Ecological Risk Assessment – What Is It And Why Should I Think About Using It?

Andrew Botfield, MBS Environmental
James Cumming, MBS Environmental
Karen Ganza, MBS Environmental
David Allen, MBS Environmental

Abstract

Environmental risk assessment has been used within the mining industry for a number of years, primarily as a tool to assess the potential impacts of a project or a specific task and to prioritise work programs. It is effective in investigating how a project or activity interacts with the broader environment and generally involves assessment of impacts on flora, fauna, water and air. The management recommendations that come from this assessment process are not usually based upon a detailed understanding of geochemical processes, contaminant transport or ecological toxicity. This may result in recommendations that do not address key contaminant issues at the mine or that are overly conservative, resulting in unnecessary capital expenditure.

Ecological Risk Assessment (ERA) is a more specialised and targeted means of assessment that is now being used in the mining approval process. It provides a set of formal, scientific methods used for defining and estimating the probabilities and magnitudes of adverse impacts on plants, animals and/or whole ecosystems posed by a particular contaminant or stressor. The ERA process identifies ecological receptors of concern, estimates the contaminant concentration that they may be exposed to and based on the magnitude of this concentration, determines whether they are at risk.

Mine sites typically have complex environments, with a range of factors including:

- Soil, rock, waste rock and tailings geochemistry.
- Hydrology and hydrogeology.
- Design requirements for waste rock dumps and tailings storage facilities.
- Presence of pit lakes.
- Processing plants and other infrastructure.
- Sensitive receptors such as flora, fauna, human health and livestock.

Conventional environmental risk assessment methodologies were not established to deal with this level of complexity. In contrast, the ERA process is based upon a comprehensive appraisal of contaminant exposure pathways and toxicity in the receiving environment. Recommendations from this risk assessment process can be tailored to more effectively suit the specific geochemical and ecological environments surrounding a project.

MBS Environmental has been undertaking ERAs for a range of mining projects in Western Australia and Queensland. It has been an invaluable tool in the assessment of issues such as:

- Potential locations for a new tailings storage facility.
- Alternative tailings disposal forms including paste or slurry.
- Final product/concentrate transport route and associated port storage and ship loading options.
- Disposal of tailings to a historical pit lake.

This paper focuses on the latter as a case study. The proposed project involves disposal of both nickel concentrator and gold carbon-in-leach (CIL) tailings into a historic pit lake in the northern Goldfields. The discussion will address why an ERA approach was recommended to the client,

results of the ERA and practical outcomes of the ERA including how it supported project planning and the environmental impact assessment process.

Introduction

Risk Assessment in the Mining Industry

In the mining industry, the management of environmental risks associated with a project or specific activity has been based primarily upon the risk management process depicted in Figure 1.

Figure 1: Risk Assessment Process (Australian Standards 2009)

This approach is acceptable for activities commonly associated with mining projects (including land clearing, mine development, construction and processing) for which there is a large volume of scientific information and past experience. Risks can be identified, analysed and evaluated with a fair degree of certainty. Many potential environmental impacts associated with these activities also have a very prescriptive set of legislative requirements such as specific parts of the *Environment Protection Act 1986* (EP Act) in relation to the clearance of vegetation and licensing conditions specified by the Department of Environment and Conservation (DEC) such as emissions and discharges to the environment.

The EP Act and *Contaminated Sites Act 2003* have been legislated to prevent ‘potential or actual harm to the environment’. The *Mining Act 1978* requires the achievement of a ‘safe and stable landform’ upon mine closure. If an organisation is using a risk management approach to demonstrate best practice or compliance with these legislative requirements, it requires a risk analysis tool that not only demonstrates sound understanding of environmental processes, contaminant transport and ecological toxicity, but is also presented in a form recognised and accepted by the regulators.

Ecological Risk Assessment (Value and History)

Ecological Risk Assessment (ERA) emerged in Australia during the 1990s as a more targeted tool to assess risks posed by particular stressor/s to flora, fauna or an ecosystem. The value of an ERA is that the risk assessment process is based upon a comprehensive appraisal of the local environment, including contaminant exposure pathways and toxicity in the receiving environment.

