Roy Hill Iron Ore Pty Ltd

McPhee Creek Iron Ore Project - Water Management Studies

Pit Lake Water Quality Review

June 2022

Executive summary

GHD Pty Ltd was commissioned by Roy Hill Iron Ore Pty Ltd to undertake a review of the acid and metalliferous drainage (AMD) investigation of the pit void water quality undertaken by SKM in 2014 for the proposed McPhee Creek Iron Ore mine site (the Project).

The Project centres around five large open pits (Nicholson, Ord, Murray, Avon and Crescent Moon) and on completion of mining will leave exposed areas of potential acid forming (PAF) carbonaceous shale outcrops. Since completion of the 2014 assessment a number of updates have occurred including changes to the mine plan, updates to the groundwater modelling and water balance assessment (GHD, 2020) as well as additional laboratory analysis. The 2014 AMD assessment needs to be reviewed in light of this information to determine if the outcomes and mitigation measures identified are still valid.

Testing undertaken in 2013 confirmed the majority of the sulphur measured in the carbonaceous shale samples was present as sulphides and kinetic column tests confirmed the potential for the material to leach acidity and elevated concentration of trace elements. Geochemical modelling undertaken by SKM (2014) predicted that the water quality of pit lakes within the final pit voids would deteriorate over time with high concentrations of total dissolved solids (TDS) dominated by sulphate. The pH of the pit lake post closure was considered to be acidic in both Avon East and West Pits and neutral in Murray Pit. Ultimately the pit lakes were considered groundwater sinks and SKM concluded that there would be no adverse impact on the surrounding groundwater quality.

Data collected and assessed by GHD (herein) since completion of the 2014 assessment includes characterisation of the shales and non-shale exposed pit walls from 17 drill holes, with 20 representative samples analysed for sulphur, NAG pH, acid neutralising capacity (ANC) and whole rock trace elements concentrations and leaching analysis. Analysis of this spatially limited data set suggests that the majority of this material will be non-acid forming (NAF) when exposed. Leachate tests on this material confirmed a low probability of AMD generated runoff.

Geochemical modelling of the expected pit lakes in both the Murray and Avon Pits has been revisited utilising the geochemical modelling software PHREEQC version 3.6.2 and the Minteq.v4 database. The update took into account the revised mine plan and updated areas of exposed carbonaceous shale, recent groundwater quality monitoring data and updated parallel studies in surface water and groundwater, including the assessment of pit lake recovery.

Modelled Avon Pit lake water quality was found likely to be acidic in the long term with an increase in the concentration of TDS over time, which is dominated by sulphate. Modelled Murray Pit lake water quality was assessed as more likely to be neutral and less acidic compared to the Avon Pit lake, due to a lower proportion of PAF runoff relative to other pit lake inputs.

As the pits are determined to be terminal sinks to groundwater, the risk of pit lake water quality to the regional groundwater is considered to be low based on the current groundwater assessment. The findings of the updated geochemical modelling in relation to pit quality and risks to environmental receptors are considered to align with the 2014 SKM assessment.

The range of modelled results represents a high degree of uncertainty involved in the prediction of pit lake water quality and this is accentuated by predictions far into the future (10+ years in pit lake evolution). This uncertainty could be reduced with additional characterisation of identified pit wall shale material by targeted sampling and characterisation

analysis (ABA and trace element analysis) combined with pit wall wash testing during pit development.

The requirement to manage acidic pit waters during operations and closure is subject to characterisation of risk to the surrounding environment and acceptable pit lake water quality by relevant stakeholders. If required, potential management requirements to reduce the risk could consist of a combination of efforts to minimise acidity load, modify inflows or modify the pit lake water levels and quality.

Groundwater monitoring as outlined by SKM (2014) and recommended by H3 hydrogeological report (currently in development) and Groundwater Licence Operating Strategy (GHD, 2020a) will provide a basis to confirm, and update where necessary, the findings of groundwater and geochemical modelling and to improve the current estimates on the ultimate fate of the pit lakes as groundwater sinks.

Table of contents

Table index

Figure index

Appendices

1. Introduction

GHD Pty Ltd (GHD) was commissioned by Roy Hill Iron Ore Pty Ltd (Roy Hill) to undertake a review and update of the acid and metalliferous drainage (AMD) investigation of the pit voids undertaken by SKM in 2014 for the proposed McPhee Creek Iron Ore mine site (the Project).

1.1 Background

Atlas Iron Pty Limited (Atlas Iron), now part of Redstone Pty Ltd, a subsidiary of Hancock Prospecting Pty Ltd, is proposing to develop an iron ore mine (the Proposal), located at McPhee Creek in the northern Pilbara of Western Australia. The Proposal comprises five open pits situated along northeast to southwest trending ridgeline. Mining will occur above and below water table and the mining rate is expected to be up to 14 Million tonne per annum (Mtpa). Atlas Iron plans to transport processed ore via truck to the Roy Hill mine site or other third parties.

The Project includes mining areas containing carbonaceous pyrite bearing shale and there is potential for acid and metalliferous drainage (AMD) to occur which may impact water quality in the pits during mining and following closure.

An AMD assessment was undertaken by SKM in 2014 which focussed on the water quality of the pit voids following closure. Since completion of the 2014 assessment a number of updates have occurred including changes to the mine plan, updates to the groundwater modelling and water balance assessment (GHD, 2020), which require the original AMD assessment to be reviewed to determine if the outcomes of the original AMD assessment and mitigation measures identified are still valid.

1.2 Purpose of this report

The purpose of the assessment is to review the previous pit void AMD assessment and, if required, undertake AMD modelling to determine the potential in-pit water quality, assess the environmental risks associated with the anticipated pit lake quality, and identify if mitigation measures are required to manage the risks. This assessment was informed by outputs from the water balance and groundwater assessments undertaken by GHD (2020).

1.3 Scope of work

The scope of work is summarised as follows:

1. Undertake a review of the 2014 SKM AMD assessment, inputs to the AMD modelling, associated assumptions and identified mitigation measures and monitoring requirements
2. Assessment of leaching potential derived from the pit walls based on laboratory analysis of 17 drill holes which intersect the proposed pit walls. The analysis comprised total and leachable metals/major ions and acid base accounting parameters (ANC,NAPP)
3. Assess if the 2014 SKM assessment is still valid based on a review of new information including leaching potential analysis, outputs from the 2020 groundwater modelling and water balance assessment of the pit lake status. If required, undertake modelling to assess pit lake water quality
4. Confirm if the proposed mitigation measures and monitoring requirements suggested by SKM are still valid

1.4 Limitations

This report: has been prepared by GHD for Roy Hill Iron Ore Pty Ltd and may only be used and relied on by Roy Hill Iron Ore Pty Ltd for the purpose agreed between GHD and the Roy Hill Iron Ore Pty Ltd as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Roy Hill Iron Ore Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Roy Hill Iron Ore Pty Ltd and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Assumptions

The scope of the GHD AMD assessment was limited to the pit void and does not cover AMD associated with external waste dumps or other potential sources.

It is assumed that the proposed pits will not be backfilled and will ultimately be left to fill by natural means via a combination of rainfall, surface water runoff and groundwater inflow.

2. Project description

Atlas Iron is an iron ore company, mining and exporting ore from its operations in the Pilbara region of Western Australia. Atlas Iron is proposing to develop the McPhee Creek iron ore project (the Proposal), which is located approximately 30 km north of the Nullagine townsite in Mining Lease 45/1243-I. The McPhee Creek Proposal involves developing a green field mine and crushing operation, to export up to 14 Mtpa of McPhee Creek iron ore to market via trucks.

The McPhee Creek project area can be accessed via public road approximately 266 km drive southwest from the town of Port Hedland, or by public road approximately 220 km drive north from Newman. The location of the site is shown in Figure 2-1.

2.1 Key project characteristics

Within the 4,465 ha Project Development Envelope, the McPhee Creek mine will consist of conventional iron ore mining infrastructure (Figure 2-2) that includes:

- Above and below water table mining of five open pits
- Ore crushing infrastructure and truck loading infrastructure
- Waste rock dumps, ore stockpiles, topsoil stockpiles and sub-soil stockpiles
- Support facilities: including small scale power generation at each of the mine facilities (including but not limited to workshops and crusher), telecommunications tower, solar field, workshops, hydrocarbon storage, explosive mixing and storage facilities, laydown areas and offices
- Linear infrastructure: including heavy and light vehicle access roads, conveyors, pipelines, power and communications distribution
- Infrastructure for surface water management: including diversion drains, levees and culverts
- Infrastructure for dewatering and groundwater abstraction for water supply
- Dewatering water management and associated infrastructure for discharge to surface water systems.
- Construction and operation workforce accommodation camp/s
- Transport of the ore to the existing Roy Hill project or other third parties

2.2 Mining

Mining will be conventional drill and blast, load, and haul methods, with a maximum production capacity of 14 Mtpa. Mining will be undertaken on a 24 hour basis, seven days a week

A portion of the ore is located below the water table and as such dewatering will be required. It is anticipated that up to a maximum of 16 GL/yr of dewatering will initially be required, which will decrease over the life of the mine.

The initial 5-year mine scenario represents approximately 52.5 Mt of the currently identified 116 Mt potential resource, allowing for production to expand from 5 Mtpa to 12.5 Mtpa of ROM ore at the end of the initial 5-year period.

Figure 2-1 Site Location

\\ghdnet\ghd\AU\Perth\Projects\61\12520160\GIS\Maps\PDF\AMD

Figure 2-2 Site layout

\\ghdnet\ghd\AU\Perth\Projects\61\12520160\GIS\Maps\PDF\AMD

2.3 Processing

Once blasted, broken ore and waste rock will be loaded separately into haul trucks. Ore will be transported via the haul road network from the ROM pad. Crushing may be undertaken using a small mobile dry crushing and screening facility. If required, a plant may consist of primary and secondary crushing stages and dry screening facilities, samples station and product stacker(s). Stockpiling of marginal ore material will also be undertaken to ensure maximum resource recovery. No tailings or wet waste product will be produced.

Following mining, the McPhee ore will be stockpiled for transport via trucks for third-party processing or sale off the McPhee site.

2.4 Waste rock management

Approximately 126 Mt of waste rock will be mined throughout the life of the mine, in addition to 50Mt of lower grade material (LG), which will be stockpiled for future processing should a feasible solution become viable. The LG material will be stockpile assuming it can be reclaimed but also such that it can be rehabilitated should no future solution become viable.

Waste rock will initially be used to construct infrastructure (e.g. access roads and ramps, ROM and stockpile bases, drainage structures and safety bunds) with the remainder stored in above ground waste rock dumps.

Runoff from the waste rock emplacements will be directed to sediment ponds for primary treatment by settlement prior to off-site discharge.

2.5 Additional infrastructure and support facilities

Bulk explosive materials will be located in a secure compound accessible from the main access route to provide safe and efficient access for bulk supplies. Initiating explosive will be stored in separate secure magazine compound located in excess of 1.5 km from mine workings and operations services, utilising bunding and the natural topography to assist in security and isolation.

To support the mine operation, offices, workshops, power generation, communication infrastructure and parking areas will also be constructed.

A 200 person accommodation village will be constructed within the Development Envelope prior to implementation of the current proposal.

2.6 Water management

The Projects water supply will be sourced from local groundwater. All groundwater bores will be licensed under the *Rights in Water and Irrigation Act 1914* (RIWI Act), as administered by the Department of Water and Environmental Regulation (DWER). The dewatering strategy requires up to 16 GL per annum for initial dewatering, which will decrease over the life of the mine to around 2 GL per annum. Other water use (camp, dust suppression etc.) will total less than 2 GL per annum and will mostly be sourced from the dewatering supply.

The excess dewatering volume (i.e. that not utilised by the mine operations) will be discharged to nearby creeks in a controlled manner. Discharge volumes will be up to approximately 16 GL per annum initially, significantly decreasing over the life of the mine. The discharge location will be constructed with scour and erosion protection measures to minimise impact on the creek line.

