13 April 2018

STANTEC AUSTRALIA PTY LTD

Mt Keith Satellite Project: Goliath pit lake risk assessment for birdlife

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Report Number: 1806-02-R-RevA

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EXECUTIVE SUMMARY

The proposed Mt Keith Satellite project (MKS) will be located in the Goldfields region of Western Australia. The project will mine nickel ore through open cut methods and leave two voids; Six Mile Creek (backfilled during operations) and Goliath Pit, to maximum depth of ca. 450 m. The Goliath Pit void will slowly fill with groundwater as the key water balance input.

This pit lake is expected to be terminal and fill with hypersaline groundwater to a depth of around 120 m with freeboard of around 300 m. The proposed Goliath Pit lake will likely have elevated solute concentration of metals, metalloids a result of neutralised AMD (acid and metalliferous drainage) and salinity as a result of brackish groundwater inflows and consequent high rates of evapo-concentration.

Stantec Australia Pty Ltd (Stantec) engaged Mine Lakes Consulting to provide an assessment of the risk to birdlife from water quality following closure of the Goliath Pit and development of a pit lake therein.

A source-pathway-receptor (SPR) environmental risk assessment approach was adopted, as recommended by APEC, Commonwealth and State guidelines for closure of mining disturbed lands. These guidelines require all three SPR elements to be present for a valid environmental risk to be established.

Due to the terminal nature of the water balance of an arid zone pit and a high freeboard mitigating decant risk for pit lake voids, no significant pathway exists for groundwater or surface water discharge from the pit lake.

However, two pathways, both from the lake's surface, do exist. Birdlife may directly contact contaminated pit lake water through wading/swimming and ingestion. Bird life may also ingest pit lake biota that has an elevated body burden of contaminants with a risk of contaminant biomagnification.

Although the Goliath Pit lake is likely to attract some species of waterbirds, the physical features of the predicted pit lake, such as, diminutive littoral and riparian areas and very low productivity, suggests that birds are unlikely to stay for long periods due to lack of foraging habitat and opportunity.

As a consequence, although there appears to be both feasible contaminant source and receptors, a reasonable conceptual understanding of the expected Goliath pit lake's ecology fails to provide convincing transport mechanisms that would constitute a significant contaminant pathway from pit lake water quality to birdlife.

In conclusion, the Goliath Pit lake does not constitute a significant contaminant pathway risk as habitat use by birdlife is unlikely. As a result, the consequence of either of these two pathways is minor.

1.0 INTRODUCTION

Through telephone conversations and emails, Mr Peter De San Miguel of Stantec Ltd (Stantec) requested Dr Cherie McCullough of Mine Lakes Consulting (MLC) undertake an environmental risk assessment (ERA) of the Goliath Pit Lake. Services were specified to birdlife and related to closure planning requirements for the Mt Keith Satellite Nickel Project (MKS Project) The project is 100% owned and operated by BHP Limited (BHP).

Pit lake level and water balance assessment, including the risk of overflow or through-flow from the pit lake has been modelled. Together with previous work, modelling has concluded that:

- the pit lake will likely remain a long-term sink;
- risk of an acidic pit lake is unlikely; and,
- salinity and metal/metalloid concentrations will increase over time though evapo-concentration.

The risk of pit lake water to environmental receptors is identified as a current knowledge gap.

2.0 Scope of Work

The focus of risk assessment was the pit lake that will form in the Goliath open cut void following dewatering and direct and indirect birdlife interactions with this.

The following Scope of Works (SOW) was undertaken focussing on environmental risks as below.

1. Literature review identifying identified birdlife present and their likelihood contacting Goliath Pit lake water contaminants. An evaluation of the likely consequence of contact types was made.
2. Risk assessment of pit lake water to birdlife expected to be present in and around the lake. Risk assessment was undertaken consistent with:
    - 'National Environmental Protection (Assessment of Site Contamination) Measure' NEPC (2010) *Guideline on Ecological Risk Assessment (Schedule B(5));*
    - ANZECC/ARMCANZ (2000b) *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality*;
    - DIIS (2016a); Leading Practice Sustainable Development Program for the Mining Industry – Preventing Acid and Metalliferous Drainage Handbook (authored by Dr McCullough); and,
    - (APEC, 2018) *Mine Closure Checklist for Governments*.
3. A Conceptual Exposure Model identifying risks was developed and included;
    - Identification of potential significant receptors (ecological) for the surrounding area.
    - Identifying relevant source-pathway-receptor linkages to assess contaminant of potential concern (COPC) sources, receptors and likely exposure pathways.
4. Application of management actions to reduce inherent risks and to evaluate residual risks.
5. Initial letter report summarising work undertaken and findings.
6. Formal study report citing and listing scientific and/or precedent reference sources.

3.0 ASSESSMENT APPROACH

3.1 Data Review

A review was undertaken of primary literature (journal and other peer-reviewed articles) on the relationship between pit lake water quality and risk to birdlife. Documents explaining the MKS project regional characteristics e.g., climate and proposed Goliath Pit lake site-specific characteristics e.g., hydrology, hydrogeology and geochemistry.

Review was also made of documents detailing potential birdlife receptors in the MKS region.

3.2 Conceptual Exposure Model and Environmental Risk

Environmental risk assessment (ERA) is a useful tool to understand and manage contamination risk as it considers a source-pathway-receptor (SPR) model that defines the potential for impacts upon defined receptors.

An ERA was undertaken in line with leading mine closure principles. Risk Assessments require the development of a conceptual exposure model (commonly referred to as a conceptual site model; CSM), which describes three elements through which stressors (e.g. chemicals) can move from the source to a sensitive receptor:

1) sources;

2) receptors; and,

3) pathway(s)/transport.

The three elements need to be integrated to characterise the risk, as shown in Figure 1.

Figure 1. Conceptual modelling key risk elements.

In the SPR (or contaminant-transport-receptor: CTR) model, environmental risk can be managed by strategies that lead to:

- prevention of contamination to begin with;
- the lack of significant transport pathway from source to receptor; or,
- insignificant value (or tolerant) receptors being present.

An example of this approach for managing pit lake contaminant risk is presented in Figure 2.

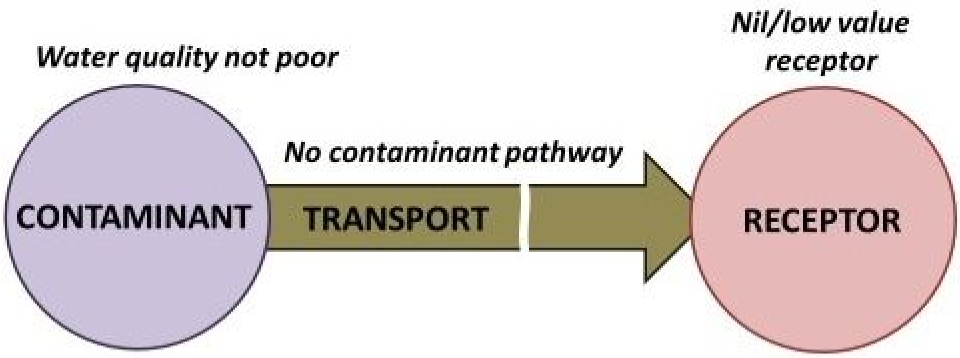

Figure 2.: Contaminant-Transport-Receptor (CTR) model for assessment of pit lake contaminant risk (after DIIS (2016a)).

- Short- and long-term pit lake water quality was considered from site and regional geochemistry, water balance (hydrology and hydrogeology) and climate. Risk was assessed both early in pit lake development and in terms of long-term water quality trend, along with the potential to decant to regional surface waters.
- The conceptual model is presented as an interpreted graphical diagram indicating potential:
  - contaminant sources;
  - transport pathways; and,
  - receptors.
- Simple likelihood/consequence risk matrix levels for on-and off site environmental consequence were used in risk assessment in addition to more complex spatio-temporal risk matrix variables as per DIIS (2016a).
- Risk assessment work was congruent with DIIS (2016a) guidelines for managing AMD risk from pit lakes.

4.0 ENVIRONMENTAL CONTEXT

The MKS Project is proposed as an open-cut nickel mining operation situated in the Northeast Goldfields of WA (Figure 3). The MKS Project is located 700 km northeast of Perth and 410 km north of Kalgoorlie. The Wanjarri Nature Reserve is the nearest gazetted conservation area, located to the east of the MKS Project.

The proposed MKS Project will consist of two open pits (Six Mile Well and Goliath), one WRL and associated supporting infrastructure. The open pits will be mined below the water table and dewatering of groundwater will be required.

Goliath open pit will be mined in two stages:

- stage 2 waste will be backfilled into the Six Mile Well pit; and,
- following mining it is anticipated the pit shell will be 1,420 m long, 1,130 m wide and 465 m deep; and,
- disturbance area of 125 ha.

4.1 Physical

Climate around the Goliath pit lake (Leinster Airport) is semi-arid, with a marked (but highly variably timed) wet season beginning in the last quarter of the year, finishing in the first quarter of the following year (Figure 4).

Figure 3. Location of MKS in Western Australia.

