred to as a feeding buzz or buzz calls (Churchill 1998; Adams, Donato, Schulz and Smith 2008). Calls made within a roost or just outside a roost are often low frequency and distinctively shaped. These are sometimes audible to humans and referred to as social calls.

Most echolocation devices provide a relative measure of bat activity and behaviour. Echolocation recording devices can be implemented around water bodies to document the presence of bat roosts and activity (feeding and drinking). Such a non-invasive approach provides a cost-effective technique to quickly gain a level of knowledge of bats in the region.

Insectivorous bats were monitored by DES at the TSF, haul road lakes, Goanna Pit and Winditch Pit in between May 2006 and August 2010 (Table 7).

Table 7. Nocturnal bat monitoring survey effort during the current and previous projects

Site visit dates	Project	Season	TSF active cell (hours)	TSF In-active cell (hours)	Saline wash /duck pond (hours)	Haul road lakes (hours)	Goanna Pit (hours)	Winditch Pit (hours)
18-22/05/2006	ACMER P58	Autumn						
11-14/9/2006	ACMER P58	Spring	4		8			
18-19/08/2007	MERIWA M398	Winter	8		8			
18-28/01/2008	MERIWA M398	Summer	12	12	12			
25-27/04/2008	MERIWA M398	Autumn	8		8			
25-28/05/2008	MERIWA M398	Autumn	8		8		8	8
29/4 – 3/5/2010	Current Project	Autumn	16			16		
11-14/05/2010	Current Project	Autumn	16			8		
2-7/06/2010	Current Project	Winter	12			12		
21-26/07/2010	Current Project	Winter	20			20		
16-21/08/2010	Current Project	Winter	12			12		
Total hours			116	12	44	68	8	8

Echolocation calls were recorded using AnaBat™ SD1 compact flashcard echolocation detectors (Titley Electronics, Ballina, New South Wales, Australia). Apart from in the forest, bat detectors were oriented to record insectivorous bat echolocation calls from the airspace above the water bodies. They were programmed to run for a continuous period of four hours from 19:30 to 23:30 over one to six nights (Table 7). Attempts were made to monitor insectivorous bats on other occasions, however the AnaBats are not waterproof and, due to rain, could not be set on some nights.

The AnaBat™ SD1 division ratio was set to 16, while sensitivity was set between 6 and 7. The bat detectors record onto compact flashcards and Anabat software (Corban 2000) was used for recording echolocation calls, while Analook W software (Corban 2000) was used to view calls.

Surveys were not intended to provide comprehensive data on the assemblage of species present either on site at BGS or in the surrounding region. Consequently, in preparation of this report DES did not attempt to positively identify the insectivorous bats recorded (to either species or genus) by analysing the characteristics of their echolocation calls.

Collation of bat calls can be used to preliminarily assess bat presence and relative abundance, however, use of bat calls to infer actual abundance should be avoided (Fenton 1970). We used this method to estimate intensity of use at each water body, rather than abundance (Park and Christinacce 2006). For this report, echolocation data from all species was grouped to analyse gross patterns of activity of insectivorous bats.

Bats alter their calls while feeding and drinking, producing a series of pulses increasing in slope, frequency and speed, culminating in a buzz (Pennay, Law and Reinhold 2004). Terminal feeding, drinking and social interaction buzzes emitted by insectivorous bats (Griffin, Webster and Michael 1960) were also counted, and these behavioural buzz rates are expressed as a buzz-to-pass ratio. The ratio of these buzzes to bat passes provide a relative measure of bat activity and behaviour. Cruising calls indicate the presence of bats at a site and feeding buzzes indicate hunting for food or drinking where water is present (Vaughan, Jones and Harris 1996; Wickramasinghe, Harris, Jones et al. 2003; Wickramasinghe, Harris, Jones et al. 2003; Pennay, Law and Reinhold 2004). One bat pass was defined as a continuous sequence of at least two echolocation calls from a passing bat (Fenton 1970). A minimum gap of five seconds between passes was applied to ensure each call sequence was in fact a separate pass (Pennay, Law and Reinhold 2004).

Aquatic macroinvertebrate (dip-net) sampling methodology

Aquatic macroinvertebrate sampling was conducted by DES during the ACMER P58 study, the MERIWA M398 study and the current study using a dip net within the TSF supernatant and other non-toxic on-site water bodies (haul road lakes, the seepage trench and Winditch Pit) for comparison (Table 8). A standard 250 µm mesh dip net with a 350 by 250 mm (triangular-shaped) opening, 50 cm net depth and 1 to 1.5 m aluminium extension handle was used. Macroinvertebrates were collected by vigorously sweeping the net through the water column, for a period of one minute, using short vertical lifts to disturb the substrate and catch the suspended organisms (Halse, Smith, Kay et al. 2001). This method was employed to ensure that both nektonic and benthic invertebrate species were collected.

All macroinvertebrates collected during sampling were preserved in the field with 70% methylated spirits (diluted with deionised water). In the laboratory, specimens were transferred to vials containing 70% ethanol solution and identified using a stereomicroscope at 10x and 50x magnification. Most macroinvertebrates were identified to the taxonomic level of order or family level using reference material (Ingram, Hawking and Sheil 1997; Davis and Christidis 1999; Andersen and Weir 2004; Gooderham and Tsyrlin 2005).

The aquatic macroinvertebrate assemblage recorded in each water body was analysed by calculating the number of taxa per sample (taxa richness) and the number of individuals (abundance) per sample.

Aquatic macroinvertebrate sampling of the TSF supernatant was conducted at various locations from the decant finger. Sampling of alternative water bodies was conducted at different locations where access was possible within each of the water bodies. The sampling regime for the TSF supernatant pond and alternative water bodies is given in Table 8.

Table 8. Summary of aquatic macroinvertebrate survey effort conducted at BGS during this and previous projects

	Total no. of samples	Aug 2007	May 2008	July 2010	Aug 2010
TSF	17	4	3	5	5
Seepage trench	9	3	3	3	
Winditch Pit	3		3		
Goanna Pit	3		3		
Haul road lakes	8			5	3

Aerial and terrestrial macroinvertebrate sampling methodology

Aerial and terrestrial macroinvertebrate sampling was conducted to confirm their presence in the TSF as a food source for wildlife. Terrestrial and aerial insects were sampled using yellow pan traps and malaise traps (Upton 1991). Pans had a surface area of 600 cm2 (20 x 30 cm) and contained tap water and several drops of dishwashing liquid. The macroinvertebrates collected were sieved using a 250 μm mesh dip net and washed into vials containing 70% methylated spirits. In the laboratory, specimens were identified to order using a stereomicroscope at 10x and 50x magnification.

Pan traps set within the TSF were placed on the decant finger on rocks just above the surface of the supernatant and on the southern wall of the active cell on rocks adjacent to wet tailings. Pan traps were also set at the haul road lakes in July and August 2010. Pans were emptied daily during sampling conducted in July and August 2010. The number of samples collected and the timing of collection is given in Table 9.

A malaise trap is a type of flight-intercept trap designed to catch flying insects (Cheal, Davis, Growns et al. 1993). Insects collide with fine terylene mesh then either drop to the ground or attempt to fly or climb over the trap. Those that attempt to climb (e.g. flies, wasps, moths) are funnelled into a collection bottle containing alcohol (or methylated spirits) in the top corner of the trap. Malaise traps were emptied daily. The macroinvertebrates collected were sieved using a 250 μm mesh dip net and washed into vials containing 70% methylated spirits.

Malaise traps were deployed at the TSF, the saline wash (duck pond) and the haul road lakes according to the schedule in Table 9.

In the laboratory, all terrestrial and aerial macroinvertebrate specimens were identified to taxa order using a stereomicroscope at 10x and 50x magnification. The assemblage recorded at each water body was analysed by calculating the number of taxa per sample (taxa richness) and the number of individuals (abundance) per sample. Macroinvertebrate specimens were also assigned to one of three size classes: < 1 mm; 1 to 5 mm; and > 5 mm.

Table 9. Survey effort of terrestrial and aerial macroinvertebrate sampling using pan traps and malaise traps conducted at BGS during this and previous projects

	Total no. of samples	Jan 2008	Apr 2008	May 2008	Jul 2010	Aug 2010
Malaise						
TSF	19	9	2	3	3	2
Saline wash	14	9	2	3		
Haul road lakes	7				3	4
Pan traps						
TSF – decant finger	7				3	4
TSF – south wall	7				3	4
Haul road lakes	7				3	4

Wildlife survey results

Wildlife visitations and deaths

On-site observations at the TSF

A total of 5 191 visitations to the TSF representing eight guilds and at least 24 species of birds and two species of mammals were recorded during 1 093 surveys between 15 June 2006 and 18 August 2010 (Table 10). Of these records 4 803 visitations were recorded before 8 May 2010 under saline TSF conditions (14 000 to 50 000 mg/L TDS) at a rate of 4.7 ± 7.2 wildlife per survey. A further 388 visitations were recorded under hypersaline conditions (8 May 2010 onward) at a rate of 5.5 ± 3.7 wildlife per survey (Table 10).

The majority of these (85.5% of overall records) were of a single species, Red-capped Plover (a wader), which was recorded at an average of 4.0 and 4.9 birds per survey for saline and hypersaline conditions, respectively. Less species were recorded under hypersaline conditions, which most likely reflects the comparatively shorter observation period. The two terrestrial mammal species observed were kangaroo and dingo. The TSF is unfenced.

No wildlife was observed during 339 (31.0%) observation sessions and the maximum number of animals observed during a session was 58.

Guild composition reflects the dominance of waders in on-site wildlife records, which made up 89.4% of records (Figure 1). Four other guilds contributed greater than 1% of records: ducks, raptors and corvids, aerial feeders (such as swallows) and bush birds (Figure 1).