The ERA has its origins in the assessment of existing contaminated sites using methodologies developed by the United State Environmental Protection Authority (USEPA) in the 1980s. In Australia, the framework for an ERA was first presented in the Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (ANZECC and NHMRC 1992). At the time it was based upon the USEPA model and comprised four main phases: data collection and evaluation; toxicity assessment, exposure assessment and risk characterisation. A *Guideline on Ecological Risk Assessment* (NEPC 1999 and NEPC 2011) was developed in the late 1990s and recently revised, by the National Environmental Protection (Assessment of Site Contamination) Measure (NEPM). Development of ERA methodologies in Australia was also further enhanced by the risk-based hierarchical assessment process adopted in the National Water Quality Management Strategy – Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ 2000).

MBS Environmental has adapted the ERA tool in two ways to facilitate the decision making process for a project:

- The assessment process now considers a broader range of receiving environments which commonly need to be addressed for a project including geochemistry, surface water, groundwater, flora, fauna, heritage and human populations.
- Similar to its former use in contaminated site assessments, the adapted assessment process can focus on existing contamination issues, but can now also be used to predict and characterise ecological impacts from potential future issues.

The Role of ERA in Decision Making

ERA can assist decision making by providing the following:

- Evaluation and comparison of design options or process scenarios.
- Guidance for controls required at the design, commissioning, production or closure stages of a project to assist meeting environmental goals.
- Technical supporting documentation for project approval documents.
- Design of monitoring programs.

Given that the application of ERA to the mining industry is fairly new, this list is not considered to be exhaustive. Often when there are uncertainties associated with a project due to limited available technical data, ERA can identify key risks that need to be addressed to enable a project to move forward.

Level of Detail Required for an ERA

As with many forms of assessment, the level of detail required for an ERA will depend on a combination of factors including the availability of data and other relevant studies and the nature of potential consequences and perceived risks. The three levels of detail that an ERA can be conducted are shown in Table 1.

Table 1: Levels of ERA (NEPC 1999 and NEPC 2011)

Level	Description
1	A desktop assessment involving screening contaminant concentrations against generic ecological screening levels (such as DEC 2010 or ANZECC & AMRCANZ 2000). Limited consideration of site specific aspects of project environmental setting, contaminant transport behaviour, fate and/or ecological toxicity.
2	A comprehensive desktop assessment, with some field studies. This level applies more specific ecological screening levels. It often involves predictive modelling, transport behaviour, fate and/or ecological toxicity of contaminants supported by geochemical modelling and detailed receptor toxicological review.
3	A comprehensive desktop assessment, with more sophisticated field studies. This level applies specific ecological screening levels determined via detailed ecotoxicology survey and laboratory test work. Predictive modelling, transport behaviour, fate and/or ecological toxicity effects of contaminants are usually more detailed and may also be supported by longer term geochemical or remedial test results (such as column leachate tests or remediation field trials).

For the majority of projects to date at MBS Environmental, a Level 2 assessment has provided an effective outcome, balancing the need to adequately address perceived risks, with the constraints of available scientific data. In several cases, where the toxicity of potential contaminants to particular species was not well understood and perceived risks to the receiving environment were high, a Level 3 assessment has been more suitable.

Key Elements of ERA Methodology

The core structure of an ERA comprises the following key elements (NEPC 2011):

- Problem identification.
- Receptor identification.
- Exposure assessment, including development of a conceptual site model.
- Toxicity assessment.
- Risk Characterisation.

These elements are discussed in the following sections.

Problem Identification

The problem identification phase is similar for all levels of assessment. It identifies the problems and issues on which to focus the ERA process. Problems typically involve a release or potential release of contaminants to the receiving environment.

Contaminants of concern are identified as part of the problem identification and are established via a review of potentially contaminating activities that may be associated with a project or activity. Typical examples of contaminants of concern associated with common mining activities are shown in Table 2.

Table 2: Typical Contaminants of Concern for Mining Activities

Activity	Typical Contaminants of Concern
Tailings Storage	Various metals and metalloids, cyanide, acidity, sulphate, salinity, neutral to alkaline drainage waters with elevated toxicants such as selenium.
Waste Rock Storage	Various metals and metalloids, salinity and natural asbestiform minerals.
Sewerage Treatment	Nutrients and biological pathogens.
Mineral concentrate storage, handling and transportation	Metals and metalloids associated with dominant minerals.
Diesel fuel facilities and mechanical workshops	Petroleum hydrocarbons and polycyclic aromatic hydrocarbons.

Receptor Identification

Receptor identification involves the assessment of ecological values associated with a site, followed by the identification of sensitive organisms or ecological communities associated with these values. Typical examples of ecological values and specific receptors that require protection are shown in Table 3.