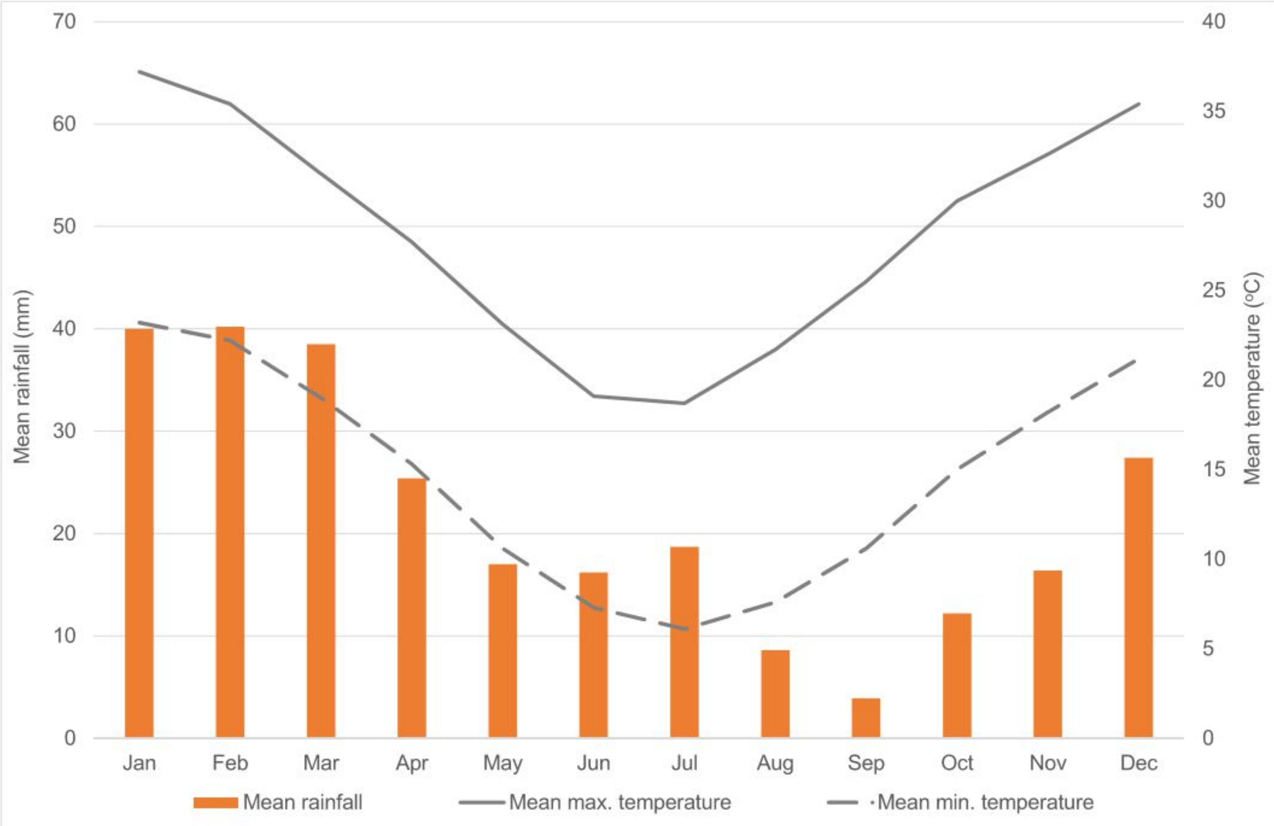

Figure 4: Climate around the proposed Goliath pit lake (Leinster Airport) (BOM, 2017).

4.2 Biotic environment

General ecological information is summarised in (BHP Nickel West, 2017c).

The MKS Project is in the Murchison Bioregion, as defined by the Interim Biogeographical Regionalisation for Australia (IBRA) classification system (Thackway, 1995). Within the Murchison Bioregion, the MKS Project is in the Eastern Murchison subregion (MUR01), which covers an area of 7,847,996 ha. This subregion comprises extensive areas of elevated red/red-brown desert sand plains with minimal dune development, breakaway complexes, and internal drainage and salt lake systems associated with the occluded palaeodrainage system. The Murchison Bioregion generally has rich flora and fauna, with most species also widespread through adjacent bioregions (Cowan, 2001). Vegetation within the Eastern Murchison subregion is dominated by low mulga woodlands (*Acacia aneura* complex) on plains, reduced to scrub on hills, with a tree steppe of *Eucalyptus* and *Triodia* on sandplains. Saltbush (Atriplex) shrublands occur on calcareous soils and saline areas are characterised by low samphire (*Tecticornia*) shrublands.

The Wanjarri Nature Reserve is the closest conservation area and the nearest Environmentally Sensitive Area (CALM, 1996) to the MKS Project (Figure 5), with its western boundary located on the eastern margin of the tenements.

There are no Nationally Important Wetlands (DOE, 2015) or Ramsar wetlands near the MKS Project.

Fauna within the Eastern Murchison subregion is known to be rich and diverse, and characterised by low levels of endemism. In the north-eastern Goldfields, 36 mammals, 178 birds, 93 reptiles and 11 amphibians have been recorded over the last 25 years (Murphy, 1994). However, no species of conservation significance have been recorded in the MKS Project area.

Several feral animal species have been found locally. The presence of feral cats (*Felis catus*) and foxes (*Vulpes vulpes*) may impact immediate and potential future recruitment of native fauna (birdlife included).

The dominant land-use surrounding the MKS Project is “*low-quality and extensive livestock grazing*” (Cowan, 2001). Other surrounding land-uses and zones include Unallocated Crown Land (UCL), Crown reserves, conservation (Wanjarri Nature Reserve) and mining (nickel and gold).

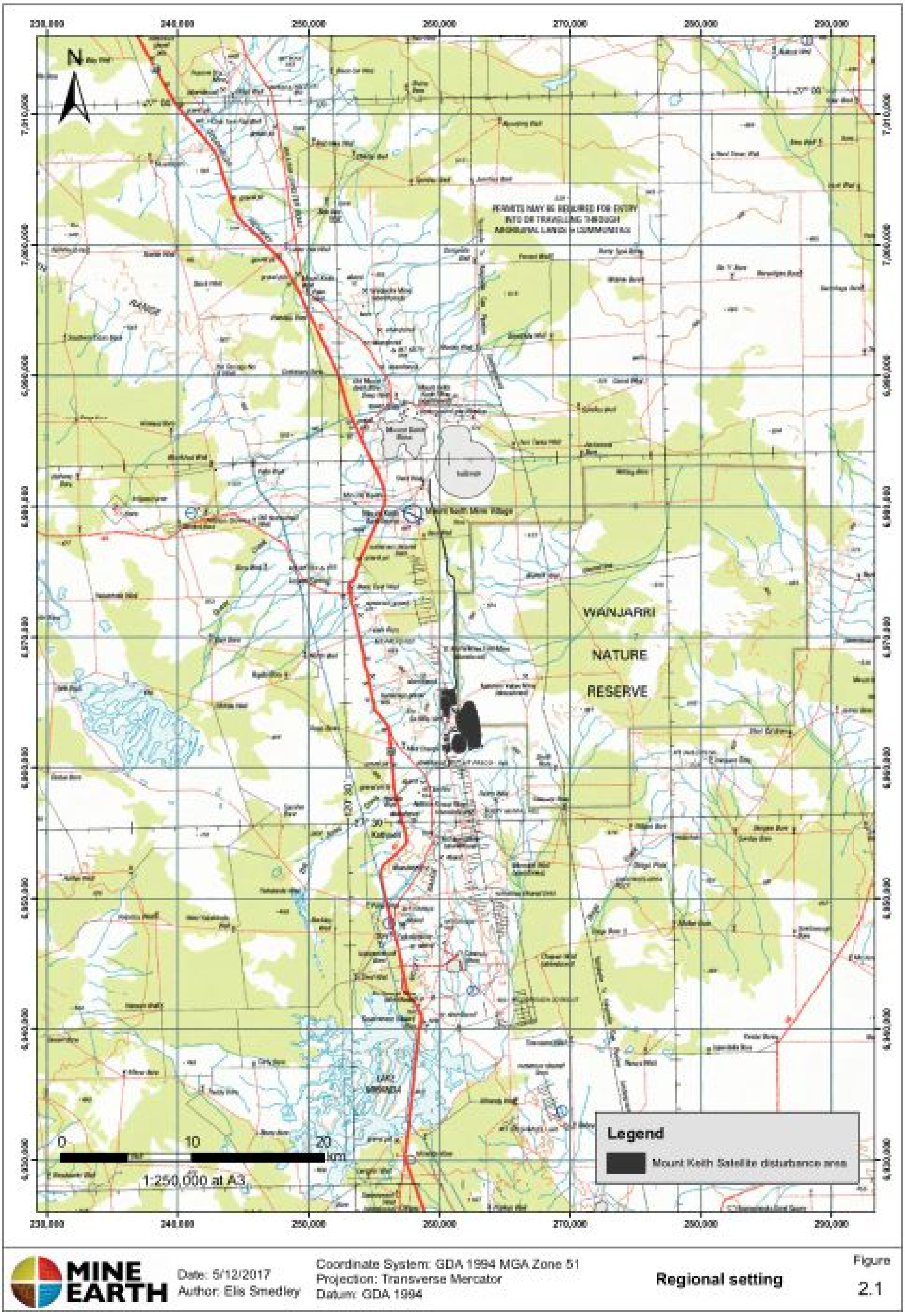

Figure 5. Regional location of MKS.