3. Site setting

3.1 Geology

The McPhee Creek project occurs within the Kelly Greenstone Belt (KGB) in the south-eastern part of the Pilbara Granite Greenstone Terrane (Bagas, 2005). The KGB consists of Archaean intrusive and extrusive igneous and sedimentary sequences including the Warrawoona Group and the Gorge Creek Group, within which the iron ore deposits occur.

The McPhee Creek deposit lies within the Gorge Creek Group which is further subdivided into the Paddy Market Formation. The Paddy Market Formation conformably overlies and is surrounded by the Corboy Formation in the core of the faulted Sandy Creek Syncline. Figure 3-1 shows the geological sequence at McPhee Creek (Potter and Warner.

The Paddy Market Formation is characterised by thinly bedded banded iron formations (BIFs) interbedded with ferruginous chert (Bagas, 2005). The Corboy Formation comprises sandstones (silicified quartzites) and basal polymictic conglomerates with interbedded shales and cherts. This is informally referred to as the Main Range Deposit Aquifer. Figure 3-1 shows the geological sequence at McPhee Creek and further detail on the geology is provided in GHD 2020a and SKM 2014.

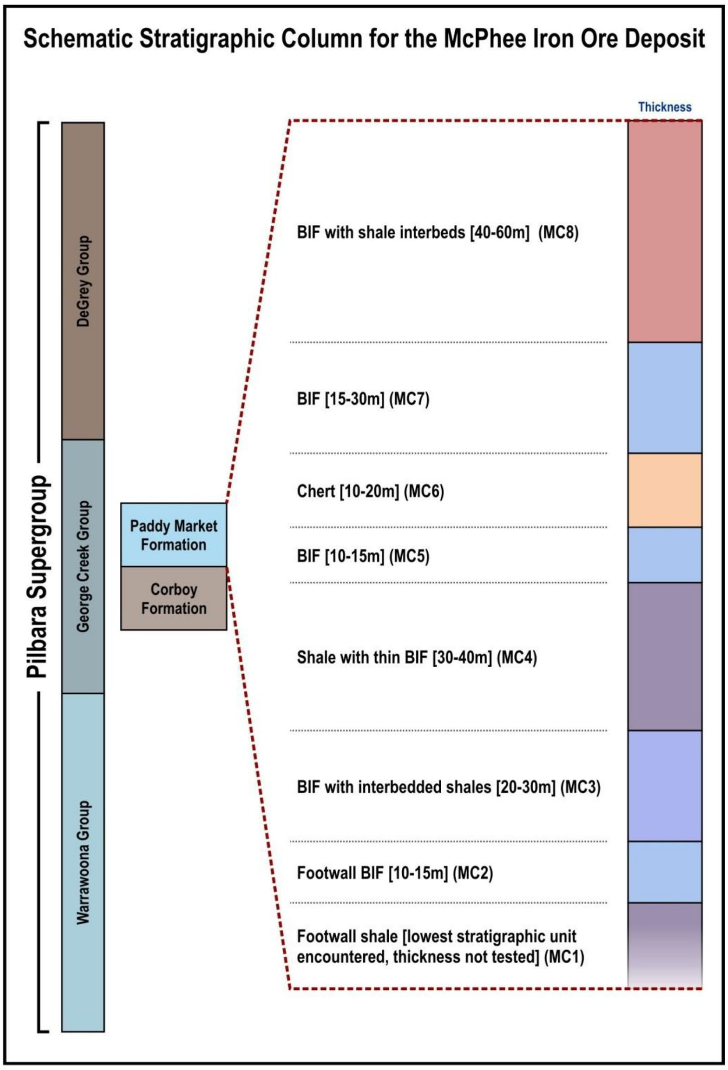

Figure 3-1 Local geology (after Potter and Warner)

3.2 Hydrogeology

The aquifers hosting the ore deposits comprise secondary porosity dominated fractured units within the Paddy Market Formation. They are contained within the elongated Sandy Creek Syncline. The Footwall Shale of the Paddy Market Formation and quartzites of the underlying Corboy Formation are considered to form an aquitard, so that the Paddy Market formation in the mine area acts as an isolated, unconfined elongated basin aquifer approximately 7,500 m long by 700 m wide and up to 250 m deep (AECOM, 2013a).

Groundwater levels within the Main Range Deposit Aquifer occur typically within the range from 406 to 410 m AHD (AECOM, 2013a). SKM (2014) identified that pre-mining groundwater was within around 10 to 20 m of the surface in lower-lying areas adjacent to drainage lines but was significantly deeper in elevated ridge areas, at 40 to 100 m below surface.

AECOM (2013a) reported that there is not a simple or regular pattern to the water table that would indicate a consistent flow gradient and direction(s) within the Main Range Deposit Aquifer. The variation in water table levels were reported to potentially be a reflection of local variations in hydraulic properties and/or structural controls present within the aquifer system.

AECOM (2013a) and GHD (2020a) report that groundwater is fresh (80 to 660 mg/L TDS) and near-neutral to slightly alkaline (pH 6.2 to 8.8).

3.3 Hydrology

The Project area is located in the headwaters of a number of creeks and is characterised by steep slopes and well defined channels within the range. Three ephemeral tributaries of the Nullagine River occur within the southern and south-western Project Area, including McPhee Creek, a tributary of McPhee Creek, and Lionel Creek.

McPhee Creek originates from the central end of the mineralisation body (MWH, 2012) and discharges into the Nullagine River, approximately 20 km downstream to the southeast of the Project. The Nullagine River flows north for approximately 200 km before entering the De Grey River, which in turn flows for approximately 200 km, ultimately discharging into the Indian Ocean (MWH, 2012).

The Project development envelope also extends into the headwaters of a number of creeks located to the north and north-west of the project area, including Spinaway Creek and Sandy Creek. They flow in a north-westerly direction discharging into the Coongan River, which is a tributary of the De Grey River (AECOM, 2013b).

4. Associated studies

4.1 AMD assessment (2014)

SKM (2014) undertook an AMD assessment which included the prediction of water quality during operations and closure by undertaking geochemical modelling/evaluation of the potential evolution of pit lake water chemistry for constituents of concern including TDS and metals. The AMD study covered the pit voids only and excluded assessment of the external waste rock dumps and other potential sources. The 2014 mine plan does not include backfilling of pits with waste. Further detail on a review of the geochemical modelling undertaken by SKM is provided in Section 6.

The findings of the assessment included:

- pit lakes were estimated to take in the order of 200 years to reach a state of water balance equilibrium, at a level up to 60m lower than the pre-mining water table.
- during operations, runoff from the pit walls from PAF and NAF rock will contribute to AMD and neutral pH saline and metalliferous drainage (NMD).
- the water quality in the pit voids will deteriorate over time post closure and the quality in each of the pits will be variable.
- the pH of the pit void water will be acid in Avon East and West. In the Murray pit the model output indicates neutral pH water due to the large proportion of groundwater relative to rainfall runoff from PAF material.
- all the pits would be dominated by sulphate due to the oxidation of sulphide minerals in the pits walls.
- TDS results showed increasing concentrations of major ions in the pit over time.
- the pits are determined to be terminal sinks to groundwater meaning that the metals, salts and acid in the pits will not seep into the local and regional groundwater, as long as the final void water level remains below the original pre-mining groundwater level.
- anticipated that there would be no adverse impact on surrounding groundwater quality.

4.2 Groundwater modelling (2021)

The long-term pit lake recovery modelling is described in the H3 hydrogeological assessment report produced by GHD (2021a). The model simulation of post-closure water level recovery covers the period of 2040 to 2390 to allow for long-term equilibration of water levels.

Numerical modelling using MODFLOW-USG indicates that the open pits will become groundwater sinks with respect to the regional groundwater flow. Permanent pit lakes will form in the Avon and Murray pits, with marginal lakes in parts of the Ord pit. The Nicholson Pit is predicted to essentially remain dry, with the possibility of forming small and intermittent accumulations of water following major rainfall events.

The recovery modelling showed that the pits lakes were expected to remain long-term evaporative sinks and not overtop into the surface water environment. While some flow through is expected for Nicholson and Ord Pit, which have an elevated base compared to Murray and Avon Pits, the pit lake system as a whole is expected to remain a sink.

4.3 Water balance assessment (2021)

GHD undertook a water balance assessment for the updated mine plan that included GOLDSIM modelling to assess the pit lake recovery following closure (GHD, 2021b). The evaporation and runoff estimates in the water balance modelling were consistent with the approach in the pit lake recovery modelling (GHD 2021a).

The water balance of the entire pit lake system is shown in Figure 4-1 and showed that the system is expected to recover to equilibrium within approximately 40 years post closure with a net groundwater inflow.

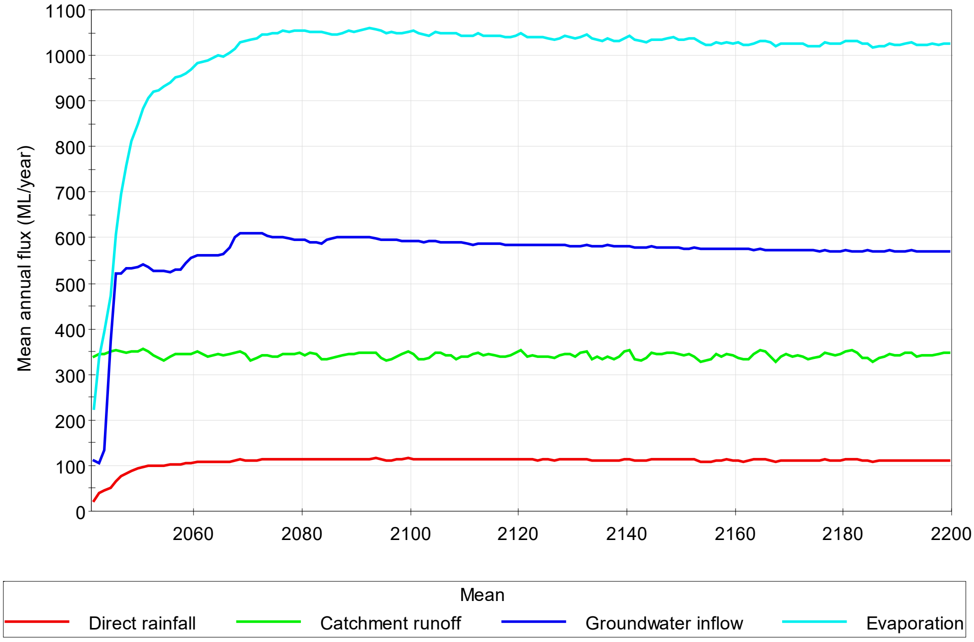

Figure 4-1 Pit lake recovery water fluxes

The estimated water levels in the pit lakes formed in Murray Pit and Avon Pit are shown in Figure 4-2. The projected equilibrium water levels in Avon and Murray pit lakes are at about 330 m AHD and 350 m AHD for Avon and Murray Pits respective, which is approximately 50 to 80 m lower than the pre-mining groundwater levels. The expected variability of pit water levels under different rainfall conditions was relatively small, with 10% and 90% scenarios presented to represent very wet and very dry conditions that may be experienced. There was evidence of a slight decreasing trend in water levels longer term, which is consistent with the regional groundwater trends.

The outcome of the assessment was that the pit lake system was expected to remain as a long term groundwater sink post closure.