Table 3: Receptor Identification Based on Ecological Values

Ecological Value	Sensitive Receptor Examples
Health and biodiversity of playa lake ecosystems.	Fringing woodland and halophyte communities, salt lake micro and macro invertebrates.
Health and biodiversity of ephemeral creek ecosystems.	Vegetation communities and livestock, rare and endangered flora and fauna, aquatic communities.
Health and biodiversity of groundwater dependent ecosystems.	Woodland, birds, amphibians, tall mulga, stygofauna and troglofauna.
Health and biodiversity of marine and estuarine ecosystems in the vicinity of export shipping facilities.	Fish, birds, reptiles, molluscs, crustaceans, flora and fauna in the water column and underlying marine sediments, and humans.
Agricultural land use.	Crop plants and livestock.
Potable water resources.	Pastoral station residents, town water supply.
Human health.	Employees and contractors at the mine, rural residential and urban residential.

Exposure Assessment

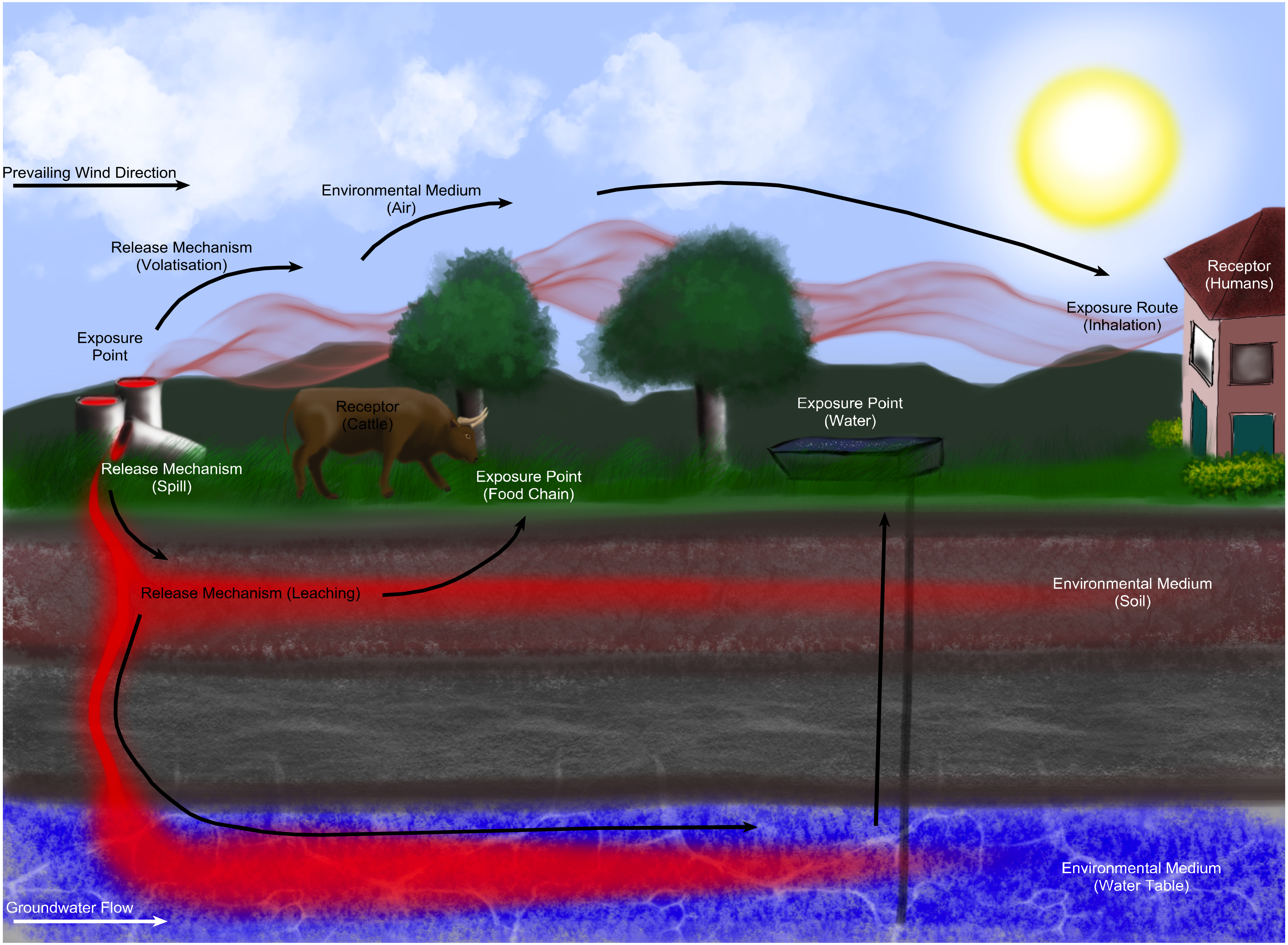
Exposure assessment identifies the mechanisms in which contaminants of concern are exposed to ecological values and receptors. This typically comprises the characterisation of contaminant release mechanisms, exposure pathway media, fate and transport mechanisms and reception mechanisms. Examples of these exposure assessment parameters are shown in Table 4.