Table 10. Results from on-site wildlife observations at the BGS TSF

		Whole dataset 15/6/06 to 18/8/10		Saline system 15/6/06 to 7/5/10		Hypersaline system 8/5/010 to 18/8/10	
		No. of records	Records per obs. session (n=1 093)	No. of records	Records per obs. session (n=1 023)	No. of records	Records per obs. session (n=70)
	Total – all species	5 191	4.75	4 803	4.70	388	5.54
Duck sp.	Pacific Black Duck	32	0.03	32	0.03	0	0.00
	Pink-eared Duck	4	<0.01	4	<0.01	0	0.00
	Australian Shelduck	34	0.03	30	0.03	4	0.06
	Duck Spp.	36	0.03	36	0.04	0	0.00
	Black Swan	16	0.01	16	0.02	0	0.00
	Grebe Spp.	9	0.01	9	0.01	0	0.00
Herons	Heron Spp.	1	<0.01	1	<0.01	0	0.00
Waders	Black-winged Stilt	13	0.01	13	0.01	0	0.00
	Red-capped Plover	4 461	4.08	4 116	4.02	345	4.93
	Golden Plover	5	<0.01	5	<0.01	0	0.00
	Red-kneed Dotterel	22	0.02	7	0.01	15	0.21
	Red Necked Avocet	6	0.01	6	0.01	0	0.00
	Black-Fronted Dotterel	19	0.02	16	0.02	3	0.04
	Wader Spp.	140	0.13	140	0.14	0	0.00
Terns	Silver Gull	5	<0.01	5	<0.01	0	0.00
	Tern Spp.	9	0.01	9	0.01	0	0.00
Raptors and Corvids	Corvid	6	0.01	4	<0.01	2	0.03
	Wedge-tailed Eagle	92	0.08	85	0.08	7	0.10
	Nankeen Kestrel	18	0.02	17	0.02	1	0.01
	Brown Falcon	3	<0.01	3	0.00	0	0.00
	Raptor Spp.	24	0.02	24	0.02	0	0.00
Aerial Feeders	Martin Spp.	49	0.04	49	0.05	0	0.00
	Welcome Swallow	71	0.06	61	0.06	10	0.14
	Wood swallow Spp.	13	0.01	13	0.01	0	0.00
Bush Birds	Magpie Lark	6	0.01	5	<0.01	1	0.01
	Australian Pipit	56	0.05	56	0.05	0	0.00
	Willie Wagtail	10	0.01	10	0.01	0	0.00
Unidentified bird	Unidentified bird	22	0.02	22	0.02	0	0.00
Terr Mammal	Dingo	1	<0.01	1	<0.01	0	0.00
	Kangaroo	8	0.01	8	0.01	0	0.00

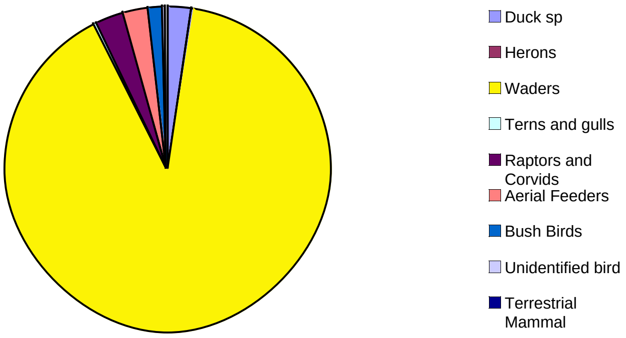


Figure 1. Guild composition of on-site wildlife records at the TSF for the complete dataset between June 2006 and 18 August 2010 (n = 5 191 records, 1 093 surveys)

A seasonal effect is evident in the total number of records per day with an obvious pattern of higher visitations during late summer and autumn (January to May) and fewer visitations in winter and spring for all four years (Figure 2). This pattern almost wholly reflects the seasonal visitations of the commonly recorded Red-capped Plovers.

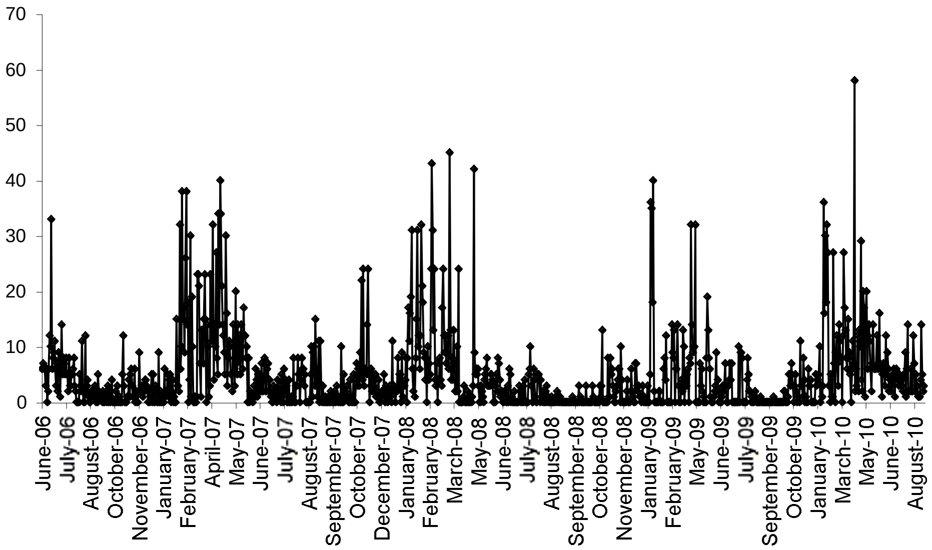


Figure 2. Daily visitation totals recorded by on-site monitoring at the TSF between 15 June 2006 and 18 August 2010 (n = 5 191 records, 1 093 surveys)

On-site observations at the seepage trench

On-site monitoring of the seepage trench recorded 2 572 visitations representing seven guilds, with at least 23 species of birds and two species of mammals recorded between 13 May 2008 and 18 August 2010 at a rate of 5.4 ± 4.1 wildlife per survey (Table 11). The reported visitation rates and the species recorded were similar for the TSF. However, there is a difference in the relative abundance with Australian Shelduck, Grey Teal and Black-fronted Dotterel contributed large numbers of records in addition to Red-capped Plover (tables 25 and 26). Although the guild composition at the seepage trench is still dominated by waders (Figure 3) other guilds make up larger proportions than for the TSF (Figure 1).

Table 11. Results from on-site wildlife observations at the seepage trench between 13 May 2008 and 18 August 2010

		No. of records	Records per obs. session (n=480)
	Total – all species	2572	5.36
Duck sp.	Pacific Black Duck	26	0.05
	Australian Shelduck	437	0.91
	Grey Teal	152	0.32
	Duck Spp.	2	0.00
	Grebe Spp.	2	0.00
Waders	Red-capped Plover	491	1.02
	Red Necked Avocet	1	0.00
	B F Dotterel	702	1.46
	Green Shank	37	0.08
	Wader Spp.	14	0.03
	Sharp Tailed Sandpiper	3	0.01
	Wood sandpiper	121	0.25
Raptors and corvids	Whistling Kite	4	0.01
	Wedgetailed Eagle	24	0.05
	Nankeen Kestrel	20	0.04
	Brown Falcon	1	0.00
	Crow	34	0.07
Aerial feeders	Martin Spp.	108	0.23
	Welcome Swallow	58	0.12
	Wood swallow Spp.	30	0.06
Granivorous	Crested Pigeon	44	0.09
	Galah	57	0.12
Bush Birds	Willy Wagtail	3	0.01
	Magpie Lark	51	0.11
	Richard Pipit	88	0.18
Unidentified	Unidentified	6	0.01
Terrestrial mammal	Dingo	1	0.00
	Kangaroo	55	0.11

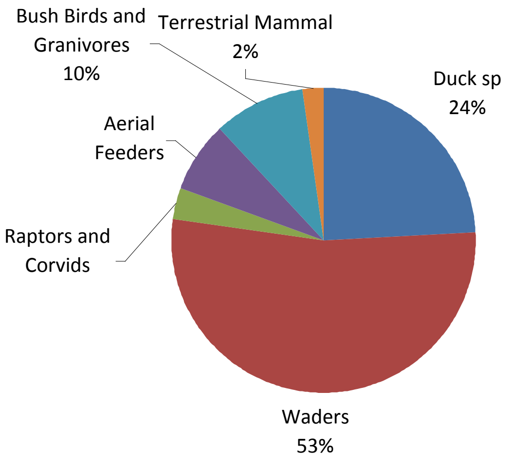


Figure 3. Guild composition of on-site wildlife records at the seepage trench between 13 May 2008 and 18 August 2010 (n = 2 572 records, 480 surveys)

A seasonal effect in total wildlife observations per day is not obvious in the seepage trench dataset (Figure 4) but tentatively the reverse effect may be evident to the TSF, that is, higher visitations in winter. Ducks and aerial species were recorded in greater numbers in winter and migratory species were only recorded in summer (as expected) while the other guilds showed no obvious seasonal pattern (Figures 4 to 6). A two-year period is insufficient to document seasonal patterns in the semi-arid Australian environment.

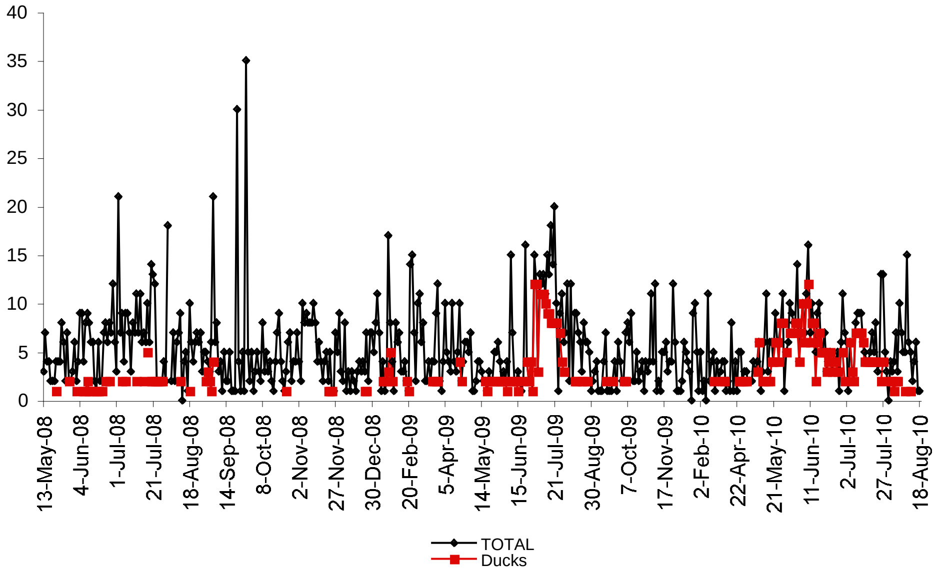


Figure 4. Daily visitation totals and duck numbers recorded by on-site monitoring at the seepage trench between 13 May 2008 and 18 August 2010 (480 surveys)

