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Appendix W – Ecotoxicology Forward Work Program

Mine Lakes
CONSULTING

19 February 2018

MCARTHUR RIVER MINING

A framework for development of site-specific guideline values for McArthur River Mine

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Report Number: 1702-005-R-Rev1

Distribution: 1 Electronic Copy – McArthur River Mine

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EXECUTIVE SUMMARY

Glencore's McArthur River Mine is located in monsoonal northern Australia.

Water quality and ecology of tropical northern Australian waterways are not well-represented in ecotoxicological data used to derive guideline water quality criteria. Furthermore, mining regions frequently have elevated contaminant of potential concern (COPC) concentrations as result of enriched catchment geochemistries. As a result, site-specific guideline values (SSGVs, termed 'trigger values' in earlier guidelines) are recommended for managing water quality values for life of mine (LOM), including mine closure.

A summary of the current Australian and New Zealand Water Quality Guidelines approach to water quality guideline value development is given in the context of life of mine, mine water discharges. Where relevant, recent updates and modifications to the recommended GV development methodology and application are also given.

Where generic GVs are exceeded or not applicable, we recommend a risk-based approach to SSGV derivation. A simple decision tree framework is presented to direct decision.

Emphasis is given as to the likely need to develop SSGVs in the context of a naturally geochemical enriched catchment that mining presents. Recommendations are for the thrust of SSGV derivation to be made from ecotoxicological data. Ecotoxicological data should be developed from assemblage and community tests within the region's aquatic ecology, waters and land use objectives.

Many of these recommendations do not require immediate action. However, development with milestones are recommended.

In conclusion, where COPC concentrations present low environmental risk and where generic GVs for 95% ecosystem protection are not exceeded we recommend use of generic GV values. Generic GVs should be updated as the science improves data robustness and relevance.

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1.0 BACKGROUND

The McArthur River Mine (MRM) is located in the Gulf Region of the Northern Territory ca. 45 km south-west of the township of Borroloola and 470 km south-east of Darwin. MRM is the world's largest producer of zinc in bulk concentrate form. The concentrate is transported from the mine to the Bing Bong loading facility 100 km north-east of the mine.

Key Project elements are as follows.

- The redesign of the overburden emplacement facilities; following an improved understanding (Overburden Management Project) of the overburden (waste rock) geochemistry and the need to manage it differently from previous proposals.
- Reduction of overburden emplacement facility footprints.
- Re-processing of tailings waste and placement within the open cut void on cessation of processing, removal of the Tailings Storage Facility and rehabilitation of the former facility area.
- A revised open cut final void closure strategy.
- An acknowledgement of the need and plan for ongoing monitoring and management in the long-term to maintain protection of the downstream environment.

The Northern Territory Environmental Protection Authority (NT EPA) decided that the McArthur River Mine Overburden Management Project required assessment under the Environmental Assessment Act at the level of an EIS. Overburden management is a controlled action and requires assessment and approval under the Environment Protection and Biodiversity Conservation Act 1999 before it can proceed. The proposal is being assessed under the bilateral agreement between the NT and Australian Governments via a single EIS document.

Closure of the final void has been proposed as a sequential series of steps including the following.

1. In-pit dumping of waste rock for the last 6 years of mining.
2. Disposal of sulfidic tailings following reprocessing into the bottom of the pit.
3. Rehandling highly sulfidic waste rock from temporary stockpiles into the pit void.
4. Rapidly flooding the final void with a diversion from the McArthur River.
5. Maintaining an isolated mine pit lake for a short period.
6. Opening the lower portion of the mine levee wall to create a ‘backflow’ connection between the McArthur River and the mine pit lake.
7. Ultimately opening the upper mine levee wall to create a seasonal flow-through mine pit lake connection with the McArthur River.

Current modelling of the Mine Pit Lake limnology indicates a flow-through closure scenario which presents long-term water quality within the mine pit lake likely to be acceptable to stakeholders. Water quality compliance is predicted at downstream compliance point SW11 with lake water column mixing with River water only occurring to ca. 50–80 m depth (maximum 110 m) under a backflow scenario (Tropical Water Solutions, 2017). The possibility of tailings remobilisation from in-pit tailings disposal is identified by MRM as a key closure risk with potential failure to meet compliance point water quality with this closure scenario.

Mine Lakes Consulting (MLC) was contracted by McArthur River Mine, Glencore (MRM) to provide advice for management of receiving water quality values. The objective of this report is to provide a framework for development of reliable and site-specific guideline values for protection of water quality end use values influenced by MRM mine water discharges.