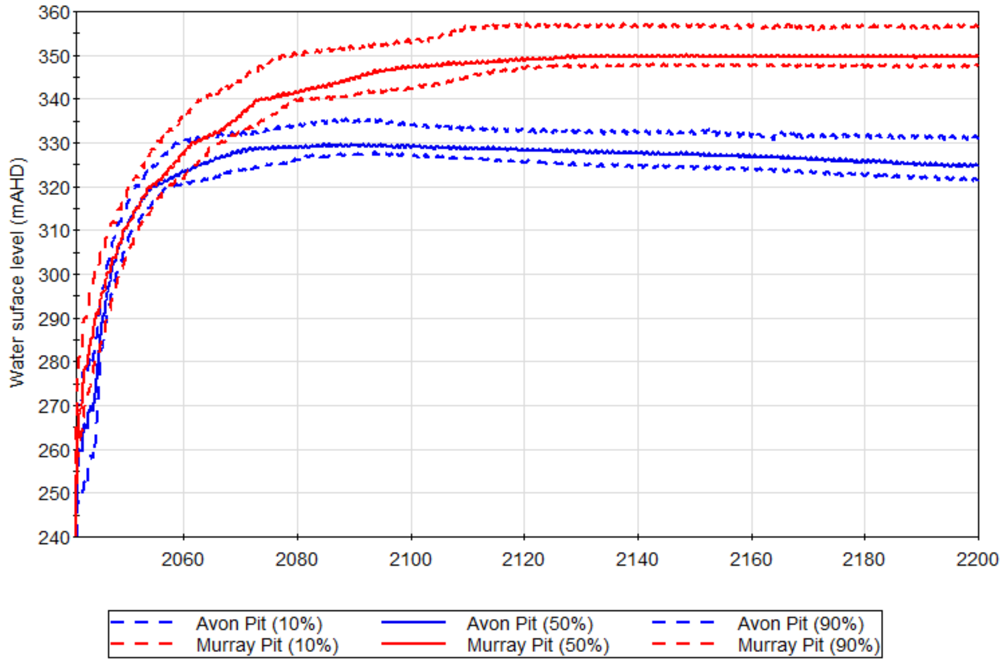

Figure 4-2 Estimated water levels in the pit lakes

5. AMD testing

5.1 Scope of AMD testing

The aim of the AMD laboratory testing of the drill cores was to provide laboratory data and corroborate the former SKM assumptions relating to the metalliferous and acidic leaching potential of the pit walls.

The primary purpose of the drilling was to complete metallurgical and geotechnical investigations, as a consequence core samples for AMD testing purposes were not always available from the pit walls intersections. Where core from pit wall intersections could not be obtained, core samples were obtained from the next available core intervals.

A total of 20 core samples were collected by Atlas Iron staff and contractors, from 17 drill holes, which intersected the pit walls. The drill cores submitted for analysis comprised shales, BIFs and other sedimentary units, generally at depths below the static water table. The drill hole location and intersection and pit names and details of the drill holes are presented in Table 5-1.

The AMD testing comprised the following laboratory analysis from 20 core samples:

- Acid neutralising capacity (ANC)
- Net acid generation (NAG)
- Sulphur speciation
- Total metals (Sb, As, Be, B, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, Hg, Se, Ag, U, Sn, Zn)

Nine selected samples from above were submitted for:

- Leach testing (major ions, pH, EC, metals) under pH 3, 7 and 10.

5.2 Results presentation

A summary of the results as geochemical inputs and evaluation of the pit lake waters, is presented in Section 7.1.1. However, an overview of the acid production potential, based on the laboratory results in Appendix A is presented graphically in Figure 5-1.

The graph indicates that 17 of the samples are predominantly deemed as non-acid forming, with a total of 3 samples deemed as potentially acid forming.

Table 5-1 Drill hole location and pit wall details

Drillhole Name	Drillhole ID/Sample	Easting	Northing	Intersect Pit @m*	Pit ID
MH5	MCDH039	200820.3	7610061	154.5	Murray
MH2	MCDH041	201412	7610733	109.6	Murray
MH10	MCDH042	200041.4	7609015	69.6	Avon East
MH4	MCDH043	200849	7610223	132.7	Murray
MH7	MCDH045	200641	7609885	133.7	Murray
MH9	MCDH046	200174	7609168	146	Avon East
MH3	MCDH048	201231.4	7610373	103.8	Murray
PSM006	MCDH049	201377.1	7610339	61.5	Murray

Drillhole Name	Drillhole ID/Sample	Easting	Northing	Intersect Pit @m*	Pit ID
PSM002_rev 1	MCDH050	203469	7613737	48.5	Nicholson
PSM013	MCDH051	200076	7609281	81.2	Avon East
PSM012	MCDH052	200733	7610211	106.2	Murray
PSM007_rev 1	MCDH053	201181.9	7609799	64.7	Murray
PSM010	MCDH054	200826	7609179	74.5	Avon East
PSM011_rev 1	MCDH055	200693	7608731	75.2	Avon East
Notes: * meters down-hole					

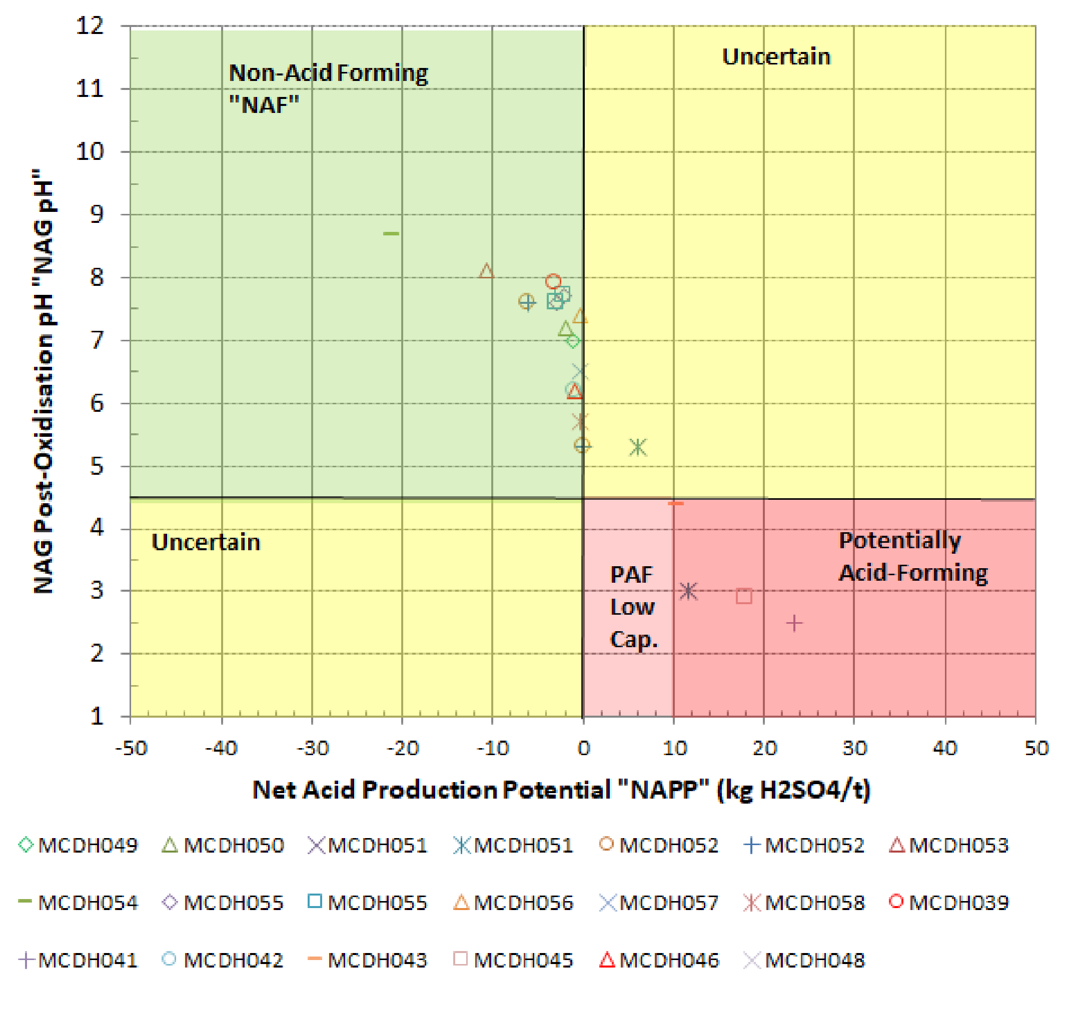

Figure 5-1 Summary of acid production potential

5.3 Shale exposure in pit walls

The predicted shale surface exposure within the final pit walls has been provided by Roy Hill based on the existing geological model and current mine plan for the site. These areas are indicated in red on Figure 5-2 to Figure 5-6 and form the basis for the estimate of the exposed areas (shale PAF and non-shale NAF) which were adopted for characterising the pit lake water quality.