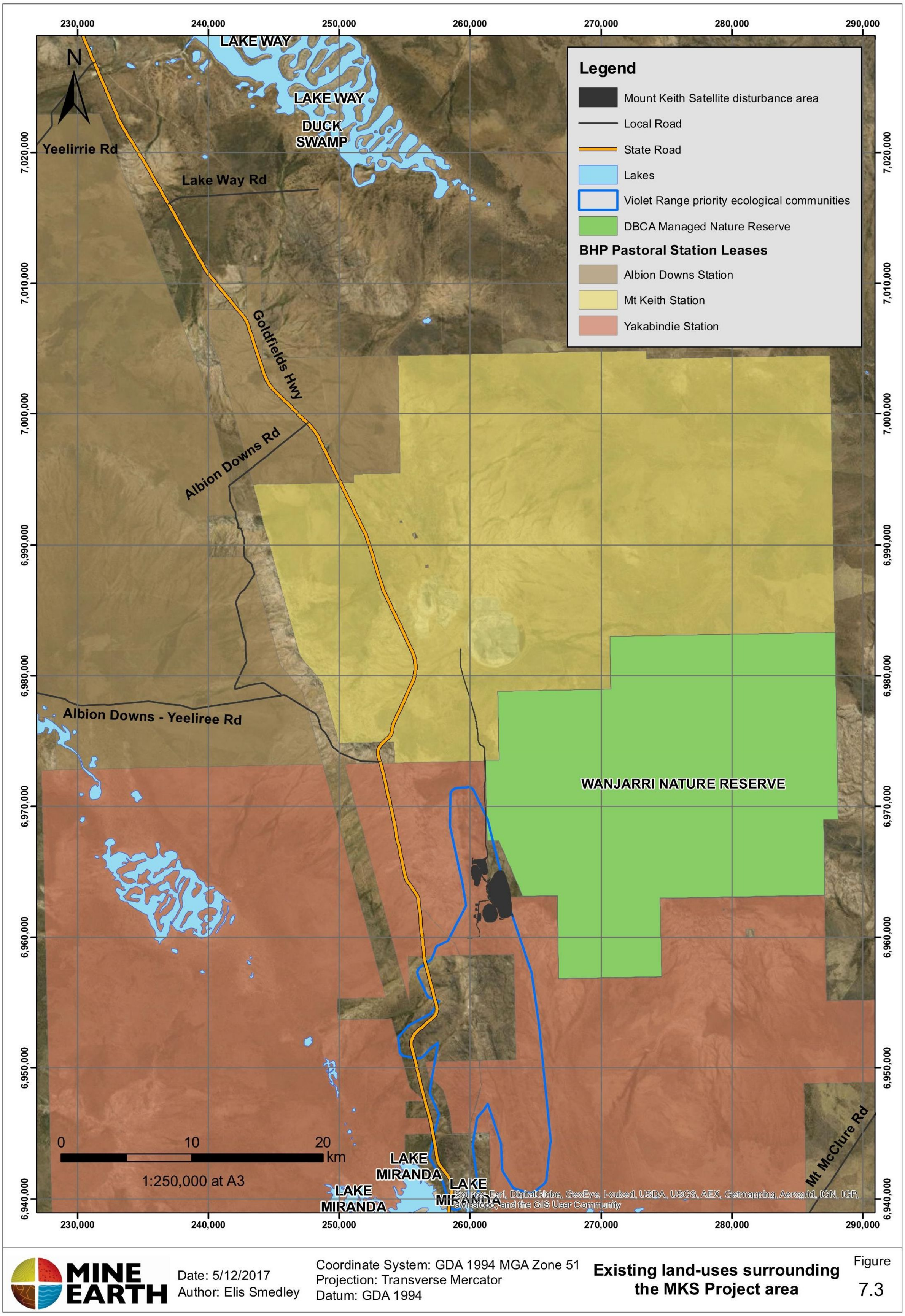

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Figure 6. Location of MKS to regional landuse and lentic waterbodies.

4.3 Hydrology

Regional hydrology is provided by MWES (2017) and (MWH, 2016).

The MKS Project is situated within the Jones Creek upper catchment (Figure 7). The Jones Creek is incised into the Barr-Smith Range. The upper slopes of the valley are relatively steep, rocky and sparsely vegetated. Short ephemeral creeks drain down the sides of the Barr-Smith Range and flood out onto the sedimentary deposits on the lower slopes of the valley.

Jones Creek is a lateral tributary stream which drains to the southwest and terminates into a large floodplain area which contains numerous clay plans. Jones Creek is a freshwater system that after significant rainfall, rapidly dries to form a series of disconnected pools. In contrast, on filling, the Jones Creek terminal clay-pan sustains a fresh-brackish water ecosystem for several months. Beyond this, the system drains into the major regional valley which contains Lake Miranda.

Due to the temporal nature of the creek, water quality is highly variable. However, baseline water quality is generally low salinity, low turbidity, low levels of nickel and zinc with elevated copper, exceeding (ANZECC/ARMCANZ, 2000b) 80% trigger level for protection of moderately-disturbed freshwater ecosystems.

Baseline stream sediment is typically 85% sand sized particles and up to 1.2% clay sized particles. Metal concentrations are generally well below the sediment quality guideline low trigger value for aquatic ecosystems (ANZECC/ARMCANZ, 2000b)) with the exception of chromium and nickel which have been recorded at values between low and high trigger values.

During large flood events water movement is rapid, due to the steep nature of the ranges and the rocky nature of the substrates. Typically, Jones Creek flows once or twice a year, in response to moderate or high intensity rainfall of 25 mm or more. In the terminal claypans, depths of over two metres have been recorded following intensive rainfall.

For the majority of creek flow events, there is no potential interaction between the flood water and proposed open pits. The potential for interaction only occurs at the margins of extreme flood levels which will occur very rarely and last only a matter of hours.

Flood studies at the nearby NMK site were used to underpin the Basis of Design (BoD) criteria determined as appropriate for surface water management features post-closure:

- Upstream catchment diversion structures will be designed to convey run-off from a critical duration 1:300 to 1:10,000 ARI rainfall event; to be determined on the basis of risk; and,
- Upstream catchment diversion structures will be designed to pass run-off from a critical duration PMP rainfall event.

The location of the Wanjarri Nature Reserve is within a separate sub-catchment area and therefore it is located outside of the drainage path for surface water flows from rehabilitation areas.

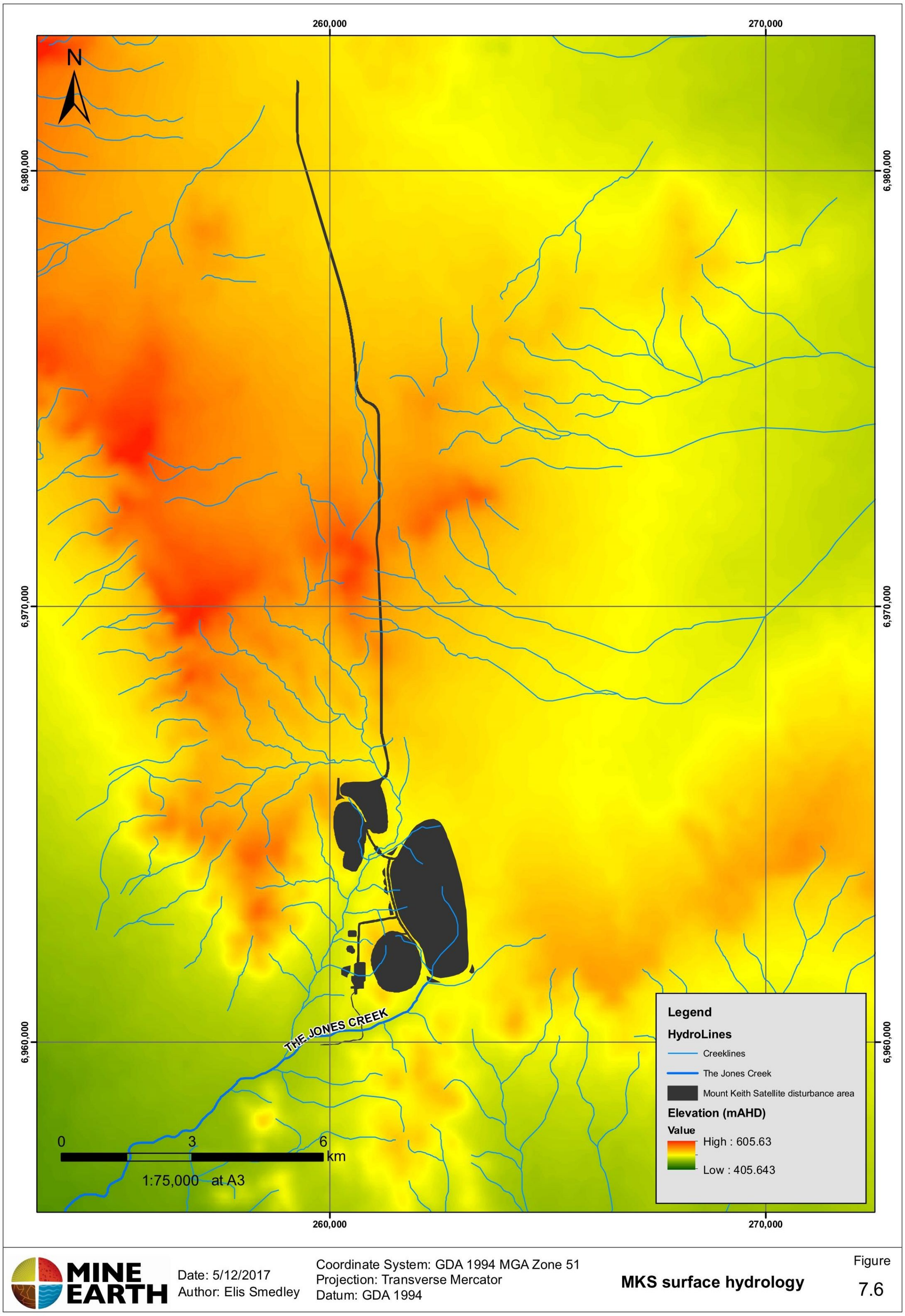


Figure 7. Location of MKS to regional topography and catchments.

4.4 Hydrogeology

Regional hydrogeology is provided by MWES (2017).

Groundwater is relatively scarce in the local region. There is no laterally continuous regolith horizon aquifer due to elevation, depth to water table and erosional denudation. Most of the bedrock lithology's have no primary or secondary porosity and drilling across most of the area has generated no groundwater yield. Nevertheless, the host greenstone belt rocks also contain an array of minor narrow, steep and localised aquifers associated with geological contacts and structural features. Water level data indicates a degree of interconnection between these features and this array is likely to be continuous for 10's of kilometres to the north and south.

Baseline groundwater quality was tested from 50 samples collected during the drilling program with the following observations:

- salinity was considered brackish, with a highly variable EC, ranging between 1000–5000 µS/cm;
- the pH was slightly alkaline;
- concentrations of most metals were low and below laboratory detection levels. The exceptions were Ni and Bo which were elevated; and,
- concentrations of nutrients were consistent with other arid regions of Western Australia.