1.1 Scope of work

This report recommends preliminary receiving water values and a framework for water bodies potentially affected by mine waters from MRM during life of mine (LOM) (including closure). The study work program follows leading international practice, and meets key components of Conditions 44 and 45 of WDL174-10.

Conditions 44 of WDL174-10 requires:

44. The licensee must review the water quality site specific trigger values for SW11 listed in Table 3 and provide a report to the Administering Agency:

44.1 with any request to amend the authorised discharge points as described in Table 2; or

44.2 with any application to renew this licence; or

44.3 prior to the expiry date of this licence.

Condition 45 of WDL 174-10 provides details of the scope of the report required by Condition 44.

45. The review and report of the site specific trigger values must:

45.1 be conducted in accordance with ANZECC 2000 Guidelines [sic];

45.2 review the SW11 and alternative site specific trigger value locations in regards to influences from river systems other than the McArthur River in determining the most suitable trigger value location to achieve environmental protection;

45.3 assess receiving environment water quality at SW11, SW12 and sites upstream of the mine site using data that has been collected over the last three years;

45.4 assess the difference between water quality measured at SW11, SW12 and sites upstream of the mine site and the site specific trigger values for SW11 listed in Table 3;

45.5 assess the difference between water quality measured at SW11, SW12 and sites upstream of the mine site and ANZECC default guideline values that represent protection of 95% and 99% species;

45.6 include and assess mine derived load estimates (and balances) reporting to the McArthur River;

45.7 propose revised trigger values and mine derived contaminant loads to be reported to the McArthur River that sufficiently protect the receiving environment at the revised trigger value location to achieve 95% to 99% species protection (whichever best reflect protection of the receiving environment based on the analysed monitoring results); and

45.8 include a copy of written review of the report by a suitably qualified professional.

1.2 Approach

In the spirit of both the Australian water quality guidelines (ANZECC/ARMCANZ 2000) and also the APEC for Mine Closure Checklist (APEC, in press), water quality TVs should be dynamic. As further understanding of water quality, receiving system ecology and ecotoxicology, and end use values evolves over mine life. However, guidance also recommends that a transparent and robust milestone-based framework be used to advance protection of water quality value and management during both operational and mine closure planning.

Following consideration of background documents MLC defined current and likely end use values that related to water quality objectives.

Recommendations were then made for a leading practice framework for future development of water quality management. These recommendations included:

- further chemicals of potential concern (COPC) for consideration; and,
- ongoing refinement of SSGVs to improve data robustness and receiving waterbody relevance.

The following framework is commensurate with the following relevant guidance.

ANZECC/ARMCANZ (2000). Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy Paper No 4. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra. 1,500p.

Batley, G. E. & Simpson, S. L. (2008). Advancing Australia's sediment quality guidelines. Australasian Journal of Ecotoxicology 14: 11-20.

Batley, G. E.; Van Dam, R. A.; Warne, M.; Chapman, J. C.; Fox, D. R.; Hickey, C. W. & Stauber, J. L. (2014). Technical rationale for changes to the method for deriving Australia and New Zealand water quality guidelines values for toxicants. Department of Science, Information Technology and Innovation, Canberra, Australia. 46p.

DIIS (2016). Leading Practice Sustainable Development Program for the Mining Industry - Preventing Acid and Metalliferous Drainage Handbook Department of Industry, Innovation and Science (DIIS), Canberra, Australia.

DITR (2016). Leading Practice Sustainable Development Program for the Mining Industry - Risk Assessment and Management. Department of Industry, Tourism and Resources, Canberra, Australia. 95p.

NTEPA (2013). Guidelines on mixing zones. Northern Territory Environment Protection Authority, Darwin, Australia. 11p.

Warne, M.; Batley, G. E.; Van Dam, R. A.; Chapman, J. C.; Fox, D. R.; Hickey, C. W. & Stauber, J. L. (2015). Revised method for deriving Australian and New Zealand water quality guideline values for toxicants. Department of Science, Information Technology and Innovation, Canberra, Australia. 45p.

2.0 Water quality values

2.1.1 Purpose

The purpose of water quality guidelines is to maintain, or improve, upon identified current water quality values (APEC, in press). A broad range of environmental values have been specifically defined in the Australian water quality guidelines (ANZECC/ARMCANZ, 2000). They include aquatic ecosystems; primary industries (irrigation and general water uses, livestock watering, aquaculture and human consumption of aquatic foods); recreation (primary and secondary contact) and aesthetics (cultural and spiritual values), potable water, and industrial uses.