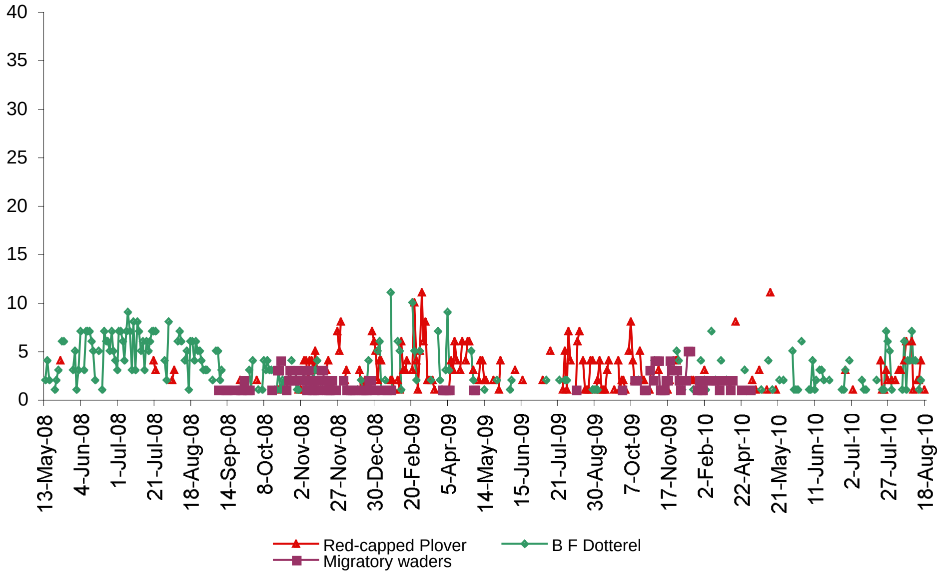


Figure 5. Daily visitation totals for Black-fronted Dotterel, Red-capped Plover and migratory waders recorded by on-site monitoring at the seepage trench between 13 May 2008 and 18 August 2010 (480 surveys)

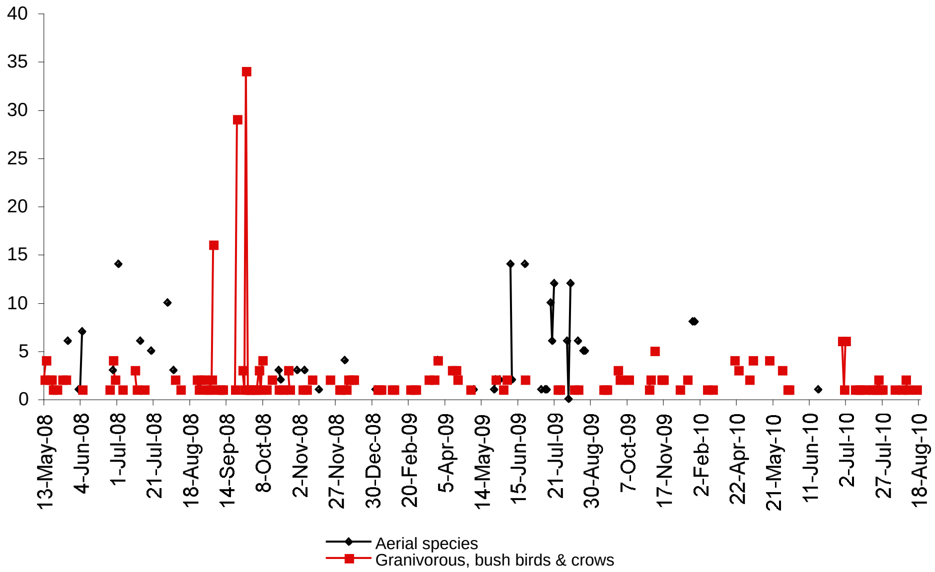


Figure 6. Daily visitation totals for aerial species and bush birds, granivorous species and crows combined, recorded by on-site monitoring at the seepage trench between 13 May 2008 and 18 August 2010 (480 surveys)

Consultant observations

DES determined wildlife visitations to the TSF as the number of individual animals visiting the TSF over a 24-hour period.

Under hypersaline conditions at the TSF (8 May to 21 August 2010) a total of 480 wildlife visitations were recorded by DES at an average rate of 21.8 ± 19.0 visitations per day for the 22 observation days (Table 12). This contrasts with an average of 31.4 ± 26.6 visitations per day on days DES observed the TSF during the saline period (34 days between 15 June 2006 and 7 May 2010). A total of 1 567 visitations to the TSF were recorded over both periods.

A maximum of 125 wildlife was recorded at the TSF during a single day (1 May 2010) and the minimum was two. Records consisted of eight guilds (Figure 7) and 18 species (Table 12). Two species, Red-capped Plover (a wader) and Welcome Swallow (an aerial species) dominated the observations (Figure 7), which was consistent with on-site observations. Only one species of migratory wader was recorded, Red-necked Stint, for which one was recorded on 25 April 2008 and ten on 26 April 2008. Mammal species other than bats were limited to a single record of a kangaroo. Species and guild composition of consultant observations is broadly consistent with those of on-site observations with differences likely to be due to intensity and length of observation sessions on a given day, observer skill and the number of days observations were conducted. Guild composition recorded is consistent with that previously recorded elsewhere and reflects the habitat provision and availability of resources within and adjacent to the TSF. Most of the guilds are cosmopolitan, being found across Australia.

Table 12. Summary of wildlife visitations to the active cell of the TSF as determined from daily totals observed between 18 May 2006 and 21 August 2010

		Total records	Records per day (including opportunistic records (n=56)	Average records per 20-min survey (n=232 surveys over 44 days)
	Total	1 567	28.0 +/-25.2	16.0 +/- 17.2
Ducks	Pink-eared Duck	2	0.04	
	Australian Wood Duck	2	0.04	0.02
	Musk Duck	2	0.04	
	Australian Shelduck	13	0.25	0.05
Endemic Waders	Red-capped Plover	932	16.6 +/- 17.4	12.5 +/- 14.7
Migratory Waders	Red-necked Stint	11	0.21	0.09
Raptors and corvids	Wedge-tailed Eagle	11	0.21	< 0.01
	Nankeen Kestrel	11	0.21	
	Brown Falcon	7	0.13	
	Crow	1	0.02	
Granivores	Crested Pigeon	2	0.04	
	Galah	20	0.38	
Aerial	Welcome Swallow	530	9.5 +/- 15.8	3.3 +/- 9.4
	Tree Martin	1	0.02	<0.01
	White-backed Swallow	7	0.13	0.04
	Black-faced Woodswallow	1	0.02	
Bush birds	Richard's Pipit	8	0.15	0.04
	Pied Butcherbird	1	0.02	< 0.01
	Magpie-lark	4	0.08	
Terrestrial Mammal	Kangaroo	1	0.02	< 0.01

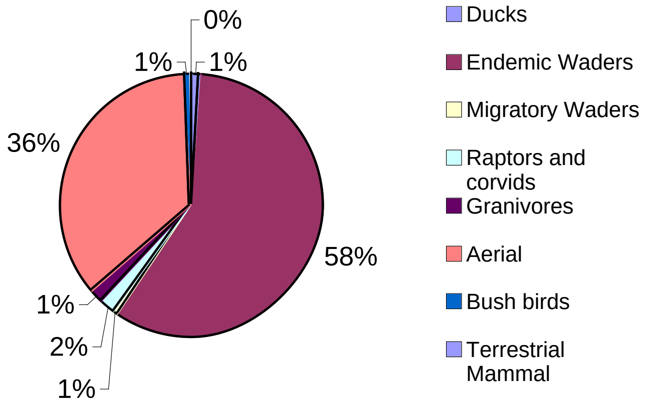


Figure 7. Guild composition of wildlife observations at the active cell of the TSF recorded by DES as determined from daily totals recorded between 18 June 2006 and 21 August 2010

Visitation rates are also determined from 20-minute surveys (Table 12). DES conducted 232 20-minute surveys over 44 days at the TSF and recorded an average of 16.0 ± 17.2 visitations per 20-minute survey (Table 12). A maximum of 79 wildlife was recorded in a 20-minute survey, and in 11 surveys no wildlife was recorded although Red-capped Plovers may have been present and undetected as the species often hides in tailings cracks and against dam walls.

Effects of salinity and seasonality on wildlife visitations

Comparing wildlife visitation rates between saline and hypersaline conditions, it is evident that for Red-capped Plover, and for all species combined, visitation rates were higher under saline conditions (Table 13). In contrast, recording rates for Welcome Swallow were higher in the hypersaline dataset. However, this is due to a seasonal distortion since all of the survey work for the hypersaline TSF was conducted in autumn and winter (Table 4), whereas for the saline conditions surveys occurred in summer when visitation rates for Red-capped Plover were substantially higher (Table 13). When visitation rates are viewed on a seasonal basis it looks as if visitation rates are highest in summer for Red-capped Plover and in winter for Welcome Swallow (Table 13). This is consistent with on-site data. Red-capped Plovers may be taking advantage of higher winged macroinvertebrate activity in summer, which is the only source of food on the TSF for this species. The reverse pattern for Welcome Swallow is likely to be due to regular seasonal movements (north in autumn and south in spring, Higgins et al 2007). It appears that the largest determinant of visitation rates to the TSF is seasonal rather than tailings salinity, although the dataset under hypersaline conditions is short.