Table 4: Examples of Exposure Assessment Parameters

Exposure Assessment Parameter	Examples
Release Mechanism	Chemical spillage, leakage, tailings or waste rock dump seepage, dust generation, transportation collision or container failure.
Exposure Pathway Media	Surface water, groundwater, air, sediment, soil, food.
Fate and Transport Mechanisms	Processes such as mixing, dispersion, mineral dissolution and chemical environments that control solubility such as pH and materials that may adsorb contaminants such as clays and iron oxide minerals.
Reception Mechanisms	Inhalation, ingestion and dermal absorption by humans and fauna, root uptake of bioavailable contaminants, leaf tissue absorption, uptake of bioavailable contaminants by flora and fauna in sediments or within the water column.

The objective of exposure assessment is to identify critical pathways from contaminant release to reception in the surrounding environment. These critical pathways are best presented schematically as a conceptual site model (CSM), such as the example shown in Figure 2. Conceptual site models provide a means in which to visualise the exposure assessment, summarising the release mechanisms, exposure pathways, environmental fate and transport aspects, as well as the reception mechanisms.

Figure 2: Example of a Conceptual Site Model (CSM) (MBS 2012)



Toxicity Assessment

Toxicity assessment determines the likely dose - response relationship for sensitive receptors in terms of the contaminant concentration and form that they may receive.

A Level 1 ERA toxicity assessment involves the screening of contaminant concentrations against either generic ecological screening levels (such as DEC 2010 or ANZECC & ARMCANZ 2000) or pre-determined site-specific ecological screening levels.

Level 2 and 3 assessments necessitate more targeted dose - response data which may be obtained by characterisation of the following:

- Relative toxicity of dominant chemical forms of the contaminant. In some cases, particularly in relation to heavy metals, toxicity can be significantly reduced in environments that have elevated salinity, alkalinity or are rich in organic materials. This can be established by geochemical speciation modelling and literature review.
- Bioavailability of dominant chemical forms of the contaminant. In many cases bioavailability is limited by processes such as solubility and adsorption. This can be established by geochemical speciation modelling and literature review.
- Bioaccumulation of the contaminant by an organism. This is largely determined by how the organism metabolises the contaminant and can be established via literature review or through chemical analysis of plant/animal tissue.
- Biomagnification of a contaminant in a food chain. This is largely dependent upon the type of organisms that are vulnerable to bioaccumulation of a contaminant and their respective position in the food chain. This can be established via literature review or through chemical analysis of plant/animal tissue.

Risk Characterisation

Using findings from the exposure and toxicity assessments, the risk characterisation phase evaluates the likelihood of contaminants of concern impacting on ecological values and receptors and predicts the level of impact that they will be subject to. Risk is calculated using a risk matrix developed via the principals of AS/NZS ISO 31000:2009 (Risk Management – Principles and Guidelines) (Australian Standards 2009).

Case Study - Windarra Nickel Project

Project Description

The Windarra Nickel Project (WNP), owned by Poseidon Nickel Limited (Poseidon), is located 260 kilometres north-north-east of Kalgoorlie and 20 kilometres north-west of Laverton. The WNP involves recommissioning and expansion of historic nickel and gold mining operations that commenced in 1969 and were last operated in 1994 (MBS 2012a).

Proposed processing infrastructure at the WNP consists of a nickel concentrator and a carbon-in-leach (CIL) plant. Tailings from each of these facilities will be combined to produce a single waste stream for disposal to an existing pit lake, located 16 kilometres to the south-west (Coffey Mining 2011 and Coffey Mining 2012). This method of tailings disposal equates to a form of subaqueous deposition, with all material remaining below water for the duration of the project and post-closure (MBS 2011a and MBS 2011b).