Across Australasia, a common default position for water quality management criteria by regulators is the use of the Australasian Water Quality Guidelines (Batley *et al.*, 2003). In particular 95% protection of aquatic ecosystems is often used as a conservative default position prior to better understanding of water end use values (McCullough & Pearce, 2014). Three broad ecosystem condition classifications are recognised by the Guidelines as below (ANZECC/ARMCANZ, 2000). However, all ecosystem condition classifications must explicitly and transparently demonstrate justification for classification choice \e.g., faunal survey, conservation classifications, stakeholder views, etc.

1. High value systems (99% biodiversity protection) — effectively unmodified or other highly-valued ecosystems that are of conservation or other ecological value with ecological integrity intact. Unlikely to occur outside of national parks or other conservation reserves, or outside of remote and undisturbed locations.

2. Slightly to moderately disturbed systems (95% biodiversity protection) — ecosystems in which aquatic biological diversity may have been slightly adversely affected by human activity. However, biological communities remain in a healthy condition and ecosystem integrity is largely retained.

3. Highly disturbed systems (80% biodiversity protection) — degraded ecosystems of low ecological value. Although this classification implies that degraded aquatic ecosystems still retain potential, or actual, ecological or conservation values, practical considerations mean it may often not be feasible to return them to a slightly–moderately disturbed condition.

Guideline values are typically assigned at the 95% level for many greenfield mine sites where the ecosystem is nonetheless likely to be slightly to moderately disturbed from existing catchment activities. That is; the most sensitive 5% of species making within the aquatic ecosystem in question is expected to be sensitive enough that they have already been lost due to historical disturbances.

Lower protection levels, such as 90% or even 80%, may be considered for sites more significantly disturbed, such as by grazing or historical mining, with already lowered water-quality values as a consequence. The level of protection to be assigned should always be discussed and agreed with stakeholders, as this decides the water-quality guideline values that will be applied (DIIS, 2016).

MRM will follow national guidance and leading international industry practice by flexibly developing preliminary water quality values in conjunction with stakeholders and as site knowledge develops.

2.1.2 MRM receiving system values

MRM are operating in a commercially sensitive environment, with prior public opposition and a public focus directed toward current planning. As a consequence, protection of key values must be to leading practice and rigorously executed. Key to managing this risk is the ability of flow-through to meet downstream water quality criteria (McCullough & Schultze, 2015).

Mine closure planning notes the following current and/or likely future uses for waterways within and downstream of the MRM project area (MRM, 2017b):

- potential for custodian use (spiritual, bush tucker collection);
- native aquatic ecosystems with values representative of pre-mining condition; and,
- direct livestock watering (by implication of catchment grazing with waterways not being fenced).

The following broader catchment uses are also noted:

- native wildlife conservation areas with cattle grazing excluded; and,
- beef cattle grazing.

Current and likely future uses of waterways affected by mine water discharges are therefore likely to be best meet by preliminary objectives that provide for safe contact and drinking in water bodies by livestock presenting as beef cattle; whilst not further degrading pre-mining aquatic communities and ecosystem services from their prior slightly degraded conditions.

Given historical extensive grazing throughout regional waterway catchments, preliminary water quality values are considered to be livestock watering, freshwater aquatic ecosystem protection at a protection level of 95% and consideration of higher-tropic biomagnification risk.

3.0 Conceptual source-pathway-receptor (SPR) modelling

Source–pathway–receptor (SPR) models provide a useful avenue for determining what COPC sources might translate to environmental impacts (Figure 1). For contamination (elevated COPC concentrations) to result in pollution (environmental impact) all three components of the model must first exist.

Figure 1. Source-pathway-receptor (SPR) environmental risk assessment tool.

SPR conceptual models will be developed to define the potential for mine discharge COPC to affect defined receptors.

Risk of change to ecosystem taxa composition or abundance will be interpreted as an impact. Gain of taxa not found in analogue sites and/or increase in individual taxa abundance above reference sites levels are deviations from baseline conditions.

Preferred ecotoxicological tests target key species of relevance to the ecosystems concern. In this situation, namely, tropical river ecosystems dominated by periphyton as primary producers allochthonous inputs from riparian vegetation, benthic macroinvertebrates as primary and secondary consumers, and with piscivorous fishes, reptiles, birds and mammals (including humans) as final trophic levels (Taylor et al., 2006).

Critical to understanding environmental receptors, field studies will develop a conceptual:

- understanding of likely pit lake food web; and,
- qualitative description of River food web.

Conceptual models of aquatic ecosystems and COPC paths to these receptors will be developed in order to best direct ecotoxicity-testing efforts.