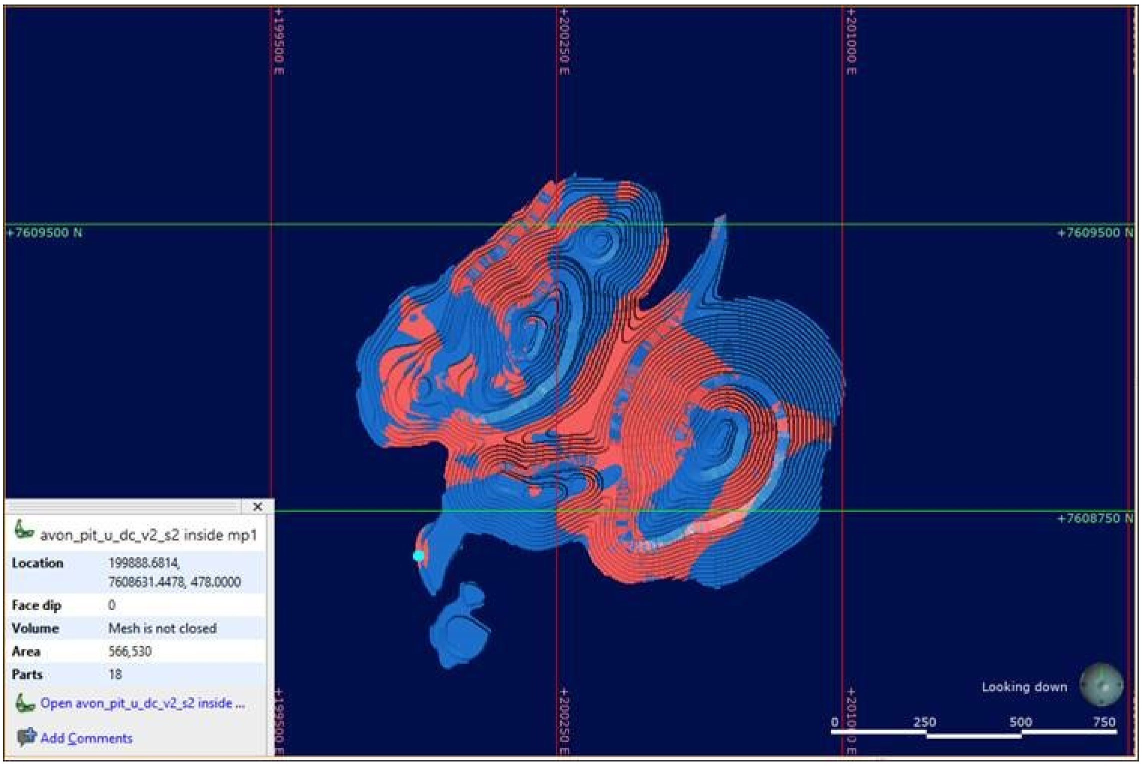

Figure 5-2 Shale Exposure – Avon Pit

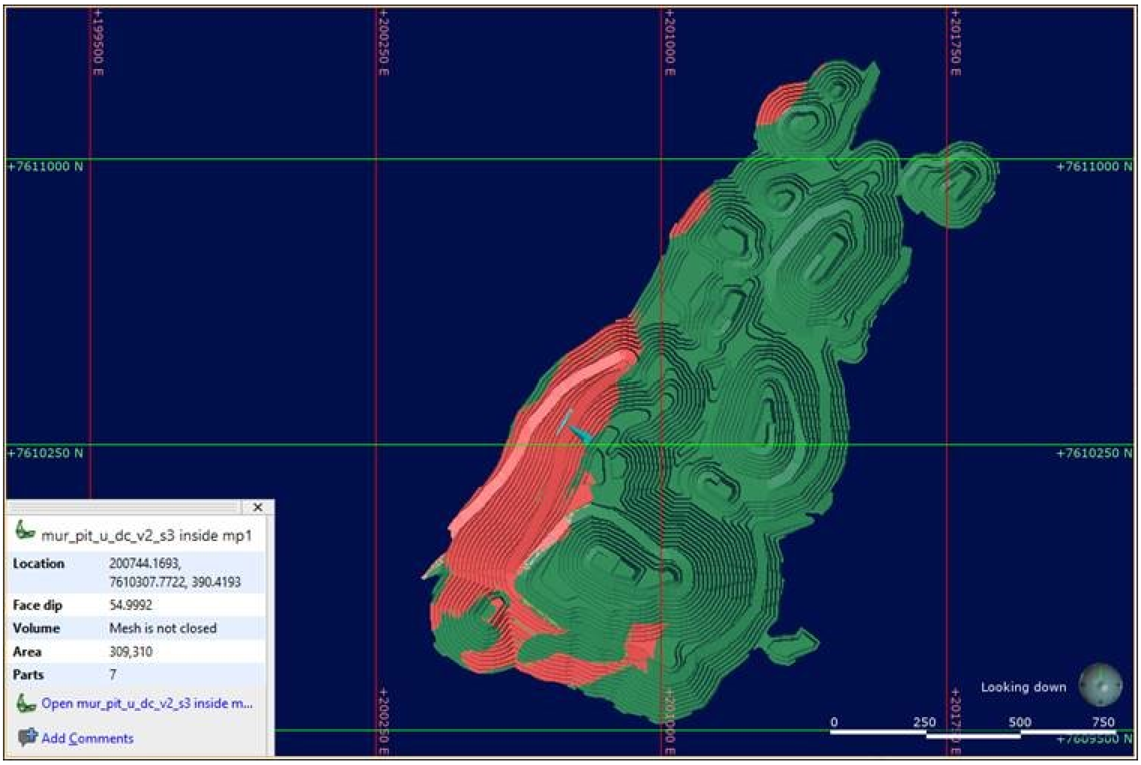

Figure 5-3 Shale exposure – Murray Pit

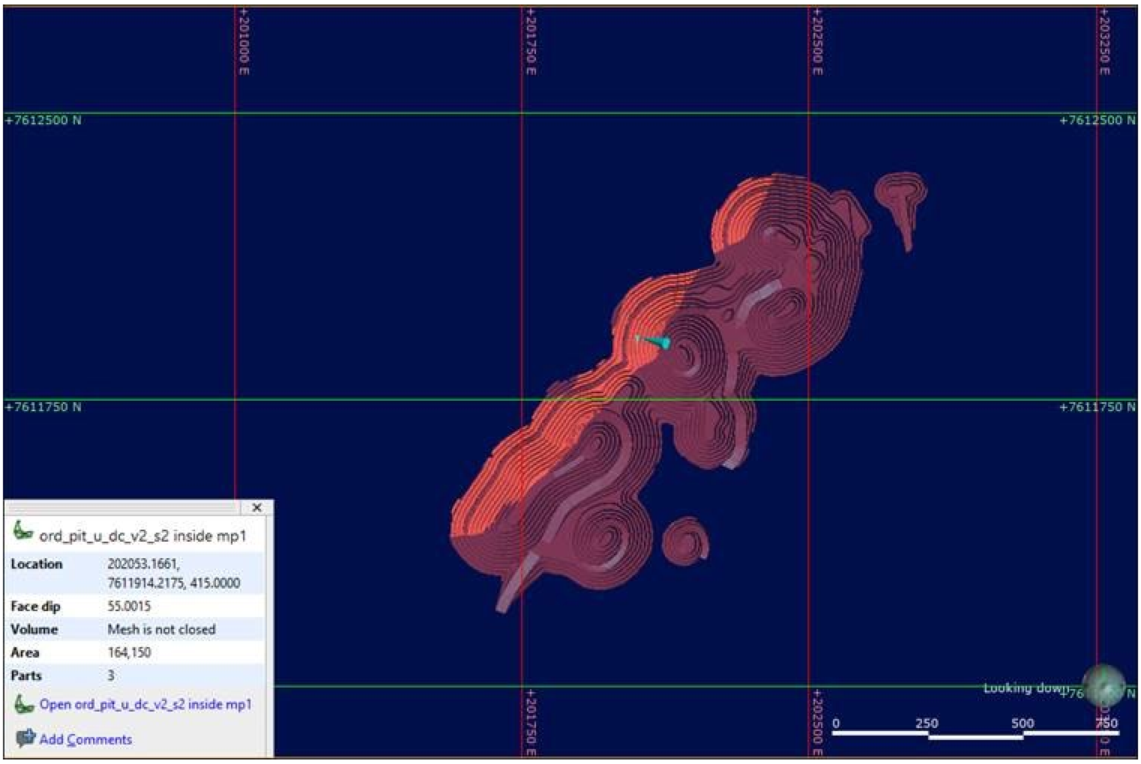

Figure 5-4 Shale exposure – Ord Pit

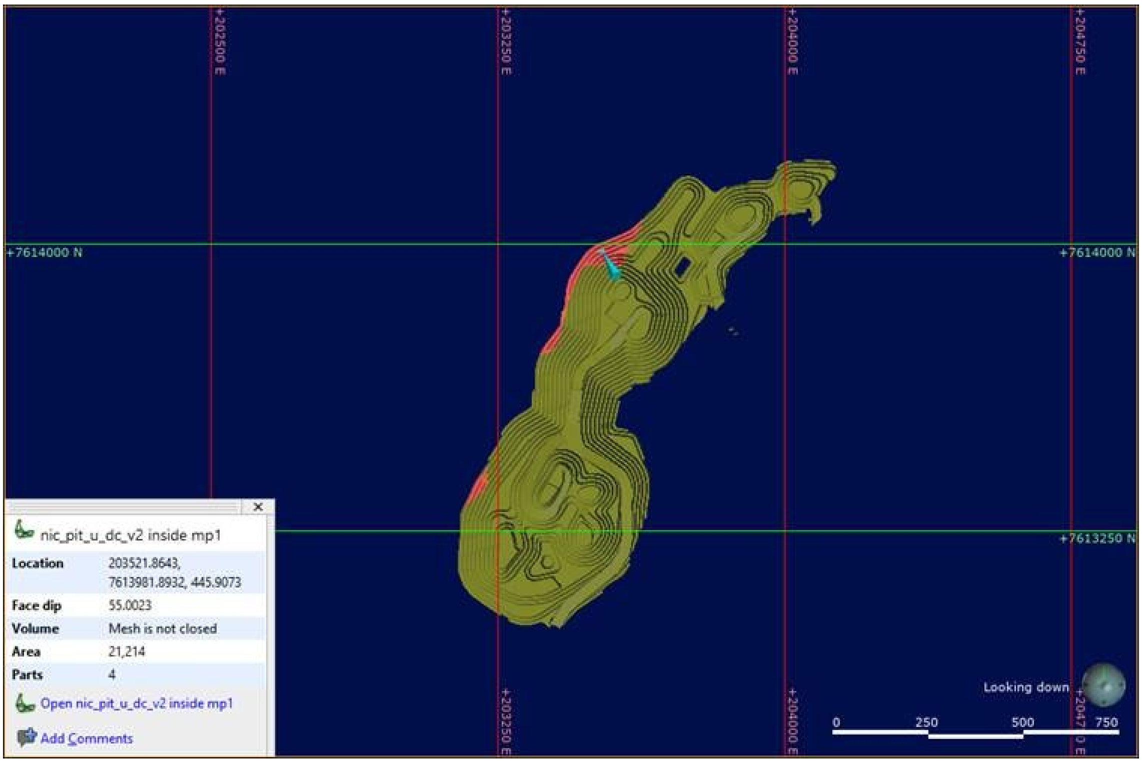

Figure 5-5 Shale exposure – Nicholson Pit

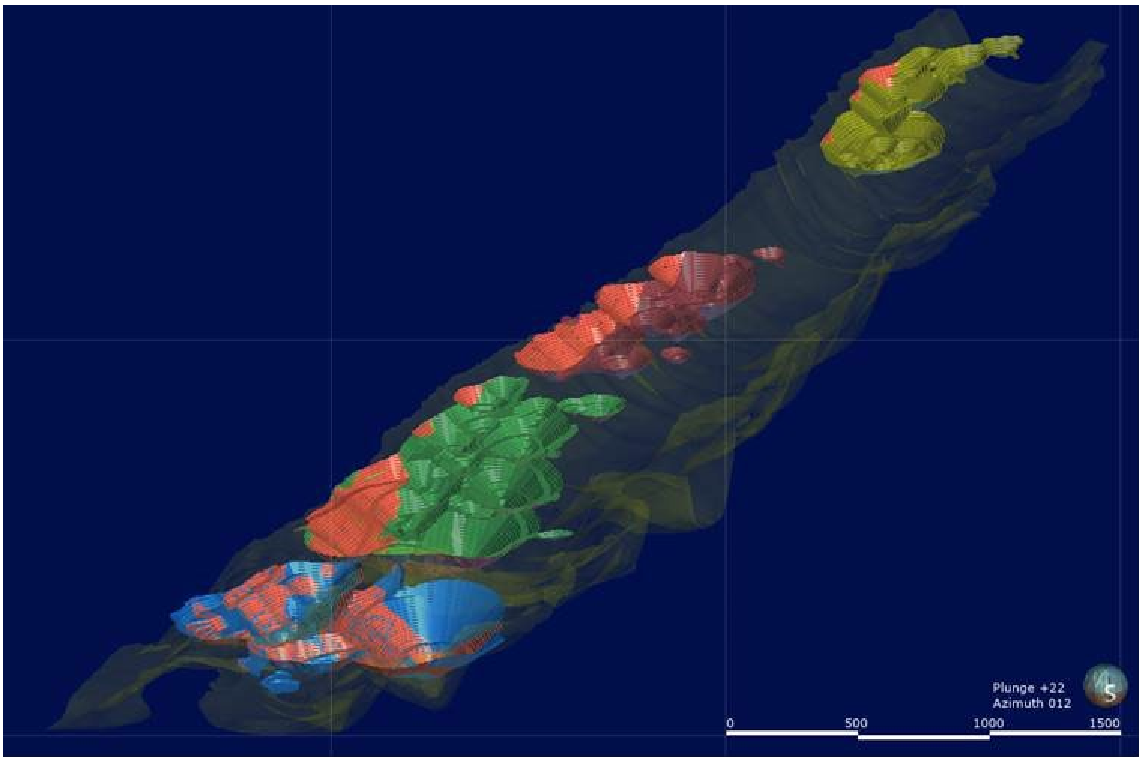

Figure 5-6 Shale exposure overview (shale outcrops in red)

6. Assessment of previous pit lake modelling

6.1 Introduction

Pit lake geochemical modelling was originally undertaken by SKM and is reported in "McPhee Creek AMD Investigation. SKM 2 May 2014. Summary Report" (SKM, 2014).

Geochemical modelling was undertaken utilising a coupled PHREEQC2 and Goldsim model to predict water quality in the three largest pits (Avon East, Avon, West and Murray). PHREEQC2 is commonly used to assess geochemical reactions of combined water qualities when an understanding of the geological and geochemical controls of mineral formation (and desorption) are well understood. Goldsim is a probabilistic software that uses elements to represent data, equations, processes and events. Both models are considered industry standard and are considered appropriate (estimating resultant pit lake water volumes and quality) as outlined in the SKM report.