Table 13. Summary of visitation rates as determined by day totals and 20-minute surveys at the TSF active cell conducted between 18 June 2006 and 21 August 2010

				All species		Red-capped Plover		Welcome Swallow	
	Season	Number of days TSF observed	Number of 20-minute surveys	Average per day	Average number of records per 20-minute survey	Average per day	Average number of records per 20-minute survey	Average per day	Average number of records per 20-minute survey
All surveys		56	232	28.0 +/- 25.2	16.0 +/- 17.2	16.6 +/- 17.4	12.5 +/- 14.7	9.5 +/- 15.8	3.3 +/- 9.4
Saline		34	119	31.4 +/- 26.6	23.1 +/- 19.2	21.8 +/- 18.9	19.9 +/- 17.2	7.0 +/- 14.5	2.8 +/- 9.2
Hyper-saline		22	113	21.8 +/- 19.0	8.5 +/- 10.6	7.8 +/- 4.3	4.6 +/- 3.4	13.3 +/- 17.3	3.8 +/- 9.6
Jan-08	Summer	11	62	42.3 +/- 14.3	24.3 +/- 17.2	40.5 +/- 12.9	24.2 +/- 17.2	0.8 +/- 2.4	0.0
Apr-May 08/10	Autumn	21	78	33.8 +/- 33.7	19.1 +/- 20.5	15.8 +/- 17.3	13.0 +/- 14.4	15.3 +/- 20.5	5.6 +/- 13.2
June – Aug 10	Winter	20	92	17.4 +/- 14.6	7.7 +/- 8.3	6.7 +/- 3.0	4.1 +/- 2.6	10.0 +/- 13.3	3.5 +/- 8.1
Sep-06	Spring	4	0	11.3 +/- 10.1		7.2 +/-3.5		4.4 +/- 4.8	

Other known seasonal wildlife patterns, such as the international migration of waders, will dictate the movements of wildlife but these species have not been commonly recorded at the TSF. Movements of wildlife according to other environmental factors that are not seasonal in nature, or operate on a greater-than-12-months time frame, are expected in this arid environment.

Foraging rates

Monitoring of foraging actions for individuals over a one-minute period was carried out for four species at the TSF (Table 14).

Pecking rates averaged 25.0 ± 17.5 for Red-capped Plover during 242 one-minute counts and 6.5 ± 3.5 for Welcome Swallow over 58 counts (Table 14). The foraging rate for Red-necked Stint was substantially higher although only two counts were conducted (Table 14). The differences most likely reflect the different foraging mechanisms and behaviours. It is notable that foraging rates did not vary much for either Red-capped Plover or Welcome Swallow between the saline and hypersaline datasets (Table 14). All three of the above species were observed pecking at prey on the surface of TSF substrates, especially wet habitats in which invertebrates become entrained.

The foraging rate for Welcome Swallow was a reflection of consistent and successful foraging behaviour, which was observed mostly in early mornings (Table 15) and mainly in autumn and winter. In contrast Red-capped Plover was present all year round and often foraged throughout most daylight hours (Table 15) but often stopped for two to three hours in the middle of the day.

Table 14. Peck rates recorded during one-minute foraging action counts for species foraging within TSF habitats (n = 305)

	All data		Saline		Hypersaline	
	No. of 1 min Surveys	Average no. of pecks (+/- s.d.)	No. of 1 min Surveys	Average no. of pecks (+/- s.d.)	No. of 1 min Surveys	Average no. of pecks (+/- s.d.)
Australian Shelduck	3	5.7 ± 2.5	2	5.5 ± 3.5	1	6
Red-capped Plover	242	25.0 ± 17.5	104	24.5 ± 19.3	138	25.4 ± 16.0
Red-necked Stint	2	80.5 ± 2.1	2	80.5 ± 2.1		
Welcome Swallow	58	6.5 ± 3.5	16	6.1 ± 3.8	42	6.6 ± 3.4

Table 15. Peck rates recorded during one-minute foraging action counts by hour

	Red-capped Plover		Welcome swallow	
	No. of surveys	Mean ± S.D.	No. of surveys	Mean ± S.D.
6:00	22	24.9 ± 15.6	14	6.1 ± 3.3
7:00	75	28.5 ± 20.2	19	6.8 ± 3.6
8:00	24	34.5 ± 23.2	15	6.0 ± 2.8
9:00	57	19.7 ± 12.1	4	11.5 ± 4.2
10:00	15	19.9 ± 11.0		
11:00	1	41		
12:00	4	30.3 ± 6.2		
13:00				
14:00	3	28 ± 24.2		
15:00	5	33.2 ± 22.3		
16:00	20	21.9 ± 15.4		
17:00	7	19.3 ± 10.0		
18:00	7	13.3 ± 6.0	6	4.0 ± 2.7

The Australian Shelduck was observed attempting to feed on two occasions. On one occasion it stopped foraging after one one-minute count and on the other occasion after two one-minute counts. On both occasions foraging was likely to be, and appeared to be, unsuccessful as it quickly stopped foraging and left the system soon after. This species feeds on aquatic plants and aquatic invertebrates, neither of which are present in the supernatant.

Habitat use and behaviour

Habitat use and behaviour is determined here by consultant data that was obtained by dedicated habitat and behaviour surveys. Data is presented here for the complete dataset and for the saline and hypersaline systems separately. Habitat use and behaviour within the TSF was dominated by endemic waders (Red-capped Plover) foraging and resting on wet tailings and beach habitats, and aerial species (Welcome Swallow) foraging over wet tailings (Table 16). Numerically, the habitat and behaviour records of remaining guilds contribute little to the overall activity budget for the TSF. These guilds were observed using habitats and behaviours expected and consistent with their known ecologies and habitat preferences, thus ducks were observed mostly on the supernatant, raptors and corvids were flying over the TSF and bush birds and granivores were either resting on the walls or flying over the system. None of these guilds were observed interacting with cyanide-bearing TSF habitats.

Differences are evident between the hypersaline and saline systems in terms of habitat use and behaviours. These are likely to be primarily seasonally influenced and skewed, with no summer surveys represented in the hypersaline data.

Table 16. Habitat and behaviour recorded during consultant wildlife counts at the active cell of the TSF (n = 683 counts, 6 964 records)

			Foraging											Resting								Locomotion						Bathing		
	No of counts	No of records	Super.	Flowing stream	Beach/Wet Tailings	Beach/Dry Tailings	Dry/Wet Tailings interface	Wet Tailings	Dry Tailings	Aerial over Super.	Aerial over Wet Tailings	Aerial over Dry Tailings	Aerial	Super.	Beach/Wet Tailings	Beach/Dry Tailings	Dry/Wet Tailings interface	Dry Tailings	Infrastructure	Wall	Wall/Nest	Super.	Beach/Wet Tailings	Beach/Dry Tailings	Wall	Aerial	Drinking Supernatant	Super.	Flowing stream	Total
All data	683	6 964	1.3	0.3	13.4	13.8	13.2	4.2	1.6	3.1	14.0	1.5	2.1	1.1	9.8	8.1	3.6	1.0	1.3	1.0	0.1	0.1	0.2	0.5	0.03	4.1	0.01	0.8	0.01	100
Ducks	15	29	0.1											0.2						0.1						0.1				0.4
Endemic waders	461	4 890	0.9	0.3	13.1	13.4	12.6	4.2	1.6					0.9	9.6	8.0	2.0	0.9	0.1	0.3	0.1	0.1	0.2	0.3	0.03	0.9	0.01	0.7	0.01	70.2
Migratory waders	6	39	0.1		0.1	0.3										0.01												0.04		0.6
Swallows	156	1 920	0.2		0.2	0.2	0.6			3.1	14.0	1.5	1.7		0.1		1.7	0.1	1.2	0.3				0.2		2.5				27.6
Raptors	36	52											0.4					0.03		0.2						0.2				0.7
Granivores and bush birds	9	34																		0.1						0.4				0.5
Saline	379	4 908	1.9	0.3	16.5	12.7	15.5	2.2	0.04	2.9	6.7	0.9	1.2	1.6	13.2	10.4	4.8	0.1	0.9	1.2	0.1	0.1	0.3	0.4	0.04	5.0	0.02	1.1	0.0	100
Ducks	13	25	0.1											0.2						0.1						0.1				0.5
Endemic waders	245	3 814	1.3	0.3	16.1	12.2	14.6	2.2	0.04					1.3	13.2	10.4	2.4		0.1	0.2	0.1	0.1	0.3	0.4	0.04	1.2	0.02	1.0		77.7
Migratory waders	6	39	0.2		0.1	0.4										0.02												0.1		0.8
Swallows	74	948	0.3		0.3	0.02	0.9			2.9	6.7	0.9	0.6				2.4	0.02	0.8	0.5						3.0				19.3
Raptors	36	52											0.6					0.04		0.2						0.2				1.1
Granivores and bush birds	5	30																		0.2						0.4				0.6
Hyper-saline	304	2 056		0.1	6.0	16.5	7.7	8.8	5.2	3.5	31.6	2.9	4.2		1.4	2.4	0.9	3.4	2.1	0.6			0.05	0.8		1.8		0.1	0.05	100
Ducks	2	4																								0.2				0.2
Endemic waders	216	1 076		0.1	6.0	16.0	7.7	8.8	5.2						1.0	2.4	0.9	3.2		0.6			0.05			0.3		0.1	0.05	52.3
Migratory waders	0	0																												0.0
Swallows	82	972				0.5				3.5	31.6	2.9	4.2		0.4			0.2	2.1					0.8		1.1				47.3
Raptors	0	0																												0.0
Granivores and bush birds	4	4																								0.2				0.2

Habitat and behaviour data for Red-capped Plover is presented separately in Table 17 due to it dominating the TSF records. Foraging was the most observed behaviour at the TSF active cell, followed by resting. Beach wet tailings, beach dry tailings and the interface between wet and dry tailings were the most used habitats. While the Red-capped Plover does not spend most of the day foraging, its habitat and behaviour data is skewed towards foraging rather than resting because the species tends to leave the active cell to rest in the adjacent non-active cell for periods of hours on a daily basis. It is most numerous and active in the active TSF cell for the first few and last hours of the day. Some remain present and active in this cell throughout the day.

Differences in habitat and behaviour for Red-capped Plover between hypersaline and saline datasets are minor. This species is present year round and seasonal influences appear to be primarily related to numbers rather than behaviour or habitat preference.