4.0 Generic guideline values

Termed trigger values in the original 2000 Guidelines (ANZECC/ARMCANZ, 2000) but termed guideline values (GVs) in later guidance documents (Batley *et al.*, 2014), guideline values (GVs) are water quality criteria that, if not exceeded, are unlikely to result in impairment to defined water quality values.

Generic water quality guidelines (WQGs) are used by many jurisdictions as broad scale tools to assist with the protection of aquatic ecosystems from the impacts of toxicants. Water quality criteria used in ecosystem protection guidelines are to protect aquatic biota (the end use value in this circumstance) and are not an end in themselves.

Default GVs are prepared by analysis of the cumulative probability distribution of the relevant toxicity data for the toxicant comprehensive set of available ecotoxicological data (Aldenberg & Slob, 1993). Specifically, the default values are prepared by analysis of a comprehensive set of available ecotoxicological data from a number of regions and species; which may, or may not be, relevant to the area of interest.

Species sensitivity distributions (SSDs) are an internationally preferred toxicologically-based statistical method for deriving site-specific WQGs using toxicity data. Test site water quality values are explicitly defined by a specific percentile (often 5%) that is extrapolated from GV development data to represent e.g., protection of 95% of taxa in the pool of species that the ecotoxicity test data demonstrated.

However, since generic WQGs cannot adequately account for the many environmental factors that may affect toxicity at a particular site, site-specific WQGs are often needed, especially for high environmental value ecosystems. Nevertheless, ANZECC/ARMCANZ (2000) caution that the derivation of site-specific WQGs is not a straightforward process and requires extensive knowledge of the toxicant(s) and ecosystem being assessed.

The reliability of guideline values is dependent upon how many toxicity tests have been undertaken in the regionally relevant context of:

- receiving water quality; and,
- aquatic ecosystem assemblages.

For the tropical northern Australian environment that MRM operates in, the relevant dataset of both international and national toxicity findings is greatly reduced. Further, toxicity test procedures that utilise species from tropical environments relevant to the MRM mine water receiving environments are expected to require further development (Simpson & Batley, 2007).

Generic GVs will be used as a first pass to water quality management. Where expected water quality is unlikely to meet default GVs, site specific GVs will be generated; first from site-specific modifying factors and secondly from site-specific ecotoxicological assessments.

5.0 Site-specific guideline values

Development of regional or even site-specific GVs is often required for adequate protection of a specific waterbody's water quality values. Site-specific GVs are especially required where generic GVs are likely to be too under-protective or over-protective (due to either or both physicochemical and biological factors). Equally, site-specific GVs are recommended where generic GVs carry too much uncertainty e.g., where there may be locally important species e.g., sawfish *Pristis pristis* or ecosystems that are not represented in the toxicity data set used to derive the generic GVs (ANZECC/ARMCANZ, 2000).

This approach is recommended particularly when natural background concentrations are higher than the generic WQG (Warne *et al.*, 2015). Surface and ground waters of catchments comprising mining resources often show elevated solute concentrations in baseline conditions due to their unique geologies. From a mine drainage risk assessment perspective, regional water quality may therefore be unique and locally-relevant such that site-specific water quality guidelines may therefore be required to most reasonably achieve water quality objectives. (McCullough & Pearce, 2014).

The key aim of undertaking site-specific toxicity studies will be to increase understanding of how a toxicant(s) may adversely affect biota under the relevant environmental conditions, such that more robust and appropriate GVs can be derived.

Where possible, field-based SSDs will be determined from local single-species test organisms (McAlpine & Humphrey, 2001). Chronic tests are also likely to be more relevant for the >7 day exposures to most-sensitive and short-lived taxa e.g., macroinvertebrates, within the River.

SSGVs will be practicable, relevant, suitably conservative and defined by strong scientific evidence in a transparently manner. Water quality values and consequent level of protection will be defined and updated as required by discussion with relevant stakeholder groups.

SSGVs will be sufficiently robust to address the risk of mine water discharge and relevant to meet the receiving environment's requirements. SSGV development will be commensurate with ANZECC/ARMCANZ (2000) (and later amendments), DIIS (2016) and leading industry practice.

5.1 Baseline water chemistry

GVs specific to a test site are often derived internationally using reference site data (Van Dam *et al.*, 2014). In these cases, although all methods are broadly based upon simple statistical distributions; specific methodology, and implications (not the least being likelihood of exceedance) varies greatly between jurisdictions. For instance, Guidelines indicate that a minimum of two years water quality data be available from a reference site un-impacted by the relevant toxicant(s) (ANZECC/ARMCANZ, 2000). If large seasonal differences exist if the dataset is then site-specific GVs should then also be derived for these defined periods.