The models utilised by SKM were not available for review, nor were the versions used and geochemical databases used outlined within the SKM report. Although likely to not considerably influence the results presented, different versions of PHREEQC2 and their associated databases (it is assumed the associated database minteq was used) have updates that may (such as to the surface-complexation database) result in differing results between versions. Other consideration, such as the assumptions around oxyhydroxide precipitation and their formation are not outlined in the SKM report.

6.2 Modelling assumptions

The key geochemical modelling assumptions relating to estimating the pit lake water quality as outlined in the SKM report and their appropriateness, are as follows:

6.2.1 PAF / NAF classification

Waste rock classification was originally reported and described in Campbell & Associates (2012 & 2013). The 2013 report was reviewed as part of this GHD assessment.

SKM summarised PAF/NAF classification as:

- Total sulphur was used to derive maximum potential acidity (MPA)
- A range of methods (not defined in the SKM report) were utilised to measure the acid neutralising capacity (ANC)
- Single addition net acid generation (NAG) was undertaken to calculate final pH and acidity
- Whole rock or exchangeable ion analyses was undertaken to infer metalliferous and saline drainage potential

In addition, sulphur, sulphate and sulphide sulphur were measured to determine reactive sulphur percentage and correlation with total sulphur investigated. The results of this assessment are included in the Campbell & Associates (2013) report and show that most of the total sulphur measured (from the samples selected) is present as sulphide.

The above classification methodology appears robust however the total number of samples tested for ABA and whole rock elemental analysis (22 samples in total of which 14 were above the pre-mining groundwater table, oxidised and classified as NAF) are considered insufficient based on the volume of waste rock, area of post mining pit wall exposure and geological heterogeneity. The actual locations of the samples are not provided, therefore it is not possible to assess the appropriateness of the samples selected with respect to their overall representativeness.

A 3D pit wall model was developed from Total Sulphur assay data (measured by XRF) from the Atlas Iron's Vulcan model utilising in excess of 77,690 data points. The provided diagrams show core locations, which are assumed to represent the approximate assay location and/or density of the 1,486 mapped holes. It is difficult to assess the representativeness of the core/sample locations based on the diagrams provided and there is a data gap in the vicinity of the south east of the Avon Pit.

The volume of data provided and on the assumption that all sulphur is present as sulphide sulphur, suggests that the diagrams showing the percentage of sulphur are a reasonably good indicator of areas of high PAF within the exposed areas of the pit walls. The high sulphur areas were correlated with carbonaceous shale and therefore based on the south east area of the Avon Pit containing a mapped incidence of carbonaceous shale, it is assumed this area also has high sulphur outcrops and therefore should be regarded as PAF.

Additional acid base accounting (ABA) data testing undertaken in 2020 (Appendix A), confers with the original assessment that sulphur is present as sulphide, therefore the MPA calculated from total sulphur by SKM is considered appropriate.

6.2.2 Pit wall runoff water quality

Non-acid forming (NAF) runoff was calculated based on one kinetic column test (deemed the least acid producing of the total nine columns) on which all constituted carbonaceous shale. This is considered potentially overly conservative as the carbonaceous shale are in general considered to be PAF and kinetic results are likely to under represent neutralisation capacity from non-carbonaceous shale areas.

PAF runoff was calculated based on the mean results from eight PAF kinetic column testing undertaken. The samples are stated to have been collected from the unoxidised zone (below the current groundwater table) so the derived leachate data is representative of fresh unoxidised material.

No additional location data for the rock samples used in the construction of the tests are provided so overall suitability and representativeness cannot be assessed further. Modelled water inputs have been derived using mean leachate values.

This is considered a simplification and may not represent long term leachate concentrations. Based on the original kinetic leachate report (Graeme Campbell and Associates Pty Ltd, 2013) the leachate shows a distinct increase in trace elements concentration throughout the 20 test cycle. A more conservative estimate of long-term leachate would be represented by utilising concentrations near the end of the 20 week column duration.

The calculated runoff water quality is therefore potentially under-representative (in terms of acid generation) from exposed PAF walls when looking at long term trends and could potentially under predict acid loading in storm events in the results provided by SKM.

Overall, the potential under representation of buffering capacity in the NAF runoff and potential under representation of acid loading from the PAF runoff could result in a different water outcome as to that stated in the SKM report.

6.2.3 Loading

Loading has been calculated using mass/area/time formulae and takes into account the estimated area of rock in the kinetic columns (assuming a particle size distribution (PSD) of

<2mm PSD and a mass of column material of 1.5 kg) resulting in a calculated exposed surface area of 12 m^2 of kg of material per column. The exposed surface of PAF has then been calculated by multiplying the exposed PAF by a factor of 200 to account for benching, fracturing and roughness. These calculations both seem appropriate. The resultant water chemistry of the PAF and NAF runoff is then calculated based on a mg/m^2/day.

It should be noted that when applied to a small volume of water (i.e. low rainfall days) the resultant runoff concentration will likely be limited by the runoff being supersaturated with respect to sulphate and a resulting ratio of sulphate to trace element generation.

This does not appear to have been taken into account within the modelling and may result in an over estimation of trace element concentration in PAF pit wall runoff particularly during low rainfall events.

6.2.4 Stratification

The model assumes that the resultant pit lakes remain fully mixed. Based on evaporation and groundwater inflow being the primary controls in inflow and outflow from the pit lakes, this is considered appropriate.

6.2.5 Mineral phases

Mineral phases allowed to precipitate from solution in the PHREEQC modelling include ferrihydrite, gypsum, calcite, jurbanite and gibbsite. These mineral phases are considered relatively stable at the redox conditions stated and are therefore considered appropriate.

6.2.6 Waste rock dumps

The modelling assumes that waste rock dumps (WRDs) are stored externally and have no source of AMD to the pit lakes. Potential impact of these WRDs on groundwater is not considered and is not part of this review / assessment by GHD.

6.3 Findings of modelling

The SKM modelling concluded that water in all pits would initially be acidic. Post closure this water quality would deteriorate further largely due to the concentration effect of evaporation. However the report suggests Murray pit water quality would eventually become neutral due to large proportion of groundwater input (which provides alkalinity) relative to runoff from PAF material.

6.4 Conclusions on modelling appropriateness

The modelling software utilised (Goldsim and PHREEQC2) are considered suitable to assess the water quality of the pit lakes. The SKM reports outlines the key modelling assumptions which seem largely appropriate based on the data provided. However, as the actual model files have not been provided, it is not possible to provide comment on the model actual application, integrity and appropriateness of the modelled results; only that they seem reasonable based on the data and assumptions outlined.

The key conclusion from the modelling is that the pit lakes would become groundwater sinks due to high evaporation rates. Ultimately it is considered that if acidic pit water with elevated trace elements is an acceptable outcome, the degree of acidity and actual concentrations of trace elements becomes somewhat less relevant. The pit lake water level is estimated to be some 100m below the pit rim and some 40-60m below the baseline groundwater level (groundwater sink) therefore discharge from the pit lake into the adjacent receiving environment (i.e. local groundwater resource) is excluded..

6.5 Outcome of review

Since the SKM geochemical modelling was undertaken in 2014, additional sample testing data has been collected and assessments updated to reflect the changes in the mine plan, including the site water balance and supporting groundwater modelling.

Additional data collection and analysis from the pit walls in 2020 has focused on areas that are not identified as carbonaceous shale and were not analysed as part of the 2014 assessment. The results of the additional testing suggests that the majority of this material can be classified as NAF. Leach testing data from these samples has enabled runoff water quality for the NAF material to be revisited.

Coupled with the data from the original kinetic tests (considered representative of the exposed PAF), an understanding of the proportion of pit wall exposure (from the updated geological site model) and updated groundwater / surface water modelling, it is considered that remodelling of the pit lake geochemistry is warranted in order to confirm if the findings of the SKM 2014 work are still valid.

7. Updated modelling methodology

7.1 Geochemical modelling

Remodelling of the pit lakes was done using the geochemical modelling software PHREEQC2 version 3.6.2 and the Minteq.v4 database. Four inflow water chemistries – geochemical end-members: groundwater, PAF runoff, NAF runoff and rainfall were derived for the modelling with proportions of each inflowing end member calculated based on the recent water balance assessment (GHD, 2020).

7.1.1 Representative water inflow chemistry

PAF runoff

The raw leachate data from the kinetic cells (GCA, 2012) was summarised with the final leach analysis utilised as per SKM, 2014. The approach is considered appropriate as by the time the pit reaches its maximum extent (and exposed surface area), the bulk of the exposed walls would have been exposed to the atmosphere for a period likely exceeding any lag period and any large initial pulses of acidity / trace element mobilisation. It is considered that the final leach test best represents sulphate oxidation and resultant trace element mobilisation in the long term.

The mean daily sulphate generation from the leach data was calculated based on the volume of the material in the column (1.5 kg), the volume of leachate collected and the timeframe between leach collection (4 weeks). The molecular ratio of sulphate to trace element generation within the leachate was then calculated and this ratio was utilised to calculate the expected daily mass based on the assumed volume of exposed PAF material.

The calculated daily mass load was then diluted into the total daily PAF runoff for each scenario. Sulphate concentrations were adjusted down (where applicable) to prevent the over saturation of sulphate in the derived water chemistry. As this model input is a considered the key model input to modelled pit lake acidity loading, total dissolved solids (TDS) and pH; modelling has focused on examining its sensitivity to the PAF runoff input sulphate concentration.

The sensitivity scenarios look at the impact of a reduced sulphate concentration in comparison to the calculated concentration based on the calculated generation rate. The scenarios have been devised based on the potential sulphate generation rate calculated directly from the kinetic data (defined as min, med and max in the results):

- ‘min’ scenario is the maximum likely sulphate generation rate (minimum resultant pit lake pH)
- ‘med’ scenario is considered a median likely sulphate generation rate based on the observed sulphate generation rates in the kinetic cell data.
- ‘max’ scenario taking into account the lower range of the calculated sulphate generation from the kinetic cell data (maximum resultant pit lake pH).

NAF runoff

Water quality associated with NAF runoff was calculated from the deionised (DI) water leachate tests undertaken on the non-carbonaceous shale material. Table 7-1 summarises the NAF leachate data and the mean values were adopted as representative of runoff from exposed NAF.