4.5 Goliath pit lake

4.5.1 Water balance

Pit lake water balance is provided by MWES (2017).

On closure, the Goliath open pit floor will sit at approximately 80 m AHD, and the water level will gradually stabilise 60 m deep at less than 140 m AHD, resulting in a pit lake with a water level more than 300 m below the pit crest. Short term fluctuations relating to the most extreme rainfall events will result in relatively minor variations from the long-term water level trend line, having a magnitude of no more than 2 m and duration of several months. Salinity has been modelled to reach approximately 5.5 g/L after 100 years and continues to rise linearly thereafter. Over thousands of years as salinity increases above 50 g/L then brine factor reductions in pit lake evaporation rate superimpose a very gradual rise in water table level and a very gradual reduction in the rate of salinity increase.

Pit dewatering will create a cone of drawdown in the groundwater table which has been investigated and predictively modelled. Twenty of the investigation drill holes have been completed as water level monitoring bores (Figure 8). Water level measurements will be recorded quarterly during operations. At closure groundwater level monitoring will be used to validate the predicted terminal pit lake water balance.

After closure, the Goliath pit will very slowly partially refill from minor groundwater inflows from the generally impermeable country rock. to form a small and very deep pit lake. The pit lake will be inaccessible as the water level will be located 300 m below the pit crest (Figure 9).

Lake water will initially reflect the chemistry of inflowing groundwater, being brackish and with only low levels of trace components except for slightly elevated boron. Over time water quality will be defined by increasingly high salinity. Evaporation is the dominant process in defining the Goliath Pit lake water balance water quality and will causing a continuous long-term increase in the concentrations of all dissolved constituents and notably increased salinity. Trace element concentrations are unlikely to affect the pit lake water quality or constrain water use at any time, since increasing salinity will be the dominant constraint to any ecological use of the resource.

There is a risk that pit lakes may attract native fauna or stock. This may result in harm to fauna accessing the pit or through contact with the water and potential increase in predators. However, likelihood of access to Goliath Pit lake water is low due to the inherent depth to water and if access were possible, studies undertaken for the Mt Keith Closure Plan (BHP Nickel West, 2017b) and Australasian guidelines for stock drinking water (ANZECC/ARMCANZ, 2000a) indicate that once the pit lake water becomes hypersaline, both stock and native terrestrial fauna are unlikely to drink the water. This risk will further be mitigated by the construction of an abandonment bund and perimeter stock fencing around the final void. Other controls will include construction of bund across the top of pit access ramps to deter stock (cattle), fauna and human access (in the event abandonment bunds and fences are breached) and diversion of surface water away from the pit to allow it to become hypersaline whilst also reducing stability (erosion) risks.

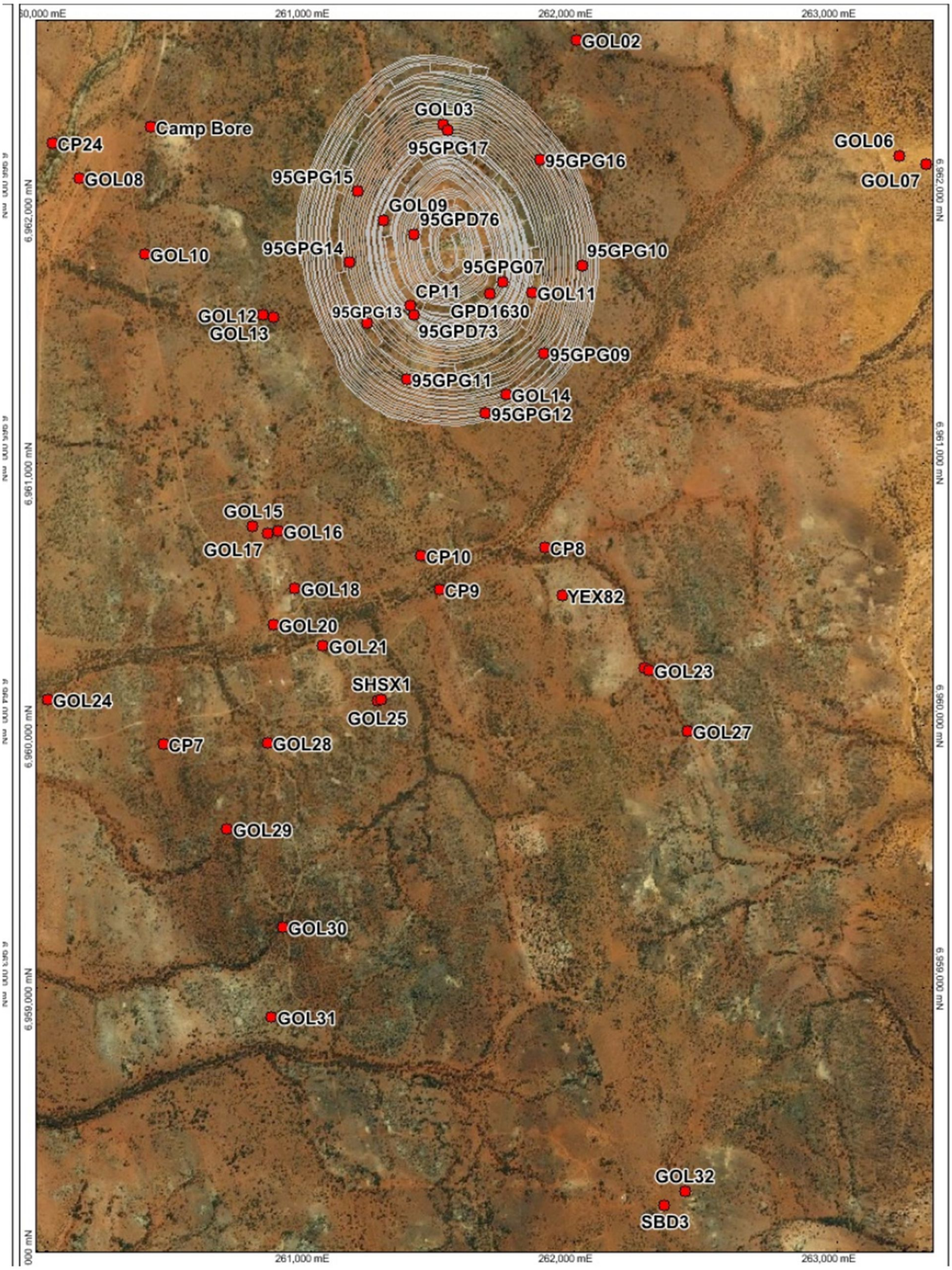


Figure 8. Goliath Pit void groundwater level sampling locations.

4.6 Geochemistry

Host geochemistry relevant to long-term pit lake water quality is summarised in (BHP Nickel West, 2017c) and (BHP Nickel West, 2017c). The understanding of pit lake chemistry evolution was based on monitoring from similar nearby pit void lakes, and published literature on pit lakes from the area e.g., (Connolly & Hodgkin, 2003; Johnson & Wright, 2003; Kumar et al., 2009; McCullough; Marchand; et al., 2013) as a more robust assessment tool than predictive simulation by hydro-geochemical modelling

ANSTO (1996) analysed samples predominantly from the Goliath deposit, with a minor number of samples from the Six Mile Well deposit. Four samples of variable weathering states were analysed for tailings geochemistry. Waste rock samples were tested for acid formation potential and salinity. GCA (2005) was commissioned as a later stage study, to assess both prior geochemical reports to ascertain whether further analysis was required for the characterisation of the deposits. In the assessment conducted by ANSTO (1996), 78 waste rock samples across 14 drill holes sampling density was applied to the Goliath void waste.

The following conclusions were made from these studies:

4.6.1 Waste Rock

- All regolith samples across both sites were classified as NAF.
- Most of the waste rocks tested for Six Mile Well and Goliath North were NAF.
- The volcanic sediment (footwall massive sulphide) present at both sites generally displays total sulphur values of 2.1%–16.4% (offset to a degree by a groundmass with pH-buffering capacity), is classified as PAF (long lag) and is recommended to be encapsulated effectively within the WRL as AMD risk waste rock.
- Based on general estimates of rock proportions within the drilling database and on a conservative basis, it is estimated that the PAF volcanic sediment (footwall massive sulphide) may comprise between 10%-25% of the total waste rock volume to be mined from both the Six Mile Well and Goliath deposits.
- Internal waste zone rocks (waste bedrocks within ore zones that are not segregated for stockpiling as low-grade ore) can be expected to create soluble Ni forms upon weathering and should be encapsulated within the WRL as AMD waste rock. All talcose ores (from oxide to fresh) are included within this category, however they are expected to be processed (under the current mine plan) and as such they will not be stockpiled at the MKS Project.
- Selenium is not present in unusual concentrations in the host rock, nor is it enriched by the nickel mineralisation. Previous environmental geochemical studies of ore, waste rock and tailings from the project site, Leinster and Mt Keith have not identified selenium as a constituent of concern. There is no history of problematic mobilisation of selenium by mining and mineral processing at the very similar hydro-geochemical conditions at Leinster and Mt Keith.

4.6.2 Tailings

- Tailings can be considered NAF but may show elevated salinity and alkalinity over time.

4.6.3 Void shell exposures

Geochemical modelling indicates that waste rock will have similar characteristics to Mt Keith geological materials (MWES, 2017). Combined with a similar climate, the geochemical risk is expected to be similar to Mt Keith where large scale mining and co-disposal with high ANC material limit the potential for acid leachate.

Larger areas of elevated sulphur are limited to the central ultramafic unit which is exposed in the floor of the pit and in bands at the north and south ends. Routinely measurable sulphur (>0.1%) is largely absent from the larger west and east walls of the pit (Figure 9). There is a small zone of higher (1-3%) S wall rock deep in the northern side between the 130 and 160m RL benches and the large majority of >0.3 % S wall rock below 160m RL. The limited distribution of elevated sulphide material in the pit walls and the large proportion of high ANC for most wall rocks indicates that the risk of acidification of the SMW backfill groundwater or the Goliath pit lake is low.