Table 17. Habitat use and behaviour of Red-capped Plovers observed using the active cell of the TSF (n = 461 counts, 4 890 records)

	Supernatant	Flowing stream	Beach/wet tailings	Beach/dry tailings	Dry tailings/wet tailings interface	Wet tailings	Dry tailings	Infrastructure	Wall	Aerial	Total
	%	%	%	%	%	%	%	%	%	%	%
All data (n=4 890)	3.8	0.4	32.6	30.9	20.7	5.9	3.6	0.1	0.6	1.3	100.0
Foraging	1.3	0.4	18.6	19.0	17.9	5.9	2.2				65.5
Resting	1.3		13.7	11.5	2.8		1.3	0.1	0.4		31.2
Locomotion	0.1		0.3	0.4					0.04	1.3	2.1
Nesting									0.1		0.1
Drinking	0.02										0.02
Bathing	1.0	0.02									1.1
Saline (n=3814)	4.8	0.4	38.0	29.7	21.9	2.9	0.1	0.2	0.4	1.5	100.0
Foraging	1.7	0.4	20.7	15.8	18.9	2.9	0.1				60.3
Resting	1.7		17.0	13.4	3.1			0.2	0.3		35.7
Locomotion	0.1		0.3	0.5					0.1	1.5	2.5
Nesting									0.1		0.1
Drinking	0.03										0.03
Bathing	1.3										1.3
Hypersaline (n= 1 076)	0.2	0.4	13.5	35.1	16.4	16.7	16.1	0.0	1.1	0.6	100.0
Foraging		0.3	11.4	30.6	14.7	16.7	9.9				83.6
Resting			2.0	4.6	1.7		6.1		1.1		15.4
Locomotion			0.1							0.6	0.7
Nesting											0.0
Drinking											0.0
Bathing	0.2	0.1									0.3

Wildlife interaction with cyanide-bearing habitats

Dry tailings habitats contain very low concentrations of WAD cyanide and are not considered cyanide-bearing. The supernatant has been well below 50 mg/L WAD cyanide at least since May 2006. Habitat interaction records for supernatant habitats (supernatant, dry tailings beach and aerial over supernatant) are considered separately to the TDZ due to the substantially lower risk they present to wildlife compared to TDZ habitats. Wildlife interactions observed with cyanide-bearing habitats during habitat and behaviour surveys are presented in Table 18 according to TDZ habitats and supernatant habitats.

A total of 6 088 records of wildlife using cyanide-bearing habitats were obtained, representing 87.4% of habitat and behaviour records, and of these 4 140 records (59.4% of all records) were with TDZ habitats. Not all of these records were of oral interaction with the cyanide-bearing habitats. Oral interaction is the only identified cyanide exposure pathway of wildlife. Other avenues for lethal doses of cyanide necessitate the presence of very high levels of free cyanide. A total of 3 141 foraging records were obtained from TDZ habitats during habitat and behaviour counts and are assessed to have involved actual or potential oral interaction with TDZ habitats (Table 18). The potential for wildlife to receive a cyanide dose exists in each of these interactions. However it was repeatedly noted that not all foraging interactions involve actual contact with TSF habitats as invertebrates often appear to be alive and take to flight as the birds strike, resulting in prey being taken just above the surface. It is also noteworthy that all records of wildlife in the TDZ are due to the presence of food.

The majority of TDZ foraging records (2 098) were of Red-capped Plover, however 1 037 TDZ foraging records for Welcome Swallow were also obtained. In addition, 199 and 57 one-minute foraging surveys of Red-capped Plover and Welcome Swallow, respectively, were conducted. The majority of these records were of Welcome Swallows and Red-capped Plovers taking small invertebrates from the surface of TSF habitats. They preferentially use wet habitats, as the invertebrates adhere to the surface.

Only three species have been observed by DES interacting with cyanide- bearing habitats within the TDZ, Red-capped Plover, Red-necked Stint and Welcome Swallow. In the case of Red-necked Stint, ten birds were observed on 26 April 2008 primarily interacting with dry tailings beaches and supernatant, but some interactions with wet tailings beaches were also observed with no effect. For Red-capped Plover, interactions with TDZ habitats occur all year. For Welcome Swallow, interactions with TDZ habitats occur primarily in winter although may possibly occur in summer. All species interact orally with TDZ habitats by pecking however it appears that Red-capped Plover at times puts its bill further into the tailings and has been observed with tailings substrate stuck to the bill.

Table 18. The number of habitat and behaviour observations recorded for cyanide-bearing habitats at the active cell of the TSF during habitat and behaviour surveys between 15 June 2006 and 21 August 2010 (n = 6088)

A Red-capped Plover nest containing two eggs was observed in May 2010, located underneath a tailings pipe along the decant causeway. In subsequent July 2010 surveys, two adults and two immatures foraged in close proximity to each other, presumably as a family unit, in the vicinity of the nest.

It is very likely that the nesting adult birds foraged on the tailings cell on a daily basis and that the adults and some of the immatures observed were from this nesting event. The presence of a nest with eggs demonstrates the ability of these birds to live on the system over a period of weeks and months even though this species is known to interact with cyanide-bearing habitats at concentrations presumed to be toxic.

Wildlife visitations to alternative water bodies

Guild and species composition at alternative water bodies (tables 19 and 20) varied, due to size and shape of water bodies, abundance of food, water depth, extent and proximity of surrounding vegetation, presence of beaches and salinity. The highest visitation rates were recorded at the fresh and saline haul road lakes, sewerage ponds, Winditch Pit and Jubilee Pit (Table 19). Guild and species composition of hypersaline water bodies differed from that at fresh and saline water bodies (Tables 19 and 20). Hypersaline water bodies (Goanna and Keringal pits) were mostly dominated by endemic waders and aerial species, a similar composition to the TSF. Ducks and aerial species were well represented at fresh and saline water bodies, and bush birds, granivores and kangaroos were present where vegetation was contiguous to palatable water.

The effect of salinity on visitation rates and guild composition was evident when comparing the pits as they have similar physical features and extent of vegetation. Winditch Pit and Jubilee Pit had substantially higher visitation rates and greater species diversity compared to the hypersaline pits. While Keringal had quite a high visitation rate it was predominantly of aerial birds flying over the pit. Goanna Pit had the highest species diversity of the hypersaline pits consisting mostly of birds flying over the pits and using the vegetated walls. Very few birds were observed interacting with the water in the hypersaline pits.

All pits were utilised by aerial birds for foraging, probably due to microclimates created by pits (such as updrafts) that either concentrate invertebrates or make them easy to collect. Aerial birds were regularly observed drinking from the supernatant at Winditch Pit, which is of interest as it has a salinity similar to the lowest salinities recorded in the TSF (approximately 8 000 mg/L TDS), although other chemistry parameters are likely to differ. In comparison, at the hypersaline Keringal and Goanna pits aerial birds were primarily over the pit and never observed to interact with the supernatant.

Granivores were only recorded at two pits (Table 19). At Goanna Pit, Crested Pigeons were observed only foraging around the edge of the pit or flying over the pit, whereas at Winditch they were foraging and drinking within the pit. Bush birds and mammals showed a similar behaviour pattern with few observed at the hypersaline pits compared to the fresh and saline pits, which is likely to be due to presence of food and supernatant palatability. The only mammal records at the hypersaline pits were of some kangaroos hopping around the edge of the pit. In contrast, kangaroos were observed drinking from the supernatant at Winditch, Phoenix and Jubilee pits.

Table 19. Visitation rates and guild composition of third-party wildlife observations conducted at alternative water bodies

Location	Species diversity	Guilds recorded	Average visitation rates from 20 minute surveys (+/-SD)	Ducks (%)	Endemic waders (%)	Migratory waders (%)	Raptors and corvids (%)	Granivores (%)	Aerial (%)	Bush birds (%)	Terrestrial mammals (%)
Fresh											
Sewage ponds	18	6	34.2 ± 14.0	58.0	3.4	0.5		9.3	25.4	3.4	
Ti-tree dam	9	2	21.3 ± 20.1	70.3				29.7			
Haul road lakes	20	8	41.1 ± 68.9	90.4	1.1	1.7	2.7	0.3		3.4	0.3
Phoenix Pit	9	5	8.0 ± 5.2	12.5			8.3		20.8	25.0	33.3
Jubilee Pit	12	4	26.3 ± 18.9	58.1					35.1	4.1	2.7
Saline											
Winditch Pit	20	6	33.7 ± 27.5	35.8			0.3	2.2	39.9	8.9	12.9
Haul road borrow pit	6	4	15.2 ± 16.8	86.8	2.6				7.9	2.6	
Sediment dam	1	1	7		100.0						
Seepage trench	18	8	7.5 ± 4.6	4.7	38.6	7.1	3.9	3.1	4.7	36.2	1.6
Hypersaline											
Saline wash (duckpond)	10	7	3.0 ± 3.9	1.9	75.5		0.9	3.8	13.2	4.7	
Lake Carey-hypersaline discharge	2	2	15.3 ± 25.7		97.8	2.2					
Goanna Pit	9	6	4.9 ± 7.5		5.6		5.6	42.6	33.3	3.7	9.3
Granny's Pit	6	3	1.0 ± 1.4						100.0		
Keringal Pit	3	2	15.0 ± 5.7		30.0				70.0		

Table 20. Species composition of third-party wildlife observations conducted at alternative water bodies

		Fresh					Saline				Hypersaline				
Location	Total	Sewerage ponds	Ti-tree dam	Haul road lakes	Phoenix Pit	Jubilee Pit	Winditch Pit	Haul road borrow pit	Sediment dam	Seepage trench	Saline wash	Lake Carey	Goanna Pit	Granny Smith pit	Keringel pit
No. of 20-min surveys	17	6	3	17	3	2	11	5	1	17	35	3	11	4	2
No. of days visited	52	6	3	17	3	2	8	5	1	17	22	3	8	3	2
Species diversity	38	18	9	20	9	12	20	6	1	18	10	2	9	6	3
Ducks															
Australiasian Grebe	62	23	1	9	3	6	20								
Hoary-headed Grebe	98	12	1	55		10	18	2							
Musk Duck	4						4								
Pacific Black Duck	242	52	2	126			62								
Grey Teal	354	25	8	273		13	12	16							

continued

		Fresh					Saline				Hypersaline				
Location	Total	Sewerage ponds	Ti-tree dam	Haul road lakes	Phoenix Pit	Jubilee Pit	Winditch Pit	Haul road borrow pit	Sediment dam	Seepage trench	Saline wash	Lake Carey	Goanna Pit	Granny Smith pit	Keringel pit
Pink-eared Duck	22	1	1	11		9									
Hardhead	9	1		7			1								
Australian Wood Duck	131	2	30	97		2									
Australian Shelduck	126		2	53		2	13	48		6	2				
Coot	7	3				1	3								
Endemic Waders															
Black-winged Stilt	19								7				3		9
Black-fronted Dotteral	55	7		2						41	3				
Red-capped Plover	138			6				2		8	77	45			
Migratory Waders															
Red-necked Stint	11			10								1			
Wood Sandpiper	12	1		2						9					
Raptors and corvids															
Wedge-tailed Eagle	8			3	2		1			1			1		
Nankeen Kestrel	7									4	1		2		
Australian Raven	1			1											
Crow	15			15											
Granivores															
Common Bronzewing	1						1								
Crested Pigeon	62	15	15	2			7						23		
Galah	8	4	4												
Zebra finch	8									4	4				
Aerial birds															
Welcome Swallow	194	47			3	5	129						3	1	6
White-backed Swallow	61				2	20	5	6			4		1	3	15
Black-faced Woodswallow	21					1				6			14		
Tree Martin	29	5					14				10				
Passerines/bush birds															
Singing Honeyeater	6						3			3					
Spiny-cheeked Honeyeater	1									1					
Richard's Pipit	49				3	3	6	2		33	2				
Magpie	1			1											
Magpie-lark	32	1		17			10						2		
White-winged Wren	13				3					8	2				
Western Bower bird	4	4													
Grey Butcherbird	1	1													

continued

		Fresh					Saline				Hypersaline				
Location	Total	Sewerage ponds	Ti-tree dam	Haul road lakes	Phoenix Pit	Jubilee Pit	Winditch Pit	Haul road borrow pit	Sediment dam	Seepage trench	Saline wash	Lake Carey	Goanna Pit	Granny Smith pit	Keringel pit
Pied Butcherbird	7			6							1				
Willie wagtail	16	1					14			1					
Terrestrial mammals															
Kangaroo	67			2	8	2	48			2			5		
Total records	1 902	205	64	698	24	74	371	76	7	127	106	46	54	4	30