Table 7-1 Representative end-member chemistries utilised for PHREEQC2 modelling

			PAF Material					NAF Material					Groundwater					Rainfall [1]
Analyte grouping/Analyte	**Moles**	**Unit**	Count	Min	Max	Mean	St Dev	Count	Min	Max	Mean	St Dev	Count	Min	Max	Mean	St Dev	Values
Physio-chemical																		
pH		pH units	8	1.90	4.10	2.63	0.680	9	4.34	7.07	6.25	0.8	6	6.2	7	6.62	0.28	5.7
EC		µS/cm	8	550	7700	3281	2716	9	5	50	21.4	17.9	-	-	-	-	-	-
Acidity		mg H2SO4/L	7	370	3800	1733	1506	-	-	-	-	-	-	-	-	-	-	
Major ions																		
Sodium	22.989769	mg/L	10	0.0001	0.0002	0.0002	0.00003	9	1	1	1	1	6	13	100	39.2	30.7	-
Potassium	39.0983	mg/L	10	0.0098	0.0145	0.0121	0.0022	9	1	5	2.1	1.5	6	0.8	2.8	2.17	0.73	-
Magnesium	24.305	mg/L	10	2.17	3.2	2.67	0.485	9	1	2	1.2	0.44	6	18	57	29.8	14.8	-
Calcium	40.078	mg/L	10	0.010	0.014	0.012	0.002	9	1	1	1	1	6	8	13	10.5	1.86	-
Sulfate	96.06	mg/L	10	1897	2804	2340	424	9	1	18	7.5	7.7	6	29	170	59.5	54.4	-
Iron	55.845	mg/L	10	354	524	437	79	-	-	-	-	-	6	<0.01	1.3	0.53	0.53	-
Metals																		
Antimony	121.76	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	<0.01	<0.01	-	6	<0.001	<0.001	0.001	-	-
Arsenic	74.9216	mg/L	10	0.00001	0.00002	0.00001	<0.00001	9	<0.01	<0.01	<0.01	-	6	<0.001	<0.001	0.001	-	-
Barium	137.327	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	6	<0.01	0.05	0.03	0.01	-
Boron	10.811	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.1	<0.1	<0.1	-	6	0.09	0.15	0.12	0.02	-
Cadmium	112.411	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.005	<0.005	<0.005	-	6	<0.0001	<0.0001	0.0001	-	-
Chromium	51.9961	mg/L	10	0.00085	0.00125	0.00105	0.00019	9	<0.01	<0.01	<0.01	-	6	<0.001	0.005	0.005	-	-
Cobalt	58.933195	mg/L	10	0.021	0.031	0.026	0.005	9	<0.01	0.13	0.039	0.035	6	<0.001	0.002	0.001	0.001	-
Copper	63.546	mg/L	10	0.037	0.055	0.046	0.008	9	<0.01	0.4	0.07	0.17	6	<0.001	<0.001	0.001	-	-
Lead	207.2	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	0.01	0.01	-	6	<0.001	<0.001	0.001	-	-
Manganese	54.938044	mg/L	10	0.006	0.009	0.007	0.001	9	<0.01	1.25	0.23	0.54	6	0.33	0.78	0.45	0.18	-
Mercury	200.59	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.0001	<0.0001	<0.0001	-	6	<0.0001	0.0003	0.0003	-	-
Molybdenum	95.95	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	0.02	0.011	-	6	<0.001	<0.001	0.001	-	-
Nickel	58.6934	mg/L	10	0.183	0.271	0.226	0.041	9	<0.01	0.59	0.114	0.24	6	0.004	0.035	0.0095	0.013	-
Phosphorous	30.973762	mg/L	10	0.001	0.002	0.001	0.0002	-	-	-	-	-	-	-	-	-	-	-
Selenium	78.96	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	0.05	0.016	0.019	6	<0.001	<0.001	0.001	-	-
Silver	107.8682	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	<0.01	<0.01	-	6	<0.001	<0.001	0.001	-	-
Strontium	87.62	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	-	-	-	-	-	6	0.02	0.11	0.067	0.03	-
Tin	118.71	mg/L	10	<0.00001	<0.00001	<0.00001	<0.00001	9	<0.01	<0.01	<0.01	-	6	<0.001	<0.01	0.001	-	-
Zinc	65.38	mg/L	10	0.013	0.019	0.016	0.003	9	<0.01	0.56	0.12	0.21	6	<0.005	0.13	0.035	0.05	-

Notes: A hyphen (-): No derived value

References: 1. Rainfall values derived from: Castendyk and Webster-Brown, 2006. Geochemical Prediction and Remediation Options for the Proposed Martha Mine Pit Lake, New Zealand. Table 1

Groundwater

Water quality associated with groundwater inflows was derived from the groundwater sampling undertaken in 2020 (Table 7-1). The mean values were adopted as considered representative.

Rainfall

Rainfall water quality was taken from Castendyk and Webster-Brown 2006. The representative water chemistry utilised in the modelling is summarised in Table 7-1 below.

7.1.2 Proportions of inflows

The inflows into the respective pits have been calculated based on the outputs of the water balance modelling outlined in GHD, 2020.

Pit lakes are expected to form in both the Avon and Murray Pits where they will function as terminal groundwater sinks. Pit lakes are generally not expected to form in the Ord and Nicholson Pits.

It is likely that runoff from these pits may influence groundwater quality through seepage into the potentially receiving Murray Pit. The exposed PAF areas within the Ord and Nicholson Pit walls are expected to be small (0.21 and 0.04 % for Ord and Nicholson Pit respectively) (Table 7-2) and attenuation of trace elements released via the runoff pathway via groundwater within the subsurface is likely (through the adsorption onto iron oxyhydroxides).

Therefore it is considered that acidic loads from both the Ord and Nicholson are unlikely to have a significant impact on the water quality of the down hydraulic gradient Murray and Avon Pits. In a similar manner, groundwater flow from the Murray Pit to the Avon Pit (and its associated impact) is not considered within the geochemical assessment of the Avon Pit as the volumes are small compared to the other water balance components.

Table 7-2Proportion of exposed PAF / NAF in pit shell

Pit name	Shale exposed area (m2)	Total final pit design area (m2)	%PAF	%NAF
Avon	566,530	1,267,200	45	55
Murray	309,310	1,594,500	19	81
Ord	164,150	764,840	21	79
Nicholson	21,214	590,260	4	96

The total annual inflows and proportion of source water over time for the Avon and Murray Pits are presented in Figure 7-1 to Figure 7-4.

Both pits show a high proportion of surface water runoff during the early years of filling (both PAF and NAF runoff). With time, the groundwater and rainfall inputs as a proportion of all inflows increase. Based on these changing proportions of source water, geochemical modelling has focussed on five stages throughout pit lake development (2030, 2045, 2050, 2060 and 2199).