Furthermore, sulfur geochemistry is contained low in the pit void in areas that will be covered in water. Pit lakes readily stratify (Boehrer *et al.*, 2017) and lower oxygen levels in Australian warm-climate lakes have been found to limit geochemical oxidation at these depths (Boland & Padovan, 2002).

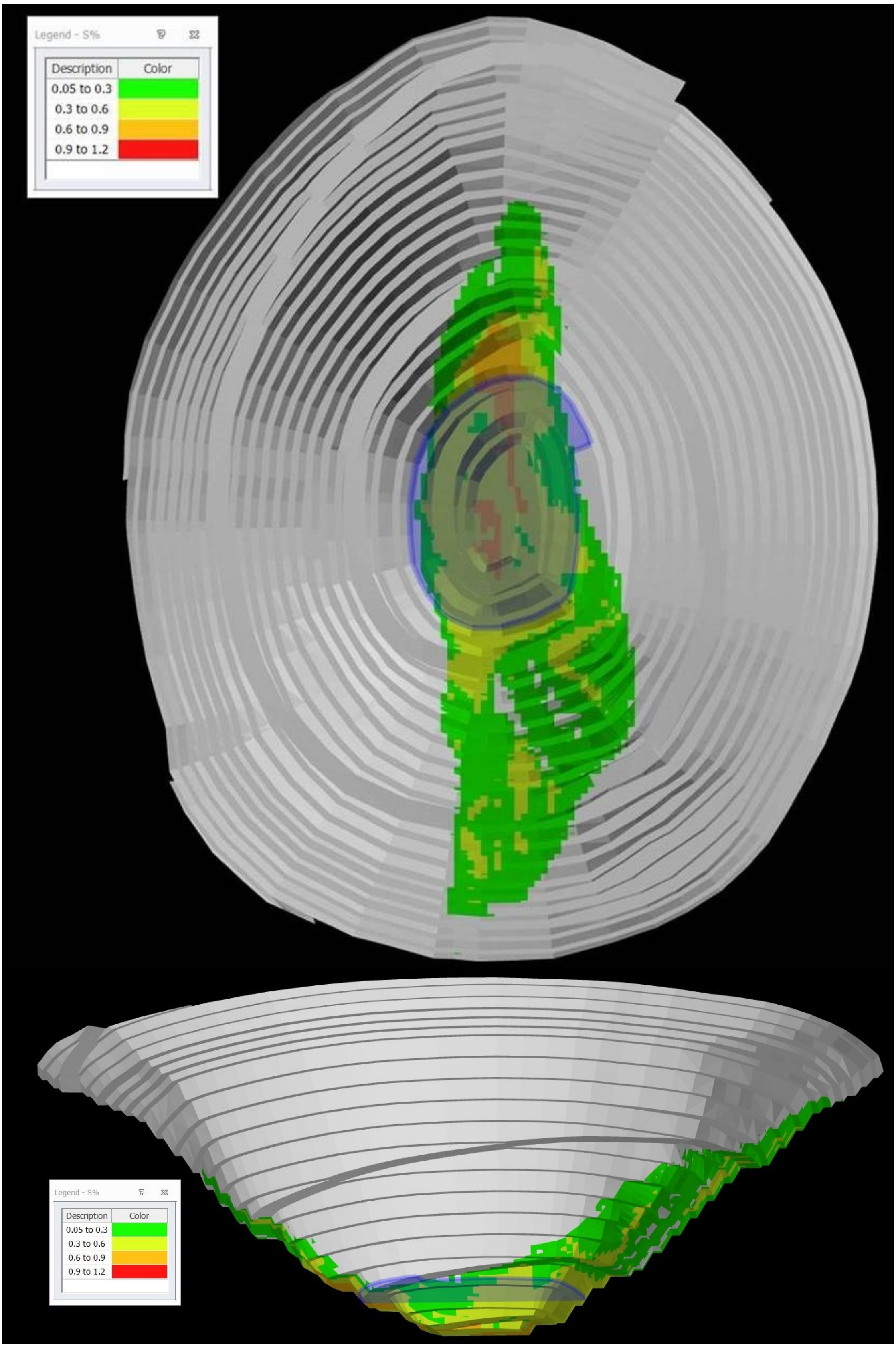


Figure 9. Total sulfur (S as %) in the Goliath pit shell: plan view (top) and looking east (bottom). Blue shade indicates equilibrium water level.

4.7 Closure

The predominant stakeholder feedback throughout IPS did not encourage a cattle grazing land-use on the heavily altered mining rehabilitated landforms (WRLs and final voids), recognising the inherent limitations and challenges in this landscape. Instead, stakeholder preferences were generally to exclude cattle from these domains and pursue a passive native vegetation outcome to soften the landscape aesthetic and increase local biodiversity.

The current plan is for the Six Mile Well open pit to be backfilled during operations. The Goliath open pit void will not be backfilled and will retain support for potential resumption of mining. Specifically:

- Mining void and immediate area will be made safe and stable with access for people and stock discouraged through fencing / bunds e.g., at top of pit access ramps, abandonment bund and rehabilitation of former access roads. Abandonment bunds will be positioned outside of the zone of influence (ZoI), or as agreed with regulators e.g., following DoIR (1997).
- The final void will be left to serve as a pit lake, which could be dewatered to support any future resumption of mining.
- The open pit will be fenced to exclude stock (cattle) such that this land-use will not inhibit or adversely impact the pastoral activity in surrounding non-mined areas.

5.0 POTENTIAL CONTAMINANT SOURCES

5.1 Summary of sources

Following from the discussion on Goliath Pit lake formation, there is a single source of contamination to regional birdlife as summarised in Table 1.

Table 1: Potential contaminant sources of the Goliath pit lake

Source Name	Source Location	Potential Contaminant Type(s)
Goliath pit lake water	Within wetted pit lake margins and capillary transport into riparian margins.	Acid and metalliferous drainage (AMD) (neutral to weakly alkaline), elevated heavy metal/metalloid concentrations.

6.0 POTENTIAL CONTAMINANT PATHWAYS

6.1 Groundwater

A good understanding of the hydrogeology (groundwater) and hydrology (surface water) is essential to determining the pit lake that will form after closure (DMP & EPA, 2015). Water balance modelling of the Goliath pit lake indicates that the lake will form a terminal sink *sensu* McCullough; Marchand*; et al.* (2013).

Boreholes were drilled specifically for hydrogeological and geotechnical investigations and to reliably assess permeability. The holes were highly targeted towards potentially higher yielding zones (using structural and geophysical methods) and demonstrate a strong bias towards higher permeability zones. Regionally minor aquifers exist at a variable density, permeability and degree of interconnection with the Goliath Pit area presenting a very low intensity of such features. Drawdown from the Goliath Pit will be of very limited extent due to the absence of permeability.

Based upon the water balance, other pit lakes water balances and long term water quality from the region, the Goliath Pit final void is reasonably expected to become a terminal sink (pit lake) of poor water quality, with net outflows (evaporation) generally exceeding inflows (rainfall and groundwater infiltration) (Kumar *et al.*, 2013; McCullough; Marchand*; et al.*, 2013). A groundwater cone-of-depression toward the lake is expected to be maintained following closure.

Consequently, there is no apparent groundwater contaminant pathway away from the pit lake.

6.2 Surface Water

6.2.1 Decant

Due to the very high freeboard at equilibrium (300 m) (BHP Nickel West, 2017a), decant is not considered a credible pathway for Goliath Pit lake contaminants.

6.2.2 Pit lake

Unlike other native animals of the arid interior, birds (particularly water fowl) may be exposed to the pit lake through drinking from the lake or by consuming aquatic organisms. Drinking is expected to be a minor component of contaminant intake relative to food intake (Hoffman *et al.* 2002, Spallholz and Hoffman 2002).

Birdlife may still be able to access the surface and feed from pit lakes directly (Doupé & Lymbery, 2005; McCullough & Lund, 2006) such that the main ecological receptor for isolated pit lakes is expected to be birds; and water fowl in particular (DMP & EPA, 2015).

Consequently, a site-specific ecological risk assessment was warranted taking into consideration the types of pathways that surrounding birdlife, in particular, are likely to be exposed to COPCs. In order of priority, these are expected to be though pathways of:

- ingestion of water;
- direct dermal contact; and,
- ingestion of pit lake aquatic wildlife.

6.3 Contaminant pathway summary

Due to the terminal nature of the water balance of an arid zone pit lake (Niccoli, 2009; McCullough; Marchand*; et al.*, 2013) and a high freeboard mitigating decant risk for pit lake voids (McCullough; Kumar*; et al.*, 2012; McCullough; Ballot*; et al.*, 2013), no pathway for groundwater or surface water discharge from the pit lake is expected.

A summary of potential contaminant pathways is presented in Table 2.

Table 2: Potential contaminant pathways from the Goliath pit lake

Source Name	Pathway Type(s)	Pathway
Pit lake	Pit lake water	Direct contact (drinking/dermal contact)
Pit lake biota	Constructed aquatic habitat with only basic biodiversity and ecosystem function (80%) aquatic ecosystem values.	Pit lake aquatic ecosystem biota containing elevated heavy metal/metalloid body burden concentrations

7.0 SIGNIFICANT POTENTIAL RECEPTORS

7.1 Pit void catchment habitat

The GOLIATH void catchment will be minimised through abandonment bunding to further reduce sheet flow contributions toward the pit void habitat.

No rehabilitation or revegetation will be established in the pit void catchment. Unstable and steep embankments within the pit void will also be maintained to limit vegetation establishment as birdlife food sources and habitat. A lack of suitable littoral riparian habitat is also typical with the short and steep littoral margins that are expected to form given the very steep void hypsography (Van Etten, 2011; Pal *et al.*, 2014) (Figure 9).