Foraging rates were recorded for Red-capped Plover (Table 21) at the saline wash (duck pond) and were about half that recorded at the TSF (Table 14). Reasons for this are not apparent. Foraging rates were also recorded for Black-fronted Dotterel at the saline wash (Table 21) and were significantly higher than for Red-capped Plover although only five one-minute counts were conducted.

Table 21. Average rates of foraging actions at the saline wash adjacent to the TSF

	No. of 1-min. surveys	Average no. of pecks (+/- SE)
Black-fronted dotterel	5	59.8 ± 7.7
Red-capped Plover	10	12.1 ± 2.1

Infrared camera traps

Haul road lakes

Avian species were present every day that observations took place on haul road lakes. Ducks were observed utilising haul road lakes more than any other guild and more diverse behaviours were recorded at the haul road lakes than for other guilds. Ducks numbering less than 20, including Australian Shelduck, Pacific Black Duck and Grey Teal, were observed resting on the water body, diving, foraging, wading and preening on an internal mudflat within the lake. They were observed exhibiting most of these behaviours from just before dawn, early morning, at varying stages throughout the day and at dusk. Black-winged Stilt and Silver Gulls were observed wading and resting on the lake usually from late morning until the afternoon. These species were present with the ducks on the lake although the partitioning between the species was clear, with each maintaining exclusive areas. The Silver Gulls were also observed resting on the embankment of the lake. Female and male Magpie Larks were observed wading and foraging on the lake and at the lake margin from early morning to early afternoon. These numbered less than five. A Torresian Crow was observed around the edge of the water body on one occasion in the afternoon. Two Black-fronted Dotterels were observed on separate days before dawn wading at the lake margin. It is unclear whether any of the species were drinking as well as foraging or only drinking when they were observed to be foraging.

Two Red Kangaroos (Macropus rufus) were observed, once drinking, at the margin of the lake in the early evening.

Tailings storage facility

Wildlife was not evident in most infrared camera photographs at the TSF. Red Capped Plover (Charadrius ruficapillus) was the only species photographed. It was photographed foraging on the beaches close to the decant finger and wading into shallow water just enough to cover its feet. The birds were observed early morning and briefly in the afternoon. They numbered less than five in all photographs.

No other fauna species was recorded using the TSF by infrared cameras.

Three black balloons (decoy carcases) were observed in the photographs floating on the TSF.

Songmeter recordings

Songmeters recorded avian calls in 18 five-minute survey periods at the TSF, representing 7% of five-minute periods surveyed (Table 22). Of these, Red-capped Plover calls were recorded in 13 (72%) of the total. Only four species were identified and three of these were only recorded once. These results are consistent with results from intensive observations by DES.

The hours of 6:00 to 7:00 and 10:00 to 11:00 contained the most records, both numerically and as a percentage of survey blocks. This may represent peak calling times rather than peak activity times. Only one species, Red-capped Plover, was recorded in hours of darkness (Table 22).

Table 22. Summary of songmeter data for the TSF. Twenty-minute surveys were divided into four five-minute periods and species recorded were marked as present (giving four potential presences per survey). Recording rate is given as the average number (%) of five-minute periods calls were recorded by hour for each species.

			Number (%) of 5-minute periods calls were recorded in					
	No. of 5-min. periods (20-min. surveys)	Total hours	Total	Australian Shelduck	Red-capped Plover	Pied Butcherbird	Torresian Crow	Unidentified
Total	256 (64)	21:20	18 (7.0)	1 (0.4)	13 (5.1)	1 (0.4)	1 (0.4)	2 (0.8)
4:00	8 (2)	0:40	0					
6:00	28 (7)	2:20	8 (28.6)	1 (3.8)	5 (17.9)	1 (3.8)		1 (3.8)
7:00	28 (7)	2:20	1 (3.8)		1 (3.8)			
8:00	28 (7)	2:20	2 (7.6)		1 (3.8)		1 (3.8)	
9:00	28 (7)	2:20	0					
10:00	20 (5)	1:40	4 (20.0)		3 (15.0)			1 (5.0)
16:00	24 (6)	2:00	0					
17:00	28 (7)	2:20	0					
18:00	16 (4)	1:20	1 (6.3)		1 (6.3)			
19:00	16 (4)	1:20	1 (6.3)		1 (6.3)			
20:00	12 (3)	1:00	0					
21:00	12 (3)	1:00	1 (8.3)		1 (8.3)			
22:00	8 (2)	0:40	0					

At the haul road lakes a total of 117 presences of birds in five-minute periods were recorded. Seventeen species were recorded at the haul road lakes although six of these were only recorded once (Table 23). The Grey Teal is underrepresented as it was visually observed on most occasions and yet was only recorded once. Five species, Australian Shelduck, Australian Wood Duck, Black-fronted Dotterel, Magpie Lark and Torresian Crow were regularly recorded (> 5% of five-minute blocks). Species composition is consistent with the visual 20-minute surveys although two species, Owlet-nightjar and Ground Cuckoo-shrike, have not previously been observed.

The most number of calls were recorded at the haul road lakes between 6:00 to 8:00 and 17:00 to 19:00, which is consistent with generally accepted peak calling times for birds. Seven species were recorded calling in hours of darkness.

Table 23. Summary of songmeter data for the haul road lakes. Twenty-minute surveys were divided into four five-minute periods and species recorded were marked as present (giving four potential presences per survey). Recording rate is given as the average number (%) of five-minute periods calls were recorded by hour for each species.

				Number (%) of 5-minute periods calls were recorded in																	
	5-min. periods (20-min. surveys)	Total hours	Total presences	Australian Shelduck	Pink-eared Duck	Australian Wood Duck	Grey Teal	Pacific Black Duck	Red-capped Plover	Black-fronted Dotterel	Owlet Nightjar	Crested Pigeon	Galah	Ground Cuckoo-shrike	Crested Bellbird	Magpie Lark	Australian Magpie	Pied Butcherbird	White-winged Fairywren	Torresian Crow	Unidentified
Total	216 (54)	18:00	117	18 (8.3)	6 (2.8)	14 (6.5)	1 (0.5)	3 (1.4)	1 (0.5)	17 (7.9)	1 (0.5)	1 (0.5)	1 (0.5)	1 (0.5)	1 (0.5)	16 (7.4)	6 (2.8)	6 (2.8)	2 (0.9)	16 (7.4)	6 (2.8)
4:00	12 (3)	1:00	6			2 (16.7)	1 (8.3)	2 (16.7)		1 (8.3)											
5:00	12 (3)	1:00	4		1 (8.3)	1 (8.3)				2 (16.7)											
6:00	32 (8)	2:40	24	7 (21.9)	2 (6.3)	4 (12.5)			1 (3.1)							6 (18.8)		3 (9.4)		1 (3.1)	
7:00	20 (5)	1:40	22	3 (15.0)	1 (5.0)										1 (5.0)	1 (5.0)	4 (20.0)	2 (10.0)	1 (5.0)	8 (40.0)	1 (5.0)
8:00	20 (5)	1:40	10	1 (5.0)								1 (5.0)				5 (25.0)	1 (5.0)			2 (10.0)	
9:00	20 (5)	1:40	4	2 (10.0)																2 (10.0)	
10:00	16 (4)	1:20	1																	1 (6.3)	
16:00	16 (4)	1:20	2											1 (6.3)						1 (6.3)	
17:00	36 (9)	3:00	19	2 (5.6)		2 (5.6)				3 (8.3)			1 (2.8)			4 (11.1)	1 (2.8)	1 (2.8)	1 (2.8)	1 (2.8)	3 (8.3)
18:00	16 (4)	1:20	17	3 (18.8)	2 (12.5)	5 (31.3)		1 (6.3)		5 (31.3)											1 (6.3)
19:00	16 (4)	1:20	8							6 (37.5)	1 (6.3)										1 (6.3)

Nocturnal bat monitoring

Little is known of bat behaviour, presence and associated cyanide risks on tailings systems. The M398 study is the only published literature regarding bat activity on tailings systems. An avoidance of hypersaline TSFs was previously reported in the M398 study for BGS, GSI and BKB gold mines (Adams, Donato, Schulz and Smith 2008) (see Table 14, p.45, M398 volume 2). This has been found again with further surveying at BGS. Seasonality, rainfall, temperature, moon phase and insect activity all influence bat activity. Table 24 provides an assessment of the bat activity at the saline and hypersaline BGS TSF and other water bodies. It illustrates an avoidance of hypersaline and saline water bodies.