A rolling 80th percentile (upper or lower as relevant) of the background water quality distribution is taken to represent the SSGV. This SSGV then compared to the test site results. A significant limitation resulting from this approach is that the method is by no means necessarily ecologically relevant. Consequently, it remains indeterminate if exceedance of the SSGV generated by simple water quality distributions has ecological significance.

Baseline water chemistry will be well-understood through ongoing monitoring programs above and below mine water discharge influence.

5.2 Single-species direct toxicity assessment

ANZECC/ARMCANZ (2000) provides comprehensive guidance on the conduct of site-specific toxicity assessments. This guidance includes selection of appropriate regionally relevant test species, receiving water, biological endpoints and statistical methodology, other test design considerations (e.g. acute vs chronic, single chemical vs complex mixture, laboratory vs in situ), and Quality Assurance and Quality Control considerations (QA/QC). Although dated, this guidance is still current for water quality management across Australia and as leading practice within the Australian mining industry (DIIS, 2016).

ANZECC/ARMCANZ (2000) guidance recommends using chronic toxicity test results for at least five species from a minimum of four taxonomic groups and deriving the WQG from a SSD. However, a current review of the guidance has recommended that data from at least eight species are used (Warne *et al.*, 2014). Comprehensive datasets for non-local species may be preferable to small datasets for local species which could lead to less robust GVs.

No effect concentrations (NEC) will be preferred end point data resulting from toxicity assessments. Similarly, effect concentrations at a defined % relative effect (ECx) are preferred to the use of no effect concentration data (NOEC) (Warne *et al.*, 2015).

Leading GV derivation advice also now put an increased emphasis on relevance of toxicological findings (Van Dam et al., 2014). To ensure that any GV derivation is in the appropriate context of aquatic ecosystem protection of the McArthur River, chosen single-species tests will demonstrate relevance to instream foodwebs and/or keystone roles and ecosystem function.

Single species ecotoxicity testing will focus on regionally-relevant species, chronic exposures and non-lethal end points in relevant receiving water mixtures. Site-specific GVs will be independently reviewed prior to further review by relevant regulatory bodies.

5.2.1 Complex COPC mixture assessment

MRM mine water discharge management presents a situation where DTA assessment will be required as there are locally important species that require specific toxicological data, there are mixtures of COPC present and local water composition is likely substantially different to mixtures used in default GV derivation.

Mine waters often consisted of composite mixtures of COPC, often at elevated salinity and reduced pH. Direct toxicity assessment (DTA) accounts for the more complex toxicity assessment these mixtures may require over simpler, single-component mixtures (van Dam & Chapman, 2001).

Within these mixtures, individual COPC toxicities may be additive, antagonistic or even synergistic (Warne & Hawker, 1995). Consideration will be given to Whole Effluent Testing (WET) (Chapman, 2000) that may be of much greater relevance to the complex elemental discharge mixture of COPC expected from mine water discharges.

Consideration will given to modified toxicity from interactions between COPCs.

5.3 Multiple lines of evidence

Confidence in site-specific WQGs increases markedly if they are supported by multiple lines of evidence. As a result, multiple lines of evidence (MLE) toxicity test procedures that utilise a number of single LOE have found favour both internationally and in Australia in the last decade (Chapman, 1990).

Different lines of evidence (LOE) are often presented by difference scales and levels of ecosystem complexity (McCullough, 2009; Spivak *et al.*, 2010; Van Dam *et al.*, 2014). For example, scales for ecotoxicological evaluation can be represented as:

- manipulative single species bioassay;
- manipulative assemblage bioassay; and,
- observational field community evaluation.

Holistic environmental considerations, including MLE approaches, integrating both laboratory and field data, will be undertaken when deriving site-specific WQGs. Ecotoxicological testing will demonstrate that it complements and contributes an LOE to an MLE approach to water quality values protection.

The degree of protection afforded by laboratory-based GVs will be verified with field data, such as a Before-After, Control-Impact' (BACI) (Underwood, 1991, 1992) monitoring design that considers above-mine baseline water quality. Operational monitoring of both water quality analytes and ecological communities will be used to validate and further refine site-specific GVs. Multivariate statistical methods will provide for testing and validation of causative relationships between COPC as individual components and in mixtures (Clarke, 1993; Clarke & Ainsworth, 1993).

Water quality monitoring will include use of regionally occurring aquatic faunal and/or floral communities as sensitive indicators to ecological disturbance (Humphrey *et al.*, 1995). Given that the pit lake decant will be received by a complex ecosystem consisting of a number of assemblages: periphyton, macrophytes, invertebrates, fishes, etc; community level toxicity tests e.g., mesocosm tests may be preferred (McCullough, 2009).