7.2 Goliath pit lake ecosystem

Pit lakes very rarely achieve the diversity or abundance of natural lakes (Lund and McCullough 2011b). Aquatic macroinvertebrate communities of pit lakes are generally depauperate in both diversity and abundance (Proctor & Grigg, 2006; Thomas & John, 2006; Parsons *et al.*, 2010). This is primarily due to both water quality and habitat limitations (Larranãga *et al.*, 2010).

The pit lake will be an artificial water body and no ecological values are intended or inferred. In pit lakes with poor water quality due to high salinity, such as the Goliath pit lake, there is typically very low diversity and biomass of aquatic ecology present.

High tropic level and larger aquatic animals are not typically observed in Australian pit lakes like the Goliath pit lake. This lack of a higher food chain is for various reasons.

- An absence of transport mechanisms as there are no other aquatic habitats harbouring these species in direct connection with the pit lake (McCullough and Harkin 2015).
- Poor water quality, be it acute toxicity or chronic toxicity though bioconcentration and biomagnification mechanisms (Lund & McCullough, 2009; McCullough & Lund, 2011).
- Insufficient pit lake food resources such as biomass and degree of trophic enrichment (McCullough *et al.*, 2009).
- Lack of suitable aquatic habitat (Lund & McCullough, 2011, 2015).

7.2.1 Water quality

7.2.1.1 Contaminants

There is a risk of pit lake water presenting a pathway to birdlife receptors outside of the aquatic ecosystem that use the ecosystem for watering, food sources or habitat.

A contaminant pathway for birds of direct toxicity through contaminated water is not of consequence unless water quality is exceptionally poor. This low consequence contribution to risk is especially true for short term exposures where birds are not spending much time in pit lake waters. However, bioaccumulation of chemicals toxic to birdlife can occur if the lake is productive enough to support a food chain underpinning food items for the waterfowl inhabiting the area (DMP/EPA 2015, McCullough and Lund 2006, Miller *et al*. 2013).

The receptors considered to spend at least part of their lifecycle within or dependent upon the aquatic environment have potential exposure to water-borne chemicals from ingestion of water (bioaccumulation), ingestion of prey (biomagnification), and dermal (ambient) exposures (bioaccumulation as bioconcentration *sensu stricto*). These aquatic biota may then pass these body burdens onto higher food chain levels, such as birds, through direct ingestion of these organisms (Hoffman *et al.*, 2002; Spallholz & Hoffman, 2002).

7.2.1.2 Nutrient availability

Although not modelled, nutrients are not expected to be at sufficient concentrations in the Goliath pit lake to provide foundation for sufficient plant (algal, macrophyte) biomass to underpin an aquatic food chain of sufficient density and trophic level for waterfowl to use the lake for regular foraging.

Pit lakes are typically limited in available macronutrients, particularly carbon (C), nitrogen (N) and phosphorus (P), although micronutrients may also be limited. The Redfield ratio suggests that 106 moles of C for every 16 of N and 1 of P are required for algal growth (Redfield & Ketchum, 1963). In natural lakes, C is typically readily available through allochthonous (external) sources such as riparian vegetation input from the catchment, through natural dissolution of atmospheric CO_2 into the water (bicarbonate buffering), and from carbonates derived from the catchment and/or lake geology. Autochthonous (internal) production by algae and aquatic plants also fixes dissolved C into organic compounds in the lake.

However, pit lakes have a typically low initial and ongoing C concentration in sediments and the water column. The substrate is often almost completely mineral when the lake fills, with the only sources of C commonly being refractory carbonate minerals in host geologies. Organic C accumulates very slowly in the substrates of new (in terms relative to natural lakes) pit lakes like the Goliath pit lake due to low input rates from allochthonous (limited riparian development due to bank steepness) and autochthonous (in-lake plants and algae limited by nutrient availability) sources. Benthic algae and bacteria often occur across the lake sediment absorbing both nutrients from groundwater entering the lake and those bound to sediment.

Nitrogen is also fixed from the atmosphere by some species of cyanobacteria and bacteria, and also washes in from the catchment from biological or geological sources (surface and groundwater). In natural lakes, sources of P are mainly limited to erosion of geological materials and the limited quantities in allochthonous sources of organic matter. As a result, it is typically P that limits primary productivity in natural lakes (Wetzel & Likens, 2003). In pit lake waters, the abundance of metals such as iron, manganese and aluminium ensure that P is often bound to sediment or precipitated out of the water column, further limiting its availability (Kleeberg & Grüneberg, 2005).

7.2.2 Goliath pit lake habitat

As per above the water level, the rehabilitated void hypsography of the Goliath pit lake includes steep slopes, a hard substrate, and shallows largely limited to the ramp incline will limit habitat for macrophyte growth. Without significant aquatic macrophyte biomasses, any ingestion pathway from these aquatic plants that may have bioconcentrated contaminants from pit lake water is not present.

The lack of shallow water also limits habitat for aerially breathing aquatic macroinvertebrates that constitute the bulk of poor water quality-tolerant freshwater invertebrate fauna (Smith *et al.* 1999). Without any significant aquatic macroinvertebrate biomasses, any ingestion pathway from these aquatic plants that may have bioconcentrated contaminants from pit lake water is not present.

Habitat availability to biota is further complicated in pit lake ecosystems due to stratification. Stratification is encouraged by the steep sides, low surface area and low wind action, and is a process that can create a hypolimnion (bottom water layer) isolated from the surface. In many pit lakes, chemical oxygen demand ensures that the hypolimnion is anoxic (the low productivity of pit lakes often means that biological oxygen demand is not the principal reason). Anoxic water bodies are unsuited to most desired lake organisms such as fin fish and crayfish; and even to basic elements of the foodchain such as phytoplankton and zooplankton (Derham, 2004; Kosík *et al.*, 2011; Moser & Weisser, 2011) especially in a tropical lake (Fukushima *et al.*, 2017). The population size of this desirable endemic fishery is therefore dependent on the size and resources (food and habitat) of the oxic littoral area of the pit lake, which is typically small in pit lakes.

Deep shading is also expected from the steep sides of the pit lake with 300 m freeboard; further limiting sun exposure to the sub-surface aquatic environment each day.

As a result of these habitat limitations, few components to an aquatic food chain are expected to be present in the Goliath pit lake. The Goliath pit lake environment is, therefore, expected to develop only a very basic and dystrophic ecosystem over time; dominated by hypersaline-tolerant microbial pathways.

7.2.3 Birdlife habitat limitations

As higher trophic order, larger and more behaviourally complex organisms, birds have more specialised habitat requirements than many other wildlife associated with aquatic ecosystems such as the Goliath pit lake.

One of the key variables defining the value of lake habitat to birds is floral communities; less species assemblage than physical vegetation characteristics of height, form and cover. Most pit lakes fail to attain riparian vegetation, even many years after closure. This is mainly due to a lack of riparian species-specific planting, unstable pit lake margins, low nutrient concentrations in the soils and rapidly changing pit lake water levels during filling (Van Etten *et al.*, 2012) (Lund *et al.*, 2013). Riparian vegetation will also contribute physically to bank stabilisation, facilitating further littoral and bank vegetation establishment (Van Etten, 2011).

Other physical elements of habitat are also important for bird habitat around lakes. For instance, a major difference in the littoral area between natural lakes and the Goliath pit lake pit lake is that natural lakes tend to have diverse structural elements such as rocks, logs and plants (emergent and submerged) that provide habitat for organisms. Pit lakes have a typically poorly developed riparian zone, few plants and logs, and often sandy or muddy edges (McCullough *et al*. 2009). In natural lakes, macroinvertebrates and decomposers (bacteria and fungii) break down organic matter into usable dissolved forms and a small quantity of small fragments form a denser layer in the sediment. The substrate of pit lakes is typically dominated by bedrock and talus and has a very low organic content (Blodau *et al.* 2000). Therefore, the littoral regions of pit lakes are generally a much poorer habitat than those found in natural lakes.

As for a natural lake, a significant component of the lake aquatic ecosystem is defined by the water depth, which determines the following.

- Aquatic vegetation (biomass and assemblage).
- Sediment organic content and size.
- Access to the surface for aerially-breathing fauna.
- Euphotic depth (light penetration for photosynthesis).
- Degree of wave exposure and sediment erosion.

Aquatic macroinvertebrate food sources for birds using the lake are defined by these variables in turn. Shallower depths (5 m and under) typically harbour the highest diversity and abundances of macroinvertebrates of both pelagic and littoral forms that might form part of the diet of waterfowl (Luoto, 2012).

There are limited aquatic habitat features in the proposed Goliath pit lake where the newly hard rock formed pit lake void will remain very sparse of organic soil and riparian vegetation. Due to the steep highwalls, little littoral or even shallow water is also expected, with steep increase in lake depth from the wetted perimeter to the lake centre (Figure 9). This lack of shallow and littoral edge and dominance by a deep, pelagic zone (to around 60 m) is untypical of Australian lakes in general, and certainly of water bodies of the region (DEC, 2012).

The ecosystem that birds interact with is also more than just floral or non-living. Inter-specific interactions are also very important; and predation particularly so. Terrestrial mammals such as feral cats (*Felis catus*), wild dogs (*Canis lupus familiaris* and *Canis dingo*) and foxes (*Vulpes vulpes*) feature as the predators most likely to attack and kill waterbirds in Australia (Olsen *et al.*, 2006). However, a valuable use of the pit lake habitat can be made by birds through predator avoidance and protection in the open water body that is afforded there (Zimmer *et al.*, 2011).

7.3 Bird life

The proximity of the Study Area to the existing Mt Keith operations and Wanjarri Nature Reserve placed it in the context of numerous additional fauna surveys previously conducted in the area. These reports were reviewed by (Biota, 2017) to provide background, context and information of the ecology and environmental risks from the Mt Keith Satellite Project (Table 3). These findings are relevant also to the risk to birdlife afforded by the Goliath pit lake.

These three systematic fauna surveys were directly relevant to the Study Area because they included sites within the study area or within a mapped habitat unit that is continuous with, or within 10 km of, the Study Area. However, no species of conservation significance were recorded within the Study Area.