This approach would provide a number of environmental benefits, but also raised concerns regarding the fate of residual cyanide in gold tailings and interactions with sulphide minerals in nickel tailings (MBS 2011a). To address this issue, the option of sophisticated numerical modelling was considered. However, it was concluded that the complexity surrounding the fate and transformation rates of cyanide from the gold tailings would be subject to a large margin of error and would result in unreliable conclusions. As an alternative, a Level 2 ERA was undertaken to provide a more pragmatic, risk-based approach to inform decision-making processes.

Problem Identification

The objective of the study was to evaluate the magnitude of risk posed to sensitive receptors in the immediate vicinity of the pit lake as a result of co-disposal of gold and nickel tailings (MBS 2012b). The study identified key contaminants of concern via several information sources which included process design documents, waste characterisation reports (GCA 1993; MBS 2011a; and MBS 2011b), contaminant accumulation modelling and experimental laboratory trials (MBS 2012b). The key contaminants of concern that became the subject of the study were (MBS 2012b):

- All forms of cyanide including free cyanide (HCN and CN-), thiocyanate (SCN-), cyanate (OCN-) and various Weak Acid Dissociable (WAD) cyanide-metal complexes (which include copper and nickel cyanide complexes).
- Soluble metals and metalloids: arsenic, boron, cobalt, cadmium, copper, manganese, nickel, selenium and zinc.
- Inorganic anions: nitrate and sulphate.

This paper focuses on three of these contaminants of concern, notably cyanide, nickel and sulphate.

Receptor Identification

Ecological values identified in the study were based upon flora and fauna surveys in the vicinity of the project, geological studies of the pit and a review of beneficial water uses in the area. The following ecological values were identified (MBS 2012b):

- Human health of WNP personnel and other contractors.
- Groundwater quality for the purpose of stock drinking water.
- Health and biodiversity of native fauna that may use the pit lake as a drinking water source or habitat.

- Health and biodiversity of groundwater dependent ecosystems (particularly flora that may depend upon alluvial aquifer water resources).

A set of sensitive receptors associated with these ecological values was then identified. Sensitive receptors included (MBS 2012b):

- WNP personnel and site visitors in the immediate vicinity of the tailings outlet into the pit lake and return water process flows.
- Livestock using two stock bores located approximately two kilometres hydraulically down gradient of the pit lake.
- Significant fauna with a reasonable potential to occur in the vicinity of the pit lake; birds such the Australian Bustard, Peregrine Falcon or Rainbow Bee Eater and marsupials such as the Long-tailed Dunnart.
- Tall mulga vegetated areas within the ephemeral creek lines located approximately 1.4 kilometres west of the pit lake.

Exposure Assessment

Contaminant Transport Media

To enable examination of contaminant flow paths, the following contaminant transport media were identified in the ERA (MBS 2012b):

- The pit lake water body.
- Process return water flows from the pit lake.
- Groundwater transport in the surrounding upper alluvial and lower fractured rock aquifers.
- Air immediately above the pit lake and process return water flows.

Contaminant Fate and Transport

One of the central elements of the ERA was to understand the fate and transport of cyanide species in the pit lake. The fate and transport conceptual model is presented in Figure 3. It assumes that a significant amount of total cyanide is removed from the lake and return water streams via the following processes (MBS 2012b):

- Formation of thiocyanate due to an abundance of sulphide in the process tailings stream that will eventually biodegrade within the pit lake and surrounding aquifers.
- Formation of metal-cyanide complexes, particularly nickel-cyanide, that will eventually biodegrade within the lake and surrounding aquifers. No formation of iron-cyanide complexes due to an absence of iron in process water streams or the pit lake.
- Formation of cyanate that rapidly hydrolyses and oxidises into more biodegradable forms.

The remaining free cyanide was assumed to be subject to volatilisation and oxidation by sunlight. However the rate of volatilisation was significantly slower than normally occurs upon a tailings storage facility, due to the depth of the pit lake.