In order to use field data to develop a toxicant's SSGV, sufficient data establishing a causative biological response-toxicant concentration relationship must be collated. Field-based GVs will be derived using statistical methods that identify changes along an environmental gradient, and can identify which species are changing at certain concentrations e.g., the TITAN method (Baker & King, 2010). Sediment and water quality data will be brought together to determine whether (Van Dam *et al.*, 2014);

- differences between chemistry or ecology occur between mining-influenced and reference sites; and,
- any changes in COPC concentrations (potential contamination) reflect in changes to ecological values.

The risk of mine water discharges forming migration barriers to instream fauna is an important consideration of the chronic effects of COPC. Risk of mine water discharges acting toward migration barriers management of key species e.g., *P. pristis*, will be considered.

> *Development of SSGVs will make use of MLE approaches, including single and multi-species toxicity assessments, baseline and predicted water quality, and whole effluent toxicity (WET) mixtures.*

5.4 Further key considerations

5.4.1 COPC risk assessment

Identical to the problem formulation phase of risk assessment, key COPC concentrations must be understood within context of the water quality characteristics of the receiving environment.

Downstream water quality will be predictively modelled in terms of highest risk COPC concentrations. Likelihood of water quality criteria exceedance will be determined probabilistically so that risk is understood in more complete terms of consequence *and* likelihood. Both acute and chronic events will be considered.

As such, selection of COPC for ecotoxicological testing will be made on a risk-based determination. For instance, key consideration will be given to the predicted likelihood that predicted COPC concentrations will:

- exceed default guidelines; and,

- affect key ecosystem taxa.

Other COPC should also be considered if monitoring and/or modelling results indicates they might exceed or even approach default GVs.

Development of more robust GVs will be prioritised toward analytes that are most likely to exceed default guideline criteria and/or affect key aquatic ecosystem foodweb taxa.

5.4.2 Dissolved organic carbon influences of ecotoxicity

Dissolved organic carbon may reduce metal toxicity through (Hogan *et al.*, 2005). Indeed, one of the advantages of riverine flow-through as a closure strategy is the deliberate influx of dissolved organic carbon to remediate elevated metal concentrations (McCullough & Schultze, 2015). Equally, carbon is a fundamental nutrient for energy flow in most the ecosystem function of most waterbodies e.g., (Taylor *et al.*, 2006).

Interaction between riverine organic carbon contributions to the lake's nutrient budget should also be considered from perspectives of both:

- elevated pit lake metal concentrations; and,
- nutrient budgets required downstream for baseline river ecosystem function.

Nutrient dynamics will be studied and understood for key receiving ecosystem foodwebs. the effect of carbon as a modifier on COPC toxicity will be considered in water quality assessment and GV derivation.

5.4.3 Bioaccumulation and biomagnification

Where the risk presents to higher trophic consumers (including humans) SSGVs will incorporate assessment factors and other buffering for risk of bioaccumulation and biomagnification (Ribaa *et al.*, 2005; Miller *et al.*, 2013). For example, pit lake decant COPC with concentrations elevated relative to TVs and COPC that bioaccumulate and biomagnify e.g., Cd, Tl, Se.

Bioaccumulation and biomagnification risks will be considered through understanding receiving ecosystem food webs, including any bushtucker use, and COPC propensity to bioaccumulate/biomagnify.

5.5 Mixing zone

Mixing zones are defined as an area around an discharge where ambient water guideline values do not need to be achieved (ANZECC/ARMCANZ, 2000; NTEPA, 2013). Mixing zones are particularly important in understanding the pathway term in SPR conceptual COPC risk assessment models.

For instance, the mixing zone for the MRM flow-through diversion would be from the pit lake levee breach and decant point to either a recognised below mixing zone monitoring point e.g., SW11, or a point at which water quality below the decant no longer statistically significantly differs from ambient below pit lake river water quality.

The distance down-reach and the extent to which mixing zone extends across the reach width require consideration of both decant and down-reach hydrological conditions in order to understand the effect of elevated COPC concentrations being diluted by the mixing zone. This can be important as mixing zones can contribute significantly to COPC transport that can lead to:

- bioaccumulation at, and around, the site;
- similarly, risk to ingestion/recreation by humans (including biomagnification) within the mixing reach;
- impacts on species sedentary in the area; and,
- acute toxicity during migration through the decant plume (particularly during ebb flows).