Two WC Act Schedule and two DBCA Priority 4 listed bird species were recorded in the vicinity of the Study Area, or may occur there based on their known distribution: the Malleefowl (*Leipoa ocellata*, WC Act Schedule 3, EPBC Act Vulnerable), Peregrine Falcon (*Falco peregrinus*, WC Act Schedule 7), Princess Parrot (*Polytelis alexandrae*, Priority 4) and Striated Grasswren (*Amytornis striatus striatus*, Priority 4).

The Night Parrot (*Pezoporus occidentalis*, Schedule 1) was considered as the recent confirmed sighting in the Murchison Bioregion and the release the “Interim guideline for preliminary surveys of night parrot (*Pezoporus occidentalis*) in Western Australia” ((DOE), 2016).

A number of migratory species were also returned from the EPBC Act Protected Matters database search. Although these species may visit ephemeral pools and nearby salt lakes following heavy rains when water pools and when hypersaline water is diluted, and some have been recorded from the Mount Keith tailings facility (Donato, 2006), these species are unlikely to be dependent on the habitats of the Study Area. Migratory species are therefore not addressed below.

No Conservation Significant birdlife (including waterfowl) were found in the immediate project area (Table 4). However, a number of common species of waterfowl might occur in the Goliath Pit region, as indicated by database search results and/or survey (Table 5). The risk of pit lake water to bird life was only considered significant to waterfowl as these species are likely to interact directly in a regular manner with pit lake waters; either for drinking, habitat or feeding.

While water birds do not currently appear to inhabit the project area (consistent with the current dry landscape), the presence of water in the pit lake may also attract some wide-ranging waterfowl to the location.

Table 3: Documents reviewed by MLC relevant to birdlife risk from the Goliath pit lake

Reference #	Reference Title
1	Fauna Assessment, Western Mining Corporation, Yakabindie. ATA Environmental (2005a). Unpublished report for SKM Consulting/BHP Billiton.
2	Wanjarri Land Swap Proposal: Ecological Assessment. Biota Environmental Sciences (2006a). Unpublished report for SKM Consultants/BHP Billiton.
3	Fauna Habitat and Fauna Assemblage of the Mt Keith Mine Project Area. Biota Environmental Sciences (2006d). Unpublished report for BHP Billiton Nickel West.

Table 4: Conservation significant birdlife found in database searches (excluding migratory species).

Species	Status under the WC Act [EPBC Act]	Suitable habitat units in study area	Locality of records	Recorded from study area
Night Parrot (*Pezoporus occidentalis*)	Schedule 1 [Endangered]	Sandplain supporting mature Spinifex (roosting, nesting) shrubland, Wanderrie Bank grassy shrublands, bluebush shrublands and Chenopod plains (foraging).	Murchison bioregion (exact location unknown)	No
Malleefowl (*Leipoa ocellata*)	Schedule 3 [Vulnerable]	Drainage Line Areas of Internal Drainage – Mulga	Wanjarri Nature Reserve and numerous locations at Yeelirrie	No
Peregrine Falcon (*Falco peregrinus*)	Schedule 7 [NA]	Drainage Line	Mt Keith, Wanjarri Nature Reserve	No
Princess Parrot (*Polytelis alexandrae*)	Priority 4 [NA]	Drainage Line Areas of Internal Drainage – Mulga	Wanjarri Nature Reserve (unconfirmed)	No
Striated Grasswren (*Amytornis striatus striatus*)	Priority 4 [NA]	Undulating Plains Grass Dominated	Wanjarri Nature Reserve	No

Table 5: Database search and survey results for waterfowl potentially occurring in the study area (MKS, 2017). • symbol indicates positive record.

Family	Species Name	Common Name	Database	Survey
Anatidae	*Cygnus atratus*	Black Swan	•	
Anatidae	*Tadorna tadornoides*	Australian Shelduck	•	•
Anatidae	*Anas superciliosa*	Pacific Black Duck	•	
Anhingidae	*Anhinga novaehollandiae*	Australasian Darter	•	
Ardeidae	*Egretta novaehollandiae*	White-faced Heron	•	
Charadriidae	*Elseyornis melanops*	Black-fronted Dotterel		•
Charadriidae	*Erythrogonys cinctus*	Red-kneed Dotterel		•
Halcyonidae	*Todiramphus pyrrhopygius*	Red-backed Kingfisher	•	•
Halcyonidae	*Todiramphus sanctus*	Sacred Kingfisher	•	
Meropidae	*Merops ornatus*	Rainbow Bee-eater	•	•
Pelecanidae	*Pelecanus conspicillatus*	Australian Pelican	•	
Phalacrocoracidae	*Phalacrocorax sulcirostris*	Little Black Cormorant	•	•
Podicipedidae	*Tachybaptus novaehollandiae*	Australasian Grebe	•	
Rallidae	*Porzana pusilla*	Baillon's Crake		
Rallidae	*Tribonyx ventralis*	Black-tailed Native-hen	•	
Rallidae	*Fulica atra*	Eurasian Coot	•	
Threskiornithidae	*Threskiornis spinicollis*	Straw-necked Ibis	•	

7.4 Receptor summary

A summary of potential contaminant receptors is presented in Table 6.

Table 6: Potential contaminant receptors of the Goliath pit lake.

Receptor Name	Receptor Location	Receptor Values(s)
Regional birdlife	Highly mobile, up to hundreds of kms around GOLIATH pit void	Constructed aquatic habitat with depauperate ecosystem diversity and abundance. Vagrant migratory and other protected waterfowl may make short-term use for habitat and may briefly try to feed and water.

8.0 CONCEPTUAL CONTAMINANT SOURCE-PATHWAY-RECEPTOR MODEL

Risk assessment is used to evaluate and rank the absolute and relative significance of contaminant hazards and the efficacy of management in reducing residual risk (DIIS 2016c). As a first step in determining and evaluating risk, a conceptual framework for key sources, pathways and receptors was developed (Figure 10).

Unlike other native animals of the arid interior, birds (particularly waterfowl) may be exposed to the pit lake through drinking from the lake or by consuming aquatic organisms. Bird life may be attracted to pit lake water bodies where they may land on, ingest and consume food items from aquatic ecosystems within the lake (Doupé & Lymbery, 2005; McCullough & Lund, 2006). This food chain may provide ecological benefit to native regional biota, particularly nomadic or migratory waterfowl. However, mine water contaminants such as heavy metals may biomagnify through a foodweb pathway to consumers (Miller *et al.*, 2013). Drinking is expected to be a minor component of contaminant intake relative to food intake (Hoffman *et al.*, 2002; Spallholz & Hoffman, 2002). Consequently, food intake was considered the priority pathway for further analysis to identify potentially sensitive receptors.

There is a small risk of biomagnification to bird life, particularly so for some elements (DMP & EPA, 2015). Of these, heavy metals such as cadmium (Cd) and the metalloid selenium (Se) have been considered significant risks for pit lakes with aquatic ecosystems (Miller *et al.*, 2013) and of greatest risk for Western Australian pit lakes. The potential of pit lakes to attract and impact upon waterfowl may therefore present a risk of a pit lake with poor water quality as a possible attractive nuisance (Doupé & Lymbery, 2005; McCullough & Lund, 2006).

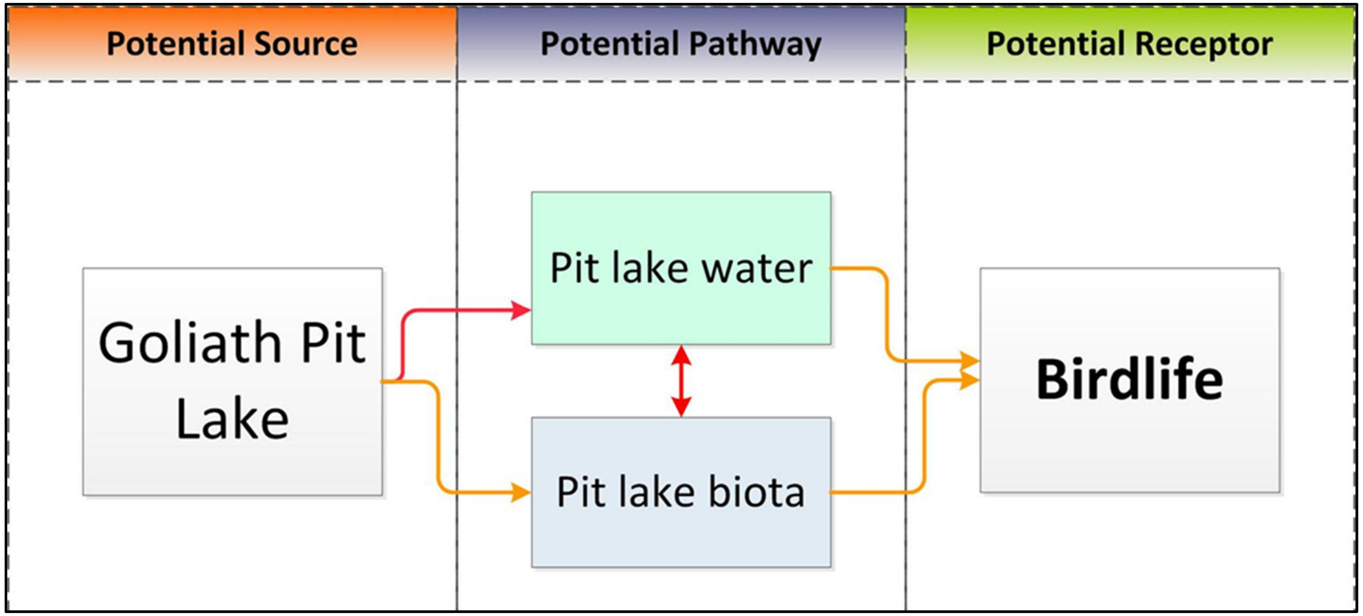
Both initial and long-term water quality, particularly in terms of elevated salinity, are expected to significantly reduce the environmental risk of the proposed Giant Pit lake final landform. This conclusion is supported by the hypersalinity of process solutions and a lack of aquatic food resources representing similarly secondary protective mechanisms that operated to prevent cyanide-related birdlife mortality on Goldfields regional tailings impoundments (Griffiths *et al.*, 2009).