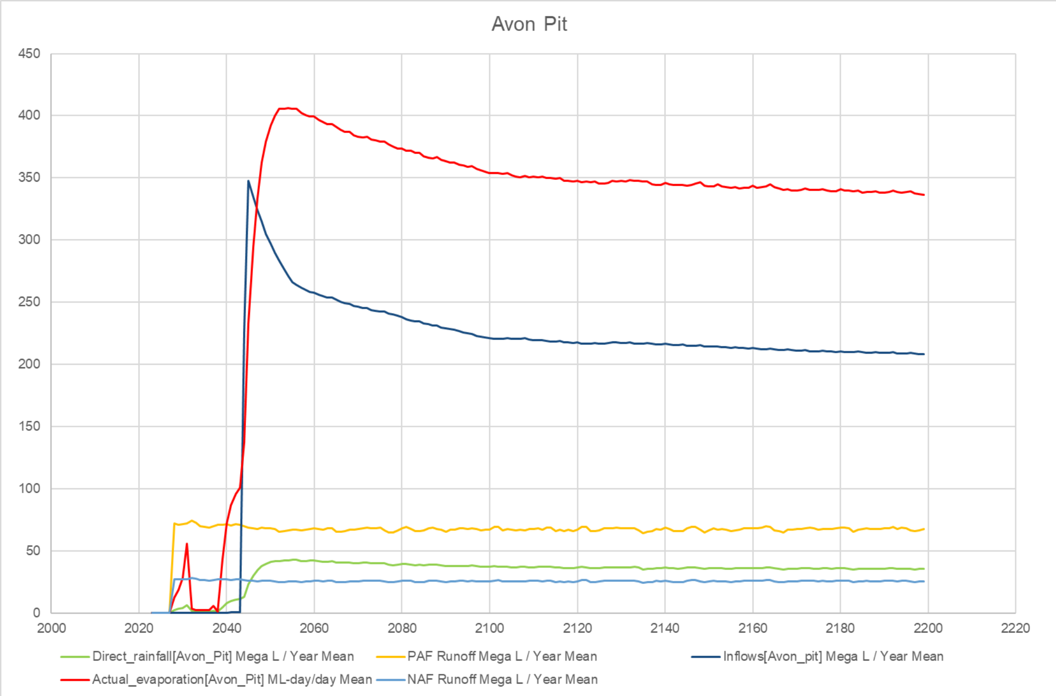

Figure 7-1 Annual inflows - Avon Pit

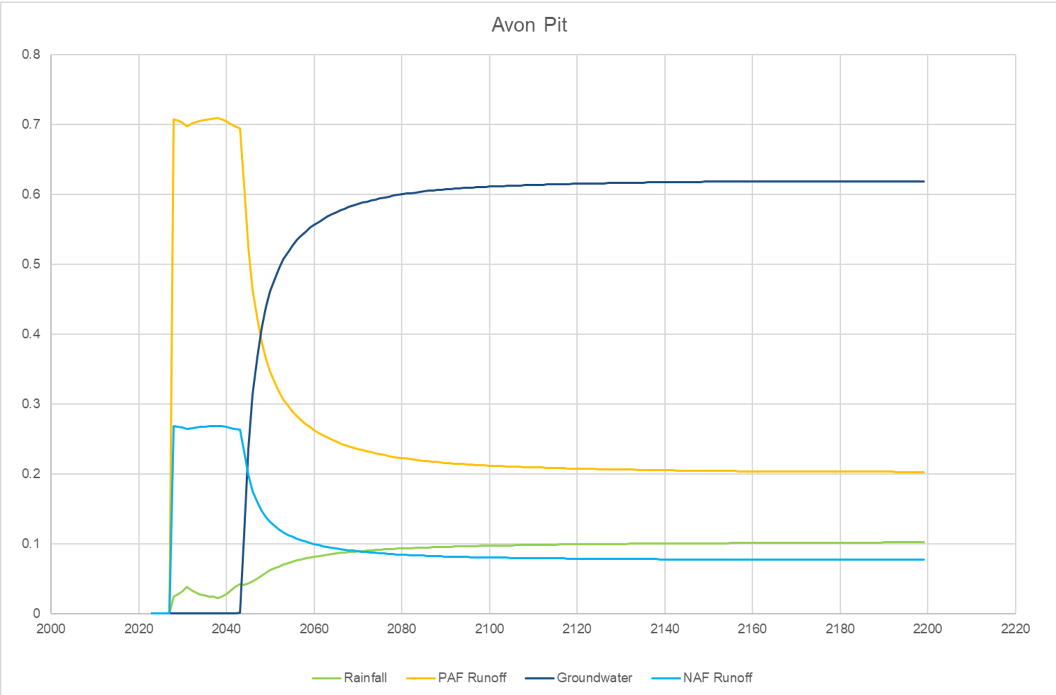

Figure 7-2 Proportion of water by source - Avon Pit

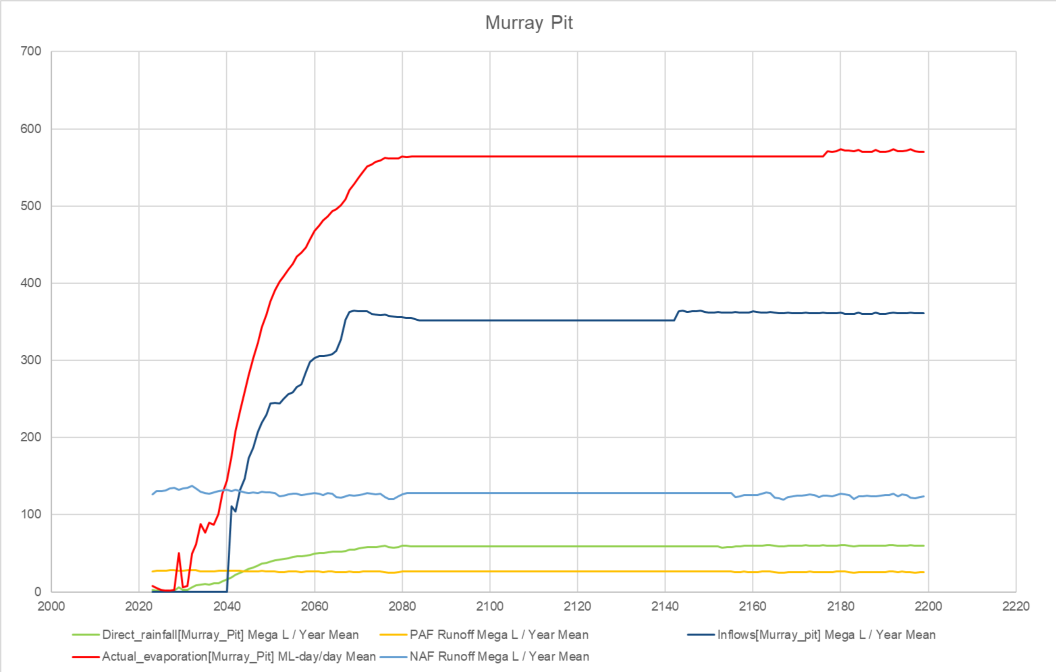

Figure 7-3 Annual inflows - Murray Pit

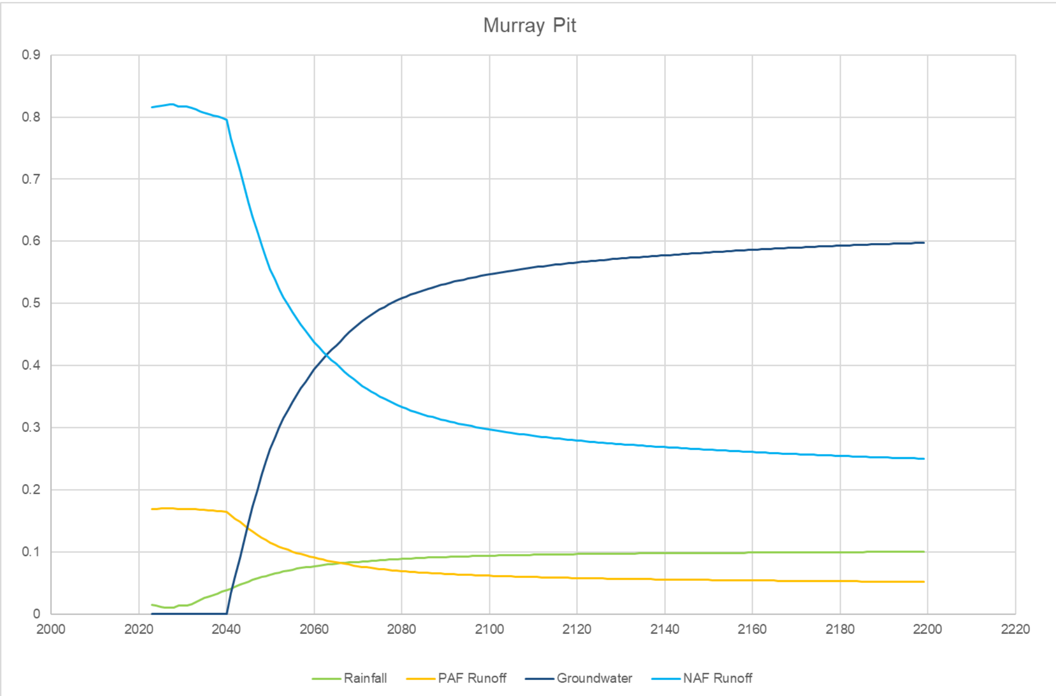

Figure 7-4 Proportion of water source - Murray Pit

7.1.3 Key modelling assumptions

Notwithstanding the assumptions already outlined, the key standard assumptions applied to the modelling undertaken are:

- No pit lake stratification has been accounted for.
- The minerals were allowed to precipitate from solution.
- A constant temperature of 25° C was assumed for all input solutions.
- The total volume of material available for oxidation has been calculated by multiplying the exposed pit wall areas of the respective pits by a factor of 0.01 and by the assumed bulk density (2.8 t/m^3). This is considered suitable based on the arid pit wall rock environment and takes into account blast damaged fractures adjacent the pit wall (Garvie et. al. 2014). It is conservatively assumed the entire calculated daily oxidised mass (and associated leachate metals) are dissolved into the applied daily runoff volume.
- The samples utilised in the kinetic cells are considered representative of the exposed carbonaceous shale within the final pit walls.
- Areas of exposed PAF (carbonaceous Shale) that will ultimately be below the final pit lake water level will remain saturated and therefore will be not be a source of acidity and oxidation products to the pit lake long term. The majority of the exposed PAF material is likely to be above the final pit lake water levels in both the Murray and Avon Pits. A reduction in acidity and associated trace element load associated with this saturation has not been considered in the modelling undertaken.
- Groundwater and PAF / NAF runoff electron activity (pE) was assumed to be the default value of 4 as per SKM, 2014.
- The pH of the calculated PAF runoff was calculated within PHREEQC.
- Once allowance for precipitation of over saturated sulphides has occurred in PHREEQC, the precipitated trace elements are not available to dissolve back into solution.
- While iron oxyhydroxide precipitates are expected within the lake, their spatial presence may be localised and as such the potential attenuation of aqueous phase trace elements by adsorption to these minerals may be limited. Furthermore, the pit lake environment is dynamic, and whilst the sorption of trace elements onto oxyhydroxides may occur near the surface where oxidising conditions prevail, desorption may occur as precipitates sink through the water column and lake mixing could result in redistribution of these species. As a consequence, trace element sorption onto oxyhydroxide precipitates has not been considered. The modelling outputs are therefore considered conservative on this basis.

8. Modelling results

8.1.1 Avon Pit

Modelling has shown that the pH of Avon Pit lake is likely to be acidic after closure with just a small increase in pH expected over time as the proportion of PAF runoff water relative to the other flow inputs decreases (Figure 8-1).

When the PAF runoff sulphate input is reduced (max scenario), the modelling shows a steady increase in pH over time. This highlights the sensitivity of the model to the assumptions around acidity loading of the PAF runoff but also highlights the potential for long term changes in pit lake acidity, particularly when factors such as the reduction in oxidation zones due to saturation, long term exposure of pit walls resulting in a reduced sulphate production rates and iron-hydroxide precipitation are taken into account. These last two factors are particularly difficult to estimate, however their exclusion (along with the reduced acidity loading due to formation of the pit lake) should be regarded as a conservative approach.

The modelled pit lake TDS concentration over time is depicted in (Figure 8-2) and are calculated based on the results of the PHREEQC analysis and correction for evaporation effects. Due to the significant proportion of pit lake evaporation over time, there is a pattern of increasing concentration of major ions over time. The calculated TDS concentration is dominated by sulphate due to the oxidation of sulphide minerals in the pit walls and, even though the actual proportion of PAF runoff (as a proportion of all pit inflows) reduces over time, the TDS increases based on the assumption of limited precipitation and concentration via evaporation.

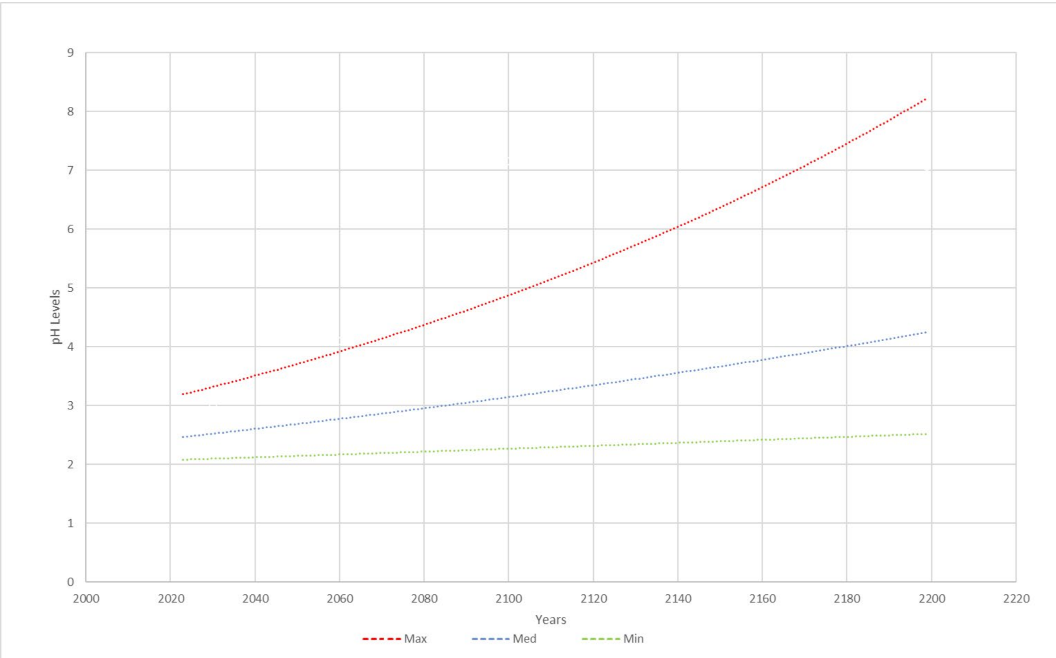

Figure 8-1 Avon Pit pH versus time

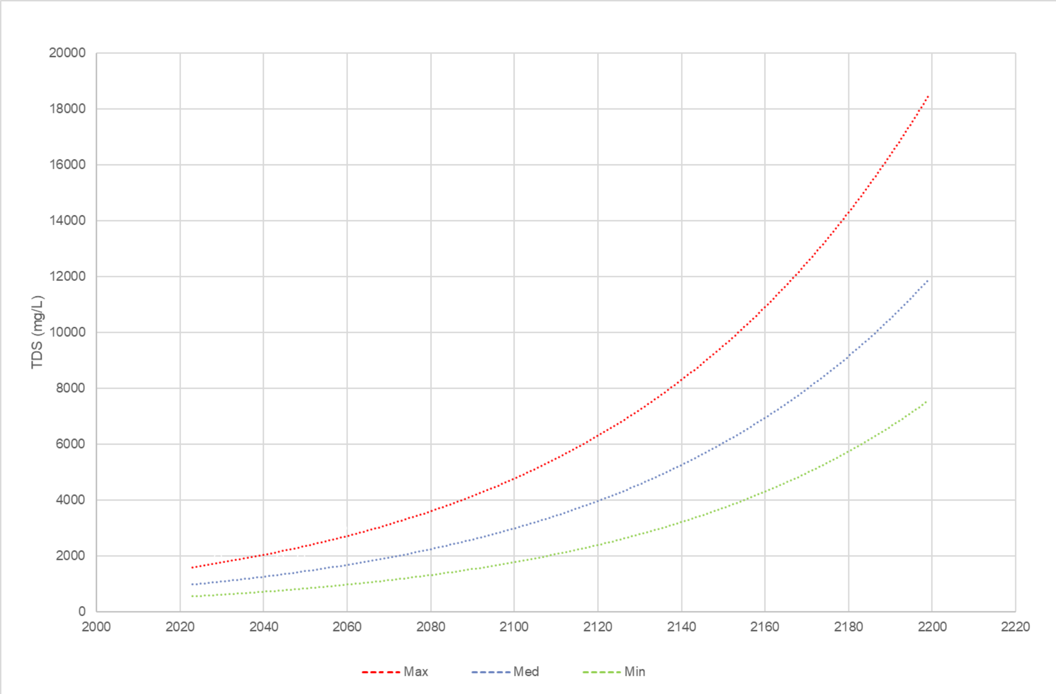

Figure 8-2 Avon Pit total dissolved solids concentration versus time

Selected modelled major and trace element concentrations in the Avon Pit lake are presented in Figure 8-3. Due to the low pH, limited attenuation by precipitation and concentration due to evaporation, major and trace element concentrations generally increase over time.