A mixing zone will be defined downstream of key mine water discharges for the three main flow events of first flush, main flow and ebb flow. Following the mixing zone water quality shall not be statistically likely to demonstrated either toxic effects to aquatic ecosystem, or higher tropic level receptors (including humans). Definition (distance down-reach width, purpose, distance to potential receptors, rationale, GVs) of the mixing zone will be commensurate with NTEPA (2013) derived from (ANZECC/ARMCANZ, 2000). Numerical hydrological modelling is expected to be a key tool in formally defining mixing zones as water quality management tools.

5.6 Sediment quantity and quality

Sediment quantity relates to a waterway's material's balance and how it may be affected by the mine; either increasing or decreasing down-reach sediment loads. Changes to sediment quantity can affect reach hydrological ecosystem function (Evans *et al.*, 2004). For example, by smothering benthos leading to wider channels and/or benthic habitat and primary productivity losses.

Sediment quality relates to concentrations and availability of COPC in sediments downstream relative to baseline analogue sites.

Sediment impact assessment will involve evaluation of sediment total concentrations against interim sediment quality guideline (ISQG-low). Recommended as an initial screening tool, these values represent low probabilities for biological impacts (Simpson & Batley, 2007).

Where ISQG are likely to be exceeded. Sediment quality will be affected by expected key mine water discharge COPC due to the sandy matrix

Due to potential for site-specific difference in River sediment chemistry, comparison of sediment predictions with analogue sites; ideally immediately upstream of known mining disturbances (Jones *et al.*, 2008). Significant changes in sediment COPC concentrations (potential contamination) will be evaluated to determine if they are likely to result in changes to ecological values (impact, namely pollution).

Mesocosm experiments can also capture sediment toxicity processes with any sediments and these data will be considered in community toxicity testing using these structures (McCullough, 2009).

A predictive materials balance model will be developed and maintained for down-reach waterway sections. The balance will determine likely mass loads increasing or increasing down-reach in both absolute and relative terms with interpretation as to implications to reach hydrological function.

Sediment toxicity is not expected likely in the fine quartzite sands of regions waterways. Nevertheless, preliminary criteria for sediment quality will be ISQG-low values which represent 10% ecotoxicological test response levels. Where these are exceeded, toxicity modifiers will then be considered and, if required, sediment ecotoxicological testing.

6.0 STUDY TIMELINE

An appropriate milestone for completion of the key SSGV workplan is prior to April 2019, when revised water discharge limits will be required by key NT regulators. Below is a recommended study timeline for execution of this SSGV framework to achieve completion and reporting prior to this date. Although workplan items are for discrete studies, the expectation is that they will contribute to, and be consolidated as, a multiple line of evidence assessment for MRM mine water toxicity SSGVs (Table 1).

Table 1. Recommended workplan milestones for SSGV framework execution.

No.	Item	Date	Notes
1	COPC risk assessment	1st quarter 2018	Determining highest risk COPCs for SSGV development and regional SPR model.
2	Field assemblage assessment	2nd quarter 2018	Assemblage-level ecotoxicological assessment of historical benthic macroinvertebrate and water quality monitoring datasets
3	Single-species bioassays	3rd quarter 2018	Single-species bioassays using regionally relevant assay taxa and diluent mixtures
4	Assemblage bioassays	3rd quarter 2018	Multi-assemblage level enclosure bioassays using regional taxa and creek waters as diluent.
5	Field community assessment	4th quarter 2018	Community-level field validation of GVs with complementary bioassays of assemblages e.g., diatoms, microinvertebrates.
6	Sediment quality	1st quarter 2019	Field sampling, analysis and reporting of sediment quality from analogue and test sites incorporating toxicity mitigation factors.
7	Mixing zone(s) definitions	1st quarter 2018	Formal definition of any mixing zones proposed to manage and mitigate mine water discharges.
8	Synthesis	2nd quarter 2019	Synthesis and summary of individual studies as separate LOEs.

7.0 CONCLUSION

A summary of the current Australian and New Zealand Water Quality Guidelines approach to water quality guideline value development has been given in the context of mine water discharges. Where relevant, recent updates and modifications to the recommended GV development methodology and application are also given.

Emphasis is given as to the likely need to develop SSGVs in the context of a naturally geochemical enriched catchment that mining presents. Our recommendations are that the thrust of SSGV derivation be made from ecotoxicological data, developed from assemblage and community tests within the region's aquatic ecology, waters and land use objectives.

To this end a simple decision tree framework is presented below to help direct decision making (Figure 2).

The framework recommends surface water quality management planning to leading international practice standards. Many of these recommendations do not require immediate action. However, development with milestones are recommended to;

- Continuously seek to improve mine water environmental management as site-specific and general scientific understandings increase;
- strategically plan for a more definitive closure plan for closure;
- allow adequate time for study execution and review;
- permit change of closure planning (if required); and,
- be prepared for later stages of mine closure planning where this knowledge will be required.