8.1 Summary Findings

The model shows that Goliath Pit lake water has two simple key potential contaminant transport pathways (Figure 10):

i) directly from birds drinking from the proposed Goliath Pit lake; and,

ii) indirectly to waterfowl feeding on Goliath Pit lake biota.



Note: Major pathways are shown in red and minor in orange.

Figure 10: Conceptual Source-Pathway-Receptor model for birdlife from the Goliath pit lake.

9.0 RISK ASSESSMENT

Risk assessment is an accepted approach to evaluate and rank the significance of hazards (DIIS, 2016c). An overview risk assessment for contamination from the proposed goliath Pit Lake is set out in Table 7 below. In addition to consideration of likelihood and consequence, additional risk assessment detail relating to the spatial extent and the likely duration of the hazard has been incorporated into the assessment.

Risk component weightings were assigned on a scale from 1 to 5 (lowest to highest) (Table 8). Risk rating was derived by successive multiplication of each component category weighting. The maximum possible risk rating for Simple risk rating was across two risk components and was 25 (i.e. 5x5). For Spatio-Temporal risk rating across four risk components the maximum was therefore 625 (i.e. 5 × 5 × 5 × 5). The minimum possible risk rating was always 1 (i.e. 1^x).

Constant to all risks was that there was to be little spatial impact with contamination confined to a short spatial (local only) distance of the pit lake only and with no transport away from site. Similarly, the time scale of impact was expected to be long with contamination production sources potentially continuing over moderate timescales of decades to centuries. Transport mechanisms affecting rate and direction of contaminant transport were also not expected to change during this time.

Table 7: Semi-quantitative environmental risk assessment for birdlife from Goliath pit lake contaminants.

Register #	Category	Item		Likelihood	Consequence	Simple risk	Extent	Duration	Spatio-temporal risk
1	ADM pit lake water quality	Direct dermal toxicity to birdlife	Inherent	2 Water birds may drink from and use pit lake surface as habitat e.g., as a predator avoidance strategy.	2 COPCs at low concentrations.	**4**	1 Localised to pit lake only with no contaminant transport pathway away from site.	5 CPOCs will remain elevated in perpetuity.	**20**
			Residual	1 Depauperate aquatic food sources, littoral riparian margin and terrestrial vegetation provide little birdlife habitat. Birdlife pit lake use low as few habitat requirements met there.	1 COPCs at low concentrations and mitigated by extremely high water hardness. Increasing salinity renders pit lake water undrinkable to wildlife in a short-term.	**1**	1 Localised to pit lake only with no contaminant transport pathway away from site.	5 CPOCs will remain elevated in perpetuity.	**5**

2	**Indirect biomagnification toxicity to birdlife**	**Inherent**	1 Birdlife may use pit lake ecosystem for food resources.	2 Birdlife may feed on aquatic biota; including adult life stages of aquatic juveniles that have developed in the pit lake. Bioaccumulation in these biota may lead to biomagnification of some COPCs; especially heavy metals.	**2**	1 Localised to pit lake only with no contaminant transport pathway away from site. Food feed unlikely to influence large region due to limited primary production.	4 CPOCs will remain elevated in perpetuity.	**8**
		Residual	1 Birdlife not expected to frequent or reside over significant periods of their lifespan or for significant life stages e.g., breeding on and immediately around the pit lake.	1 Dystrophic pit lake aquatic ecosystem provides poor food source diversity and biomass.	**1**	1 Localised to pit lake only with no contaminant transport pathway away from site. Food feed unlikely to influence large region due to limited primary production.	5 CPOCs will remain elevated in perpetuity.	**5**

10.0 DISCUSSION

Mine void pit lakes can present risks to the environment following their closure and filling (Doupé & Lymbery, 2005; McCullough & Lund, 2006). This risk may increase if lakes are terminal and solute concentrations increase with water quality becoming contaminated (McCullough; Marchand*; et al.*, 2012; McCullough; Marchand*; et al.*, 2013). Increased pit lake salinity is not expected to directly prevent toxicity, merely alter exposure pathways and key toxicants (Jehl *et al.*, 2012).

Bird life may be attracted to these large water bodies where they may land on, ingest and consume food items from aquatic ecosystems within the lake (McCullough & Lund 2006). This food chain may provide ecological benefit to native regional biota, particularly nomadic or migratory waterfowl. However, mine water contaminants such as heavy metals may biomagnify through either pathway to consumers (Miller *et al.*, 2013).

There is risk of biomagnification through such food chains, particularly so for some elements of especial regulatory concern (DMP & EPA, 2015). Of these, heavy metals such as cadmium (Cd) and the metalloid selenium (Se) have been considered significant risk for pit lakes with aquatic ecosystems (Miller *et al.* 2013) and of greatest risk for Western Australian pit lakes. The potential of pit lakes to attract and impact upon waterfowl may therefore present a risk of a pit lake with poor water quality as a possible attractive nuisance (Doupé & Lymbery, 2005; McCullough & Lund, 2006).

As such, pit lake management and closure planning good practice requires assessment of these risks when these elements are present at elevated concentrations (DIIS, 2016b; Vandenberg & McCullough, 2017).

11.0 CONCLUSIONS AND RECOMMENDATIONS

The objective of this preliminary ecotoxicological assessment was to meet requirements of DMP and EPA MCP Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015) for closure risk assessment for pit lakes. The key aspect addressed was consideration of impacts to migratory birds primarily through potential impacts to the food chain. We conclude that the risk to bird life from the presence of the pit lake containing elevated solute concentrations is not of material significance for the reasons explained further below.

A number of factors are expected to limit the development of key biotic processes within the Goliath pit lake ecosystem. These factors may include:

1) small catchments of the pit lake, which limit opportunities for organic matter and nutrients to accumulate in the lake
2) lack of vegetated riparian zones, which are expected to be non-existent with steep riparian margins and in the absence of soils
3) limited littoral habitat for the establishment of all trophic levels and taxonomic groups of the biotic communities as the lake edge is predominantly steeply angled batters
4) lack of normal lake sediments as the pit lake bed lacks the organic matter content needed to support biological processes, and
5) water quality issues associated with elevated concentrations of key toxicants (heavy metals and metalloids especially).

The birds described with potential to use the pit lake habitat are primarily beach foraging and wading birds. Although the Goliath Pit lake is likely to attract some of these species of waterbirds, the physical features of the predicted pit lake such as diminutive littoral areas and low productivity means that the overall lack of foraging opportunities suggests that birds are unlikely to stay for long periods due to lack of foraging habitat and success.

Further active discouragement of bird foraging may be undertaken by removing the little littoral habitat that will present in the pit lake from the ramp. Determination of the approximate water level at equilibrium should be undertaken for both wet and dry seasons. This analysis should then be followed by establishment of a steep bund along the ramp above and below these points. Bunding below the water level will effectively remove shallow littoral foraging habitat during both wet and dry seasons.

As a consequence, although there appears to be both feasible contaminant source and receptors, a reasonable conceptual understanding of the expected Goliath pit lake's ecology fails to provide convincing transport mechanisms that may constitute a valid contaminant pathway from pit lake water quality to birdlife.

In conclusion, the use of a pit lake does not constitute a significant contaminant pathway risk as habitat use by birdlife is unlikely. As a result, the consequence of either of these two pathways is minor.

12.0 STUDY ASSUMPTIONS AND LIMITATIONS

The overall conclusions of this ecotoxicological risk assessment should be revised should further information be made available to inform the assumptions applied herein. The following assumptions and limitations are key to interpreting this study and its findings:

- Risk assessment and management was commensurate with the recommended closure planning guidelines for pit lakes of DMP & EPA (2015) and DIIS (2016a).
- Pit lake environmental risk was limited to water quality and associated effects only.
- No other environmental receptors other than birdlife were considered.
- Only regionally present or expected birdlife were considered.
- Some species that appear in the EPBC Act Protected Matters Search Tool are often not likely to occur within the specified area as the search provides an approximate guidance to matters of national significance that require further investigation. The records from the Nature Map searches of threatened fauna provide more accurate information for the general area. However, some records of sightings or trappings can be dated and often misrepresent the current range of threatened species.
- Water balance and water level were considered as of the current modelling predicted values only.
- Stratification and mixing were not considered significant risk modifiers.
- Assumptions were also made as to the likely characteristics of the final pit lake ecosystem. These assumptions include:
    - final water level modelling;
    - final void shell shape; and,
    - expected bird species using the pit lake as habitat and their predominant behaviours during this use.

Your attention is also drawn to Appendix A entitled "Limitations". The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters. The Important Information document does not seek to alter the obligations Mine Lakes Consulting has under the contract between it and its client.

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APPENDIX A

Limitations

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APPENDIX B

Risk Assessment Matrix

Table 8. Weightings are assigned from a scale from 1 to 5 (lowest to highest) for the multi-dimensional risk component categories and then multiplied to yield the final risk rating.

Weighting	Likelihood	Environmental Consequence	Extent	Duration	Simple-risk	Spatio-temporal risk	Classification
1	Rare	Limited damage to minimal area of low significance	Immediate	Days	1-5	1-4	Very Low
2	Unlikely	Short-term impact not affecting ecosystem function	Surrounds	Months	5-10	5-36	Low
3	Possible	Significant medium-term impact on valued species but not ecosystem function	Local	Years	10-15	37-144	Moderate
4	Likely	Significant long-term impairment of ecosystem function or valued species	Catchment	Decades	15-20	145-400	High
5	Almost certain	Very significant impacts on highly valued ecosystems or components.	Regional	Centuries	20-25	400-625	Extreme