Table 24. Bat activity at BGS TSF and alternative water bodies

Location	No. of bat passes/hr (±SE)	No. of buzz/hr	Pass/buzz ratio
BGS TSF (saline and hypersaline)	0.73 ± 0.19	0.05 ± 0.02	0.06
Trench (saline)	0.92 ± 0.16	0.12 ± 0.01	0.13
BGS haul road lakes (non-saline)	5.4 ± 1.6	0.97 ± 0.3	0.16

The bat recording devices cannot be used to directly extrapolate bat abundances due to repeat recording of the same individual, although bat activity can be demonstrated. A total of 93 bat passes (all species combined) at 0.73 ± 0.19 calls/hour were recorded from above the BGS TFS (128 hours recording) (Table 24). Tadrida australis (42%) and Mormopterus spp (24%) dominated the recorded calls.

Table 25. Total number of bat passes, buzz calls and the ratio of buzzes to passes at the TSF and fresh alternative water bodies at BGS, BKB and GSI combined

Location	No. of bat passes	No. of buzz	Pass/buzz ratio
Saline and hypersaline TSFs (BKB, GSI and BGS) (n = 380 hours)	550	39	0.07
Fresh water bodies (n = 176 hours)	5 588	1 194	0.21

Bat calls could be differentiated into navigation calls and foraging ‘buzz’ calls, which can indicate feeding, drinking or social behaviour (Pennay, Law and Reinhold 2004). Table 25 illustrates buzz calls as a proportion of total number of calls. The ratio of buzz-to-cruise calls at non-saline water bodies (0.21, combined average at the BKB turkey nest and GSI turkey nest) is higher than that recorded at hypersaline supernatants (0.07 calls/hour) ($p < 0.001$) (Table 25). This indicates that the level of feeding, drinking and social contact is less at hypersaline TSF water sources compared to fresh water sources. This concurs with terrestrial and aquatic macroinvertebrate sampling, suggesting that more food resources exist at fresh water bodies compared to hypersaline water bodies.

The extent of bat activity (Wickramasinghe, Harris, Jones and Vaughan Jennings 2003) over the fresh water of the BKB turkey nest (78.3 calls/hour, TDA < 400 mg/L), GSI turkey nest (155 calls/hour, TDS < 300 mg/L) and BGS haul road lakes (5.4 calls/hour, TDS < 500 mg/L) water bodies (Figure 24). The low activity recorded at the haul road lakes reflects that most recordings were conducted during the winter months. Nevertheless, these are orders of magnitude greater than the hypersaline TSF (BGS 0.16, BKB 4.4 and GSI 1.7 calls/hour). Interestingly, the saline wash (duck pond) alternative water body at BGS is also hypersaline

(TDS 63 000 mg/L) and has recorded a similar extent of bat passes (0.3 calls/hour) as the three TSFs (Figure 24). At times the GSI stock dam was dry and during these times recorded 15.25 calls/hour.

Differences in bat pass rates between hypersaline TSFs and freshwater control sites are likely to be related to many physical and environmental factors (as for other wildlife) such as presence of food, proximity to vegetation, palatability of freshwater and physical features. However these results indicate that bats avoid saline and hypersaline TSFs and hypersaline water bodies.

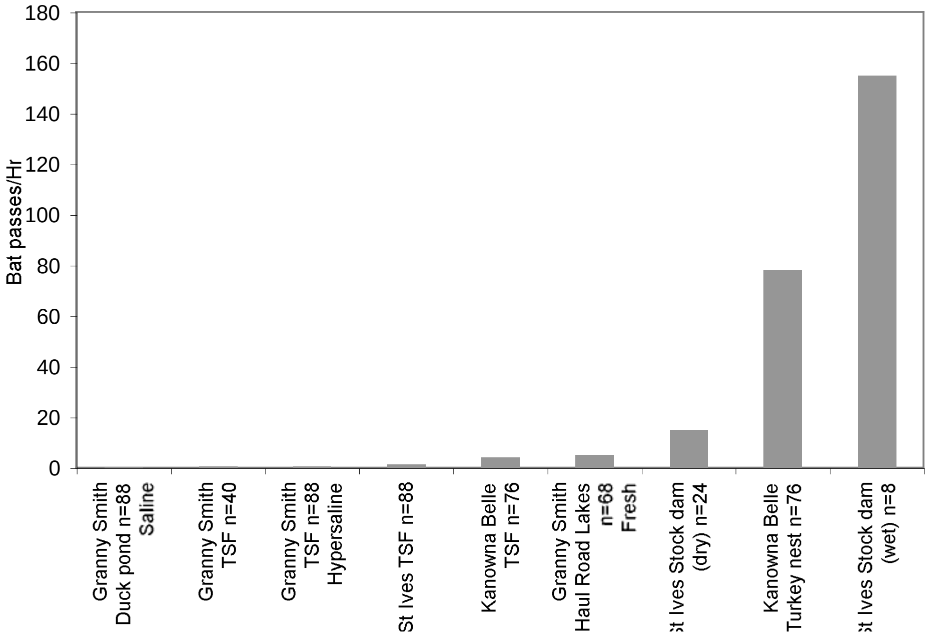


Figure 24. Average number of bat passes per hour recorded in the airspace above saline and hypersaline TSFs and corresponding nearby fresh water bodies (n = number of recording hours)

Aquatic macroinvertebrates

Dip net sampling of the TSF supernatant conducted during M398 (seven samples) recorded a total of 12 macroinvertebrates (Table 26). None were aquatic macroinvertebrates or aquatic larval forms, they were all winged terrestrial macroinvertebrates and visual inspection during sampling revealed that the specimens were all dead when collected. Specimens consisted of: winged waterboatmen nymphs (family: Coroxidae); adult water treaders (family: Veliidae); and adult water scavenger beetles (family: Hydrophilidae). Dip net sampling in July and August 2010 (ten samples in total) did not collect any macroinvertebrates.

Dip net sampling of the seepage trench collected a total of 1 894 specimens from 12 taxa in the M398 samples and 268 specimens from 5 taxa during sampling conducted during this study (Table 26). The most common taxa recorded in both datasets was mosquito or midge larvae (order: Diptera, family Chironomidae). Adult and larval beetles (order: Coleoptera) were also well represented in M398 samples (Table 26).

The assemblage was dominated by macroinvertebrates that were 1 to 5 mm in length and by smaller macroinvertebrates (less than 1 mm in length) in the M398 dataset. Sampling of the seepage trench in this project resulted in substantially less macroinvertebrates being collected with an average of 89.3

± 10.2 per sample and less diversity (five taxa) than in M398. This is likely due to the season as M398 sampling was conducted in summer and autumn while sampling for this project was conducted in mid-winter. Samples were dominated by dipteral larvae in the 1 to 5 mm size class.

The three Winditch Pit dip net samples collected a total of 228 specimens, with an average abundance of 76 ± 17.8 aquatic macroinvertebrates and 3.3 ± 0.3 taxa per sample (Table 26). Larval forms accounted for 14% of all specimens. The most common taxa recorded was beetles (order: Coleoptera; adult and larval forms combined equal 192 individuals, 84.2% of total) and dipteran larvae (31 individuals, 13.6% of total) (Table 26). Specimens from the 1 to 5 mm size class were by far the most abundant (97.4% of total).

The three dip net samples of Goanna Pit collected no macroinvertebrates.

Sampling of the haul road lakes in the current project collected 1 031 macroinvertebrates from 11 taxa (Table 26). In addition an estimated 9 000 microcrustaceans were collected in July and 15 000 in August 2010, none of which have been collected at any other on-site water body. These are likely to provide a continual and stable food source for filter-feeding birds such as ducks. Macroinvertebrates were dominated by dipteral larvae in the 1 to 5 mm size class, consistent with results from the seepage trench.

Table 26. Summary of results from supernatant dip net surveys

	M398				Current Project		
	TSF2 saline (n=7)	Trench (n=6)	Winditch Pit (n=3)	Goanna Pit (n=3)	TSF2 hypersaline (n=10)	Trench (n=3)	Haul road lakes (n=8)
Total number of macroinvertebrates recorded	12	1894	228	0	0	268	1031
Number of macroinvertebrate taxa recorded (all were identified to family or order)	3	12	6	0	0	5	11
Number of microcrustacea recorded[1]							24000
Average abundance: average number (±SE) of macroinvertebrates per sample	1.7 ± 1.1	315.7 ± 75.5	76 ± 17.8			89.3 ± 10.2	128.9 ± 20.0
Taxa richness: average number (±SE) of macroinvertebrate taxa per sample	0.4 ± 0.3	2.3 ± 0.2	3.3 ± 0.3			4	5.6 ± 0.3
Number of invertebrates (% of total, excluding micrcrustaea) by order/class							
Acarina – freshwater mite							

continued

	M398				Current Project		
	TSF2 saline (n=7)	Trench (n=6)	Winditch Pit (n=3)	Goanna Pit (n=3)	TSF2 hypersaline (n=10)	Trench (n=3)	Haul road lakes (n=8)
Diptera – fly (larvea and pupae)		1553 (82.0)	31 (13.6)			258 (96.3)	956 (92.8)
Coleoptera – beetle	2 (16.7)	312 (16.5)	1 (0.4)			10 (3.7)	11 (1.1)
Hemiptera – true bug	10 (83.3)		192 (84.2)				54 (5.2)
Odonata – dragonfly		1 (0.1)	4 (1.8)				10 (1.0)
Ephemoptera – mayfly							
Amphipoda – side swimmer		28 (1.5)					
Micricrustacea[1]							24000
Gambusia – mosquito fish							
Size class of invertebrates: number of invertebrates (% of total)							
< 1 mm		911 (48.1)	6 (2.6)			3 (1.1)	32 (3.1)
1 – 5 mm	10 (83.3)	900 (47.5)	222 (97.4)			265 (98.9)	994 (96.4)
> 5 mm	2 (16.7)	83 (4.4)					5 (0.5)

1Not included in total count of macroinvertebrates

Terrestrial and aerial macroinvertebrate sampling

Malaise trap sampling at the TSF during M398 collected substantially higher numbers of macroinvertebrates per sample than during this project (Table 27). Total number of taxa recorded was also less during this project although taxa richness per sample was similar (Table 27). As for aquatic sampling this is likely due to the season as M398 sampling was conducted in summer and autumn while sampling for this project was conducted in mid-winter.

Both the average number of macroinvertebrates collected and the taxa richness at the saline wash (duck pond) during M398 was higher than for TSF samples collected at the same time (Table 27). The taxa composition was similar however, although interestingly the total number of taxa was higher at the TSF. During the current project average abundance per malaise trap sample was similar at the TSF and haul road lakes, although taxa richness per sample was higher at the haul road lakes.