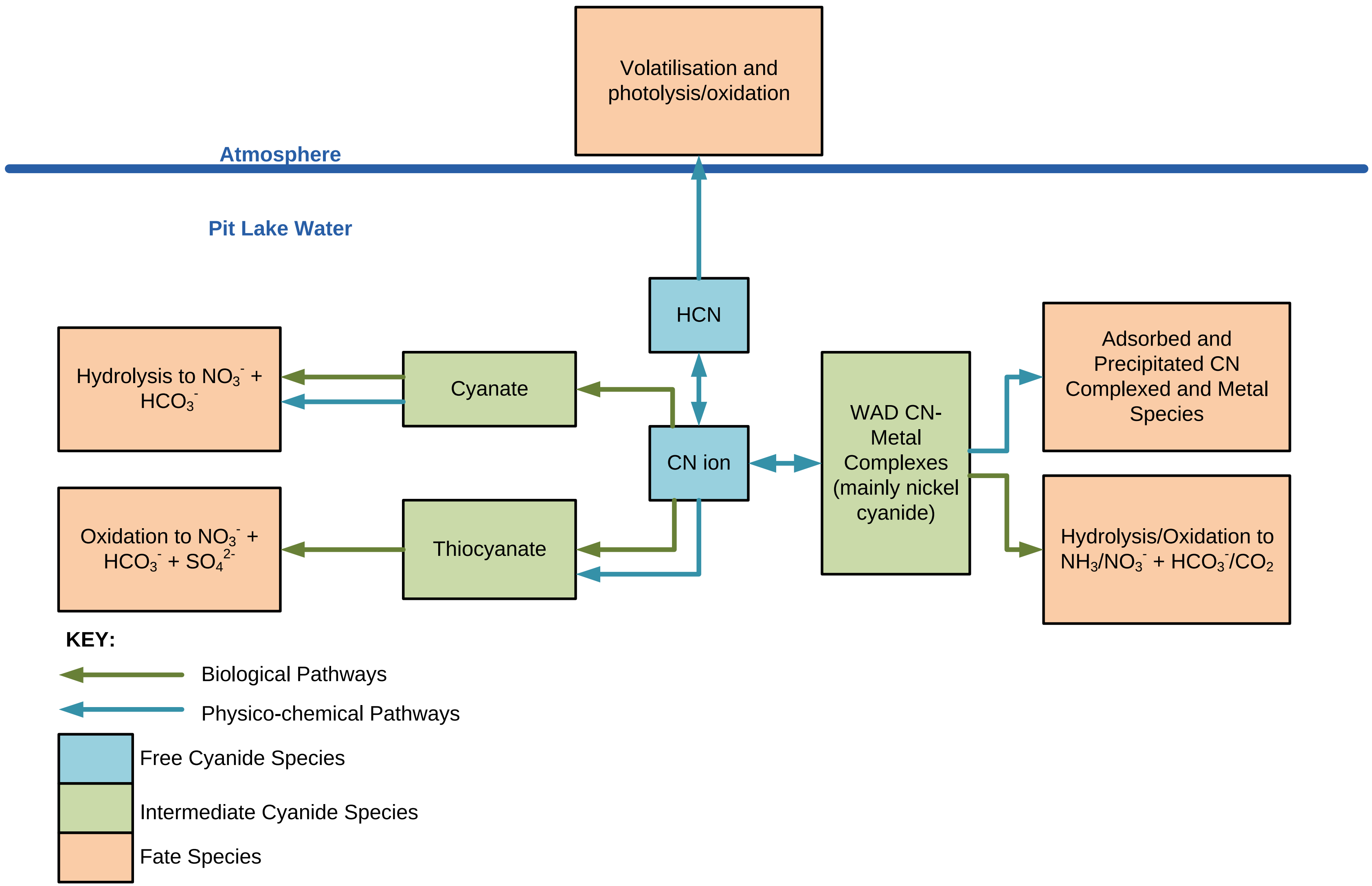
All other contaminants such as nickel and sulphate were assumed to be progressively removed from the water column by surface adsorption to tailings, sediments and pit wall regolith.

Contaminant Reception Mechanisms

To qualify the manner in which contaminants are most likely to be received by sensitive receptors, the following reception mechanisms were identified via the ERA process (MBS 2012b):

- Inhalation and dermal exposure in the immediate vicinity of the tailings discharge point and return process water by WNP personnel and contractors.
- Incidental inhalation, ingestion and dermal contact of impacted pit lake water by significant fauna.
- Ingestion of impacted groundwater by stock using the two stock bores down gradient of the pit lake.
- Root uptake of bioavailable contaminants in groundwater by mulga vegetation.