In conclusion, where COPC concentrations present low environmental risk and where generic GVs for 95% ecosystem protection are not exceeded or applicable, we recommend use of generic GV values; updating these values as the science improves data robustness and relevance. Where generic GVs are exceeded, we recommend a risk-based approach to SSGV derivation. The ability of the mine water discharge to meet these GVs during both operational and closure phases will then determine actions such as mitigation activity as per adaptive management closure process MET00247545-015 (MRM, 2017a).

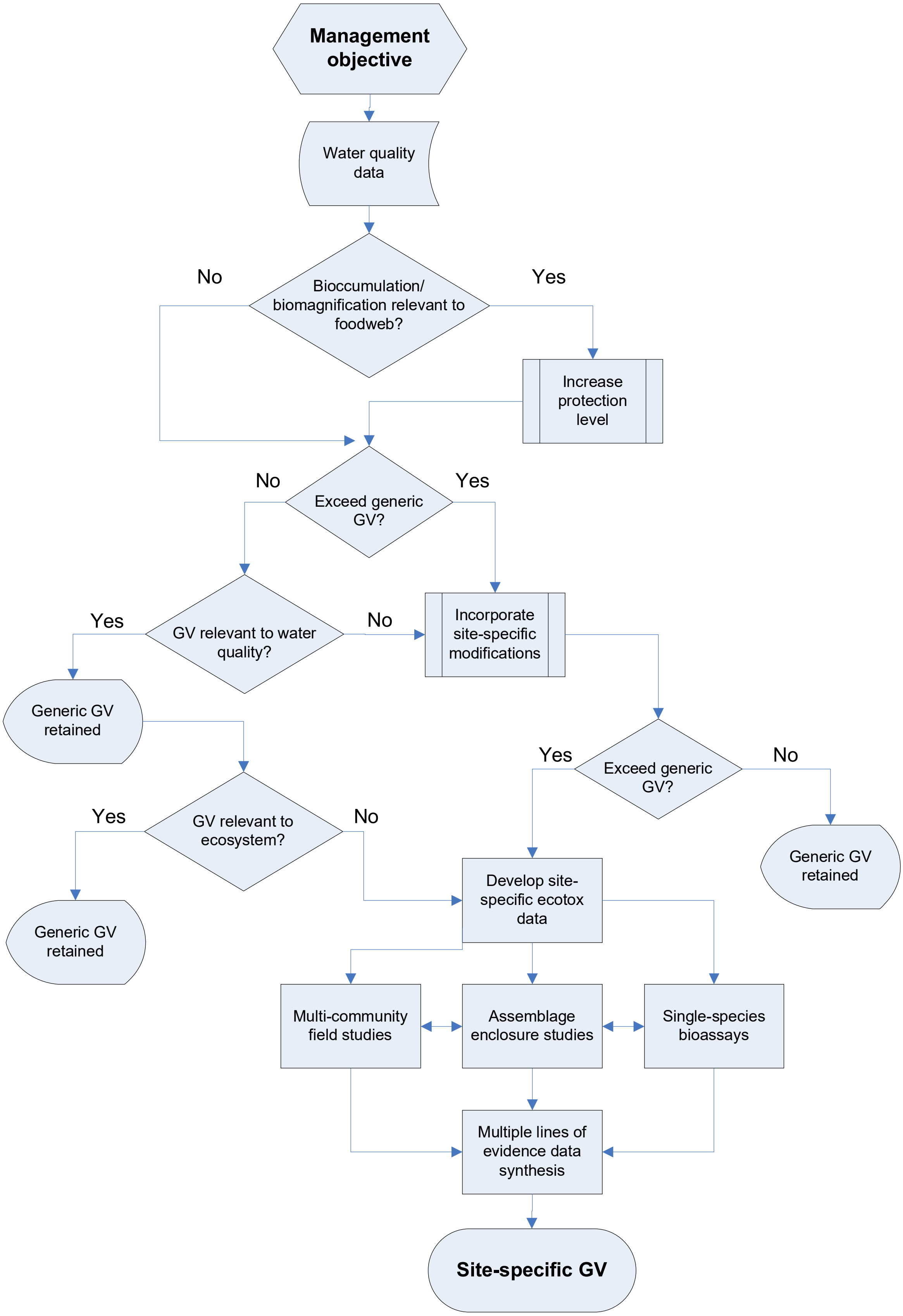

Figure 2. Decision tree for SSGV development.

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Authorisation

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APPENDIX A

Limitations

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