All samples were dominated by mosquitoes (order: Diptera, family Chironomidae) in the 1 to 5 mm size class, which are thought to have been wind blown up onto the TSF from the surrounding seepage trench that contains water. A similar proportion of chironomids contributed to the macroinvertebrate total at the saline wash (duck pond), which is adjacent to the seepage trench (Table 27). This may reflect their relative abundance as well as the propensity of the malaise trap to capture these groups as they are strongly aerial invertebrates.

Malaise trap sampling results demonstrate that a food source is present within the TSF in summer, autumn and winter and therefore probably all year round.

Pan trap samples contained substantially less macroinvertebrates than malaise trap samples (Table 27), probably due to a smaller capture area and the horizontal capture surface, which does not as readily capture wind-blown macroinvertebrates. The TSF decant finger only trapped two macroinvertebrates, however the TSF south wall trap collected substantially more (Table 27). Surprisingly the haul road lakes trap also collected very few macroinvertebrates.

Pan trap samples were dominated by chronomids in the 1 to 5 mm size class at all three sites (as for malaise trap samples). Hymenoptera (wasps) and Lepidoptera (moths and butterflies) were also well represented. Some were > 5 mm.

Table 27. Summary of results from survey of terrestrial and aerial macroinvertebrates collected by malaise traps and yellow pan traps

	Malaise trap sampling M398		Malaise trap sampling this project		Pan trap sampling this project		
	TSF2 (n=14)	Saline wash/ duck pond (n=14)	TSF2 (n=5)	Haul road lakes (n=7)	TSF2 decant finger (n=7)	TSF south wall (n=7)	Haul road lakes (n=7)
Total number of terrestrial and aerial macroinvertebrates recorded	910	1133	198	151	12	61	36
Number of macroinvertebrate taxa recorded (all identified to family or order)	9	6	5	6	2	6	6
Average abundance: average number (±SE) of macroinvertebrates per sample	65.0 ± 22.3	80.9 ± 27.3	39.6 ± 12.3	21.6 ± 2.6	1.7 ± 0.7	8.7 ± 2.9	5.0 ± 1.6
Taxa richness: average number (±SE) of macroinvertebrate taxa per sample	3.1 ± 0.3	3.9 ± 0.5	3.2 ± 0.4	3.7 ± 0.4	0.9 ± 0.3	2.7 ± 0.7	1.9 ± 0.5
Composition of taxa: number of invertebrates (% of total)							
Diptera – fly (larvae and pupaea)	847 (93.1)	995 (87.8)	158 (79.8)	99 (65.6)	7 (58.3)	35 (57.4)	21 (60)
Hymenoptera – wasp	16 (1.8)	75 (6.6)	30 (15.2)	28 (18.5)	5 (41.7)	19 (31.1)	6 (17.1)
Coleoptera – beetle	4 (0.4)	9 (0.8)		2 (1.3)			
Lepidoptera – moth	15 (1.6)	30 (2.6)	3 (1.5)	8 (5.3)		4 (6.6)	4 (11.4)
Hemiptera – true bug	1 (0.1)	16 (1.4)	5 (2.5)	12 (7.9)		2 (3.3)	2 (2.9)
Orthoptera – grasshopper	1 (0.1)						
Odonata – dragonfly		1 (0.1)					
Thysonaptera – thrips	1 (0.1)	1 (0.1)					
Arachnida – spider	25 (2.7)	6 (0.5)	2 (1.0)	2 (1.3)		1 (1.6)	3 (8.6)
Size class of invertebrates: number of invertebrates (% of total)							
< 1 mm	158 (17.0)	290 (25.6)	49 (24.7)	51 (33.8)	2 (17)	21 (34.4)	19 (51)
1 – 5 mm	721 (79.2)	792 (69.9)	134 (67.7)	85 (56.3)	7 (58)	21 (34.4)	7 (20)
> 5 mm	31 (3.4)	51 (4.5)	15 (7.6)	15 (9.9)	3 (25)	19 (31.1)	10 (29)

Balloon (carcass replication) detection

A total of 58 balloons were set on five occasions with 36 balloons being detected by on-site staff and 46 detected by DES (Table 28). In five out of six trials, on-site staff detected balloons on the next scheduled wildlife monitoring observation session (either the same day or the following morning) but in one trial no balloons were detected. On-site staff was not informed of the balloons and how many would be set.

Detectability of balloons depended on a number of factors. Where balloons came to rest close to the decant wall or on flat areas of wet tailings, they were generally easy to observe with binoculars. Where they came to rest along beaches or in supernatant or wet tailings at a distance greater than 150 m from the closest observation points, they were difficult to observe other than with a high-powered telescope. Some balloons were not seen again once placed in the TSF. Whether they burst or came to rest out of sight is unknown. Monitoring with good field binoculars, adequate training and sufficient time is necessary to increase the probability of balloon (and carcass) detection. Otherwise only the most obvious ones will be observed and little confidence can be placed in the monitoring regime.

Table 28. Summary of balloon trial results including consultant and on-site staff detection rates

	No. of balloons set	Location of placement	Location of balloons once at rest	No. (%) observed by consultants	No. (%) observed by on-site monitoring	Comments
M398						
1/20/2008	10	All in supernatant	Supernatant close to decant finger	10 (100%)	10 (100%)	Balloons easy to see when looked for.
4/26/2008	9	All in supernatant	Supernatant close to decant finger	9 (100%)	9 (100%)	Balloons easy to see when looked for.
5/25/2008	10	All in supernatant	Supernatant close to decant finger	10 (100%)	10 (100%)	Balloons easy to see when looked for.
Current study						
6/1/2010	9	In flowing stream	Wet tailings	9 (100%)	1	
7/25/2010	8	2 supernatant, 6 in flowing tailings stream	2 in supernatant close to decant finger, 6 on wet tailings, 300+ meters from decant finger.	7 (87.5%)	0	Some balloons on wet tailings quite easy to see, others difficult.
8/18/2010	12	4 supernatant, 8 in flowing tailings stream	2 in supernatant on far beach from decant finger, 8 on wet tailings, 300+ meters from decant finger, 2 not seen again after placement.	10 (83.3%)	6 (50%)	Very windy conditions on day of placement, 2 grey balloons in supernatant not seen again, the other 2 were very difficult to see and could only be seen under very still conditions. Balloons on wet tailings obvious and easily seen.

References

ACMER Project 58 unpublished data, 2007. Best Practice for the Management of Wildlife in Cyanide-bearing Tailings Solutions at Gold Mines: unpublished data.

Adams, M. D., D. B. Donato, R. S. Schulz G. B. Smith, 2008. Influences of Hypersaline Tailings on Wildlife Cyanide Toxicosis; MERIWA Project M398 (II) 'Cyanide Ecotoxicity at Hypersaline Gold Operations' Draft Final Report Volume 2 - Definitive Investigation. Perth, MERIWA.

Andersen, N. M. T. A. Weir, 2004. Australian Water Bugs: Their Biology and Identification (Hemiptera-Heteroptera, Gerromorpha and Nepomorpha). Australia, Apollo Books, CSIRO Publishing.

Cheal, F., J. Davis, J. Growns, J. Bradley F. Whittles, 1993. The influence of sampling method on the classification of wetland macroinvertebrate communities. Hydrobiologia 257: 47-56.

Churchill, S., 1998. Australian Bats. Melbourne, Reed New Holland.

Corban, C., 2000. Anabat 6. Bat call analysis software.

Corban, C., 2000. Analook. Bat call analysis system.

Davis, J. F. Christidis, 1999. A Guide to Wetland Invertebrates of Southwestern Australia. Perth, Western Australian Museum.

Donato, D., 1999. Bird Usage Patterns on Northern Territory Mining Water Tailings and their Management to Reduce Mortalities, Public Report. Darwin, Northern Territory, Department of Mines and Energy.

Fenton, M. B., 1970. A technique for monitoring bat activity with results obtained from different environments in southern Ontario. Canadian Journal of Zoology 48: 847-851.

Gooderham, J. E. Tsyrlin, 2005. The Waterbug Book. Victoria, CSIRO Publishing.

Griffin, D. R., F. A. Webster C. R. Michael, 1960. The echolocation of flying insects by bats. Animal Behavior 8: 141-154.

Halse, S., M. Smith, W. Kay, M. Scanlon J. Cocking, 2001. Manual for use of AusRivAS models for assessing river health in Western Australia. Wanneroo, WA, Department of Conservation and Land Management.

Ingram, B. A., J. H. Hawking R. J. Sheil, 1997. Aquatic Life in Freshwater Ponds: A Guide to the Identification and Ecology of Life in Aquaculture Ponds and Farm Dams in South Eastern Australia. Albury, Co-Operative Research Centre for Freshwater Ecology.

Lawrence, E. S., S. Painter B. Little, 2007. Responses of birds to the wind farm at Blyth Harbour, Northumberland, UK. Birds and Wind Farms, Risk Assesment and Mitigation. M. de Lucas, G. F. E. Janss and M. Ferrer. Madrid, Quercus: 47-70.

Park, K. J. A. Christinacce, 2006. Use of sewage treatment works as foraging sites by insectivorous bats. Animal Conservation 9: 259-268.

Pennay, M., B. Law K. Reinhold, 2004. Bat calls of New South Wales: Region based guide to the echolocation calls of Microchiropteran bats.

Pennay, M., B. Law K. Reinhold, 2004. Bat calls of New South Wales: Region based guide to the echolocation calls of Microchiropteran bats. Hurstville, NSW Department of Environment and Conservation.

Smith, G. B., D. B. Donato, C. G. Gillespie S. R. Griffiths, 2007. Ecology of a goldmining tailings facility in the Eastern Goldfields of Western Australia; A case study. International Journal of Mining, Reclamation and Environment (in press.).

Upton, M. S., 1991. Methods for Collecting, Preserving, and Studying Insects and Allied Forms. Brisbane, The Australian Entomological Society.

Vaughan, N., G. Jones S. Harris, 1996. Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers. Biological Conservation 78: 337-343.

Wickramasinghe, L. P., S. Harris, G. Jones N. Vaughan Jennings, 2003. Abundance and species richness of nocturnal insects on organic and conventional farms: effects of agricultural intensification on bat foraging. Conservation Biology 18(5): 1283-1292.

Wickramasinghe, L. P., S. Harris, G. Jones N. Vaughan, 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. Journal of Applied Ecology 40: 984-993.