Figure 3: Fate and Transport of Cyanide Species (MBS 2012b)



Toxicity Assessment

The ERA process requires an assessment of how toxic contaminants will be when they are received by sensitive receptors. The toxicity assessment was undertaken as a detailed literature review, as this was appropriate for a Level 2 ERA. The intention of the literature review was to qualify the relative toxicity attributes of the contaminants such as toxicity, bioavailability, bioaccumulation and biomagnification.

In summary cyanide is considered the most toxic in the form of free cyanide rather than thiocyanate, metal-cyanide complexes or cyanate. Cyanide in the form of free cyanide is readily absorbed into the body through inhalation, ingestion and dermal contact. Most organisms rapidly detoxify cyanide via the formation of less toxic compounds such as thiocyanate. These less toxic by-products can be readily expelled from the organism.

Metals such as nickel are micro-nutrients in low concentrations, but display various forms of metabolic toxicity at elevated concentration. These contaminants have relatively low volatility and solubility in the membranes of most organisms and thus the main bioavailable pathway is digestion or root uptake. These contaminants are not often subject to bioaccumulation and biomagnification.

Inorganic compounds such as sulphate are recognised as environmental stressors due to the associated salinity and accompanying osmotic stress in exposed organisms. These contaminants are also not subject to bioaccumulation and biomagnification (MBS 2012b).

Risk Characterisation

The study examined a total of 92 contaminant reception scenarios, focussing on the likelihood of various contaminant releases and exposure pathways and anticipated impacts on the receiving receptors (MBS 2012b). The risk characterisation was undertaken using an evaluation of probability and consequence, based upon the principles of AS/NZS ISO 31000:2009 (*Risk Management – Principles and Guidelines*) (Australian Standards 2009).

As an example, the risk posed by the reception of free cyanide by livestock using water sourced from two bores two kilometres down gradient of the pit lake was considered to be very low due to the following key aspects effecting likelihood and consequence:

- Free cyanide is not likely to migrate two kilometres through fractured rock or alluvial aquifers at significant concentrations.
- Rates of cyanide volatilisation are likely to restrict measurable free cyanide concentrations to the pit lake.
- Toxicity effects at the stock bores are not possible as free cyanide will not be present at any measurable concentration (based upon contaminant transport timeframes and rates of cyanide volatilisation).

Results of the risk assessment indicated all contaminant reception scenarios represented either a very low or low risk to ecological receptors both during tailings deposition and in subsequent decades.

All risks to humans in the vicinity of the pit lake and livestock in the surrounding pastoral leases were determined to be very low. All risks posed to significant fauna in the immediate vicinity of the pit lake and vegetation areas within ephemeral creek lines located west of the pit lake were also determined to be low.

ERA Recommendations

MBS Environmental provided the following recommendations, based upon results of the ERA (MBS 2012b):

- To undertake monitoring at the pit lake and in groundwater monitoring bores for the following analytes:
  - Free, WAD and thiocyanate forms of cyanide.
  - Arsenic, copper, manganese, nickel, cadmium, nitrate, selenium, sulphate and zinc.
- To use maximum contaminant concentrations calculated in the report as trigger values for monitoring pit lake water quality and the use of appropriate livestock drinking water guidelines (ANZECC & ARMCANZ 2000) for monitoring bores in the vicinity of the lake.
- Where monitoring indicates that free cyanide concentrations exceed trigger values for the pit lake monitoring locations, hydrogen peroxide or ferric sulphate could be used to reduce free cyanide concentrations. Dosing may be applied prior to tailings transfer at the CIL plant or at the discharge outlet to the pit lake.

How the Poseidon ERA Informed Decision Making

The results of the ERA assisted decision-making processes for the client in the following ways:

- It provided a set of monitoring requirements for the project, aimed at identifying contamination issues before they have the potential to impact on sensitive receptors. Importantly, it also eliminated unnecessary monitoring requirements by highlighting the very low risks associated with particular scenarios.
- It increased confidence in the viability of utilising a pit lake for tailings disposal, which is not a common approach in the Goldfields.
- At the project approvals stage, the ERA document provided evidence of the rigor applied to identifying key risks associated with the project.
- At the operational stage, it will provide a set of practical measures to address elevated levels of free cyanide in the lake and return process water streams.
- It provided a conceptual framework for any further modelling of contaminant accumulation and assessment of key risks for future studies associated with further development of the project.

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