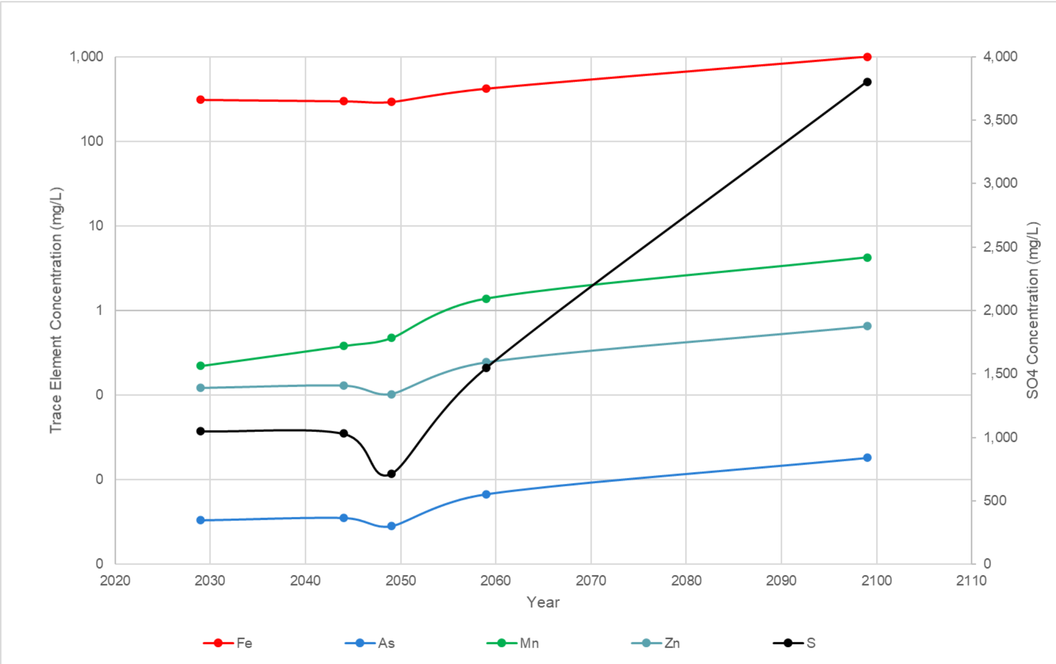

Figure 8-3 Avon Pit Selected major and trace element concentrations

8.1.2 Murray Pit

Modelling shows that the pH of Murray Pit pit lake is likely to be more neutral / less acidic post closure when compared to the Avon Pit. (Figure 8-4). This is a result of the much lower proportional input of PAF runoff water compared to the Avon Pit. The modelled scenarios still show a potential for the pit lake to remain acidic in the long term (min scenario), however based on the conservative nature of the modelling undertaken, this scenario as regarded as unlikely.

TDS concentrations are expected to increase over time (Figure 8-5) due to limited precipitation and concentration via evaporation. No loss of TDS through groundwater seepage into the underlying formation has been modelled in the case of Murray Pit.

Selected modelled major and trace element concentrations in the Murray Pit lake are presented in Figure 8-6. Trace elements show a reasonably consistent pattern through the timeframe modelled. This is slightly counterintuitive when viewed against the pH in Figure 8-4 as at a pH of approximately 6 precipitation of elements such as Zn and Fe and to a lesser extent As generally occurs. The reason for this lack of contaminant reduction lies in the modelling methodology applied which adjusts the geochemical modelled concentrations (from PHREEQC2) by the cumulative volume of evaporation. This results in an overestimate (and conservative estimate) of modelled concentrations.

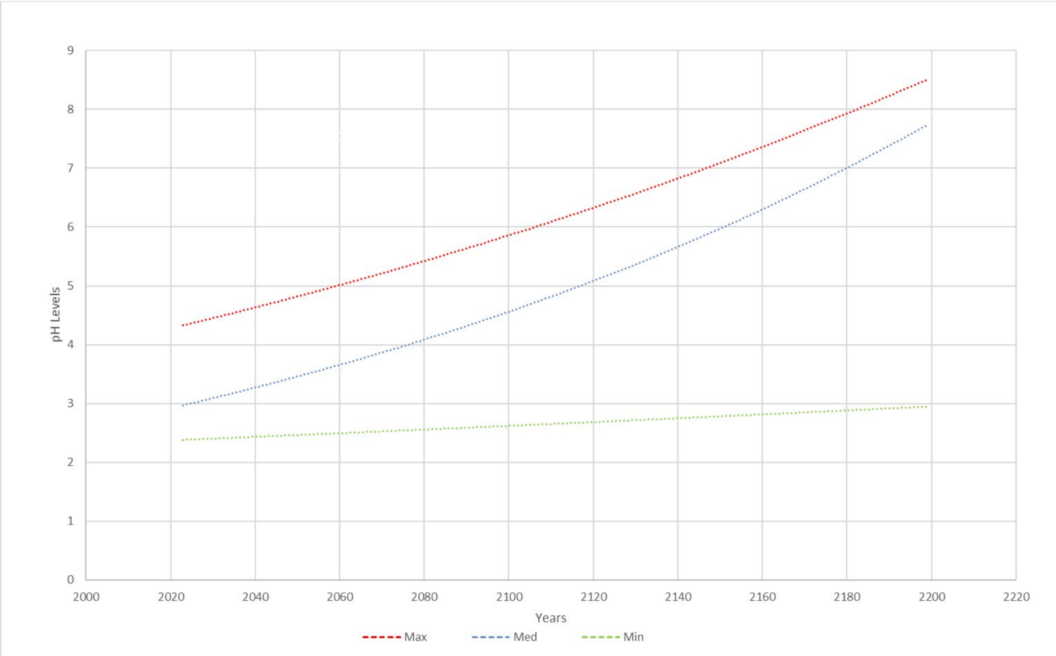

Figure 8-4 Murray Pit pH versus time

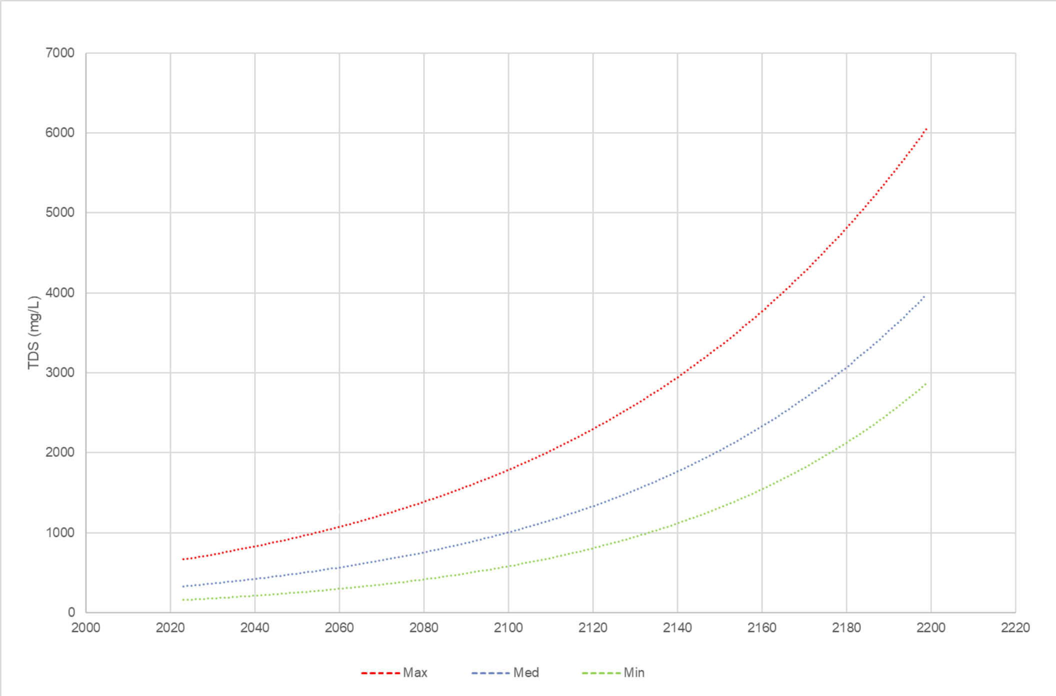

Figure 8-5 Murray Pit total dissolved solids concentration versus time

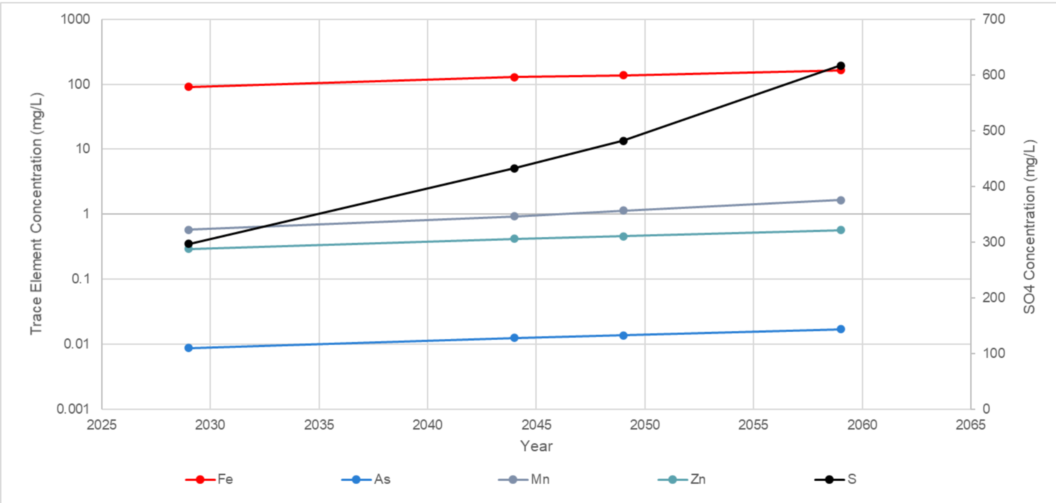

Figure 8-6 Murray Pit selected major and trace element concentrations

8.2 Results summary

Geochemical modelling of the Avon Pit lake water quality suggests that it is likely to be acidic in the long term with an increase in the concentration of TDS over time which is dominated by sulphate. Modelling of the Murray Pit lake water quality suggest a more neutral and less acidic outcome is more likely. These results concur with the original assessment reported in SKM 2014.

The outputs suggest the following:

- Avon Pit lake
  - long-term pit lake water quality is likely to remain acidic
  - small increase in pH expected over time as the proportion of PAF runoff water relative to the other flow inputs decreases, with a pH increase from 2.5 after mine closure to 4 by 2180 (based on median likely sulphate generation rate)
  - increase in the concentration of total dissolved solids (TDS) over time, which is dominated by sulphate. TDS rising from <2,000 mg/L at mine closure to approximately 9,000 mg/L by 2180 (based on median likely sulphate generation rate).
- Murray Pit lake
  - long-term pit lake water quality is likely to be neutral and less acidic compared to the Avon Pit lake, due to a lower proportion of PAF runoff relative to other pit lake inputs.
  - increase in pH expected over time, with pH increase from 3 at mine closure rising to 7 by 2180 (based on median likely sulphate generation rate)
  - increase in the concentration of total dissolved solids (TDS) over time, which is dominated by sulphate. TDS rising from <1,000 mg/L at mine closure to approximately 3,000 mg/L by 2180 (based on median likely sulphate generation rate).

Assuming also that the pH and TDS levels quoted are not 'static' throughout the year. During cyclone/wet season, large fresh rainwater water 'pulses' will flow into the pit voids, providing a significant dilution of the current levels.

Stratification in the pit lakes has not been included in this level of assessment. Fresh water is lighter than salty water. Therefore, it may be that relatively fresh rainfall provides a fresh layer on top of the higher TDS water below.

As ultimately the pits are determined to be terminal sinks to groundwater, the risk that the pit lake water quality poses to the regional groundwater is negatable based on the current groundwater assessment that has identified the pit lakes will function as sinks.

8.3 Pit lake management options

Given limited data such as the low numbers of leach testing of the pit walls (No. 20), there is a high degree of uncertainty involved in the prediction of pit lake water quality and this is accentuated by predictions far into the future (10+ years in pit lake evolution).

Any recommendations relating to managing acidic inflows will depend on the risk (and perceived risk) to the surrounding environment and acceptable pit lake water quality by relevant stakeholders.

If a particular resultant water quality is required, it is recommended that an adaptive management approach be utilised in which appropriate management options are assessed against the modelled predictions and calculated risk. Provision can then be made to include these management options in the development and closure stage with options to scale back or scale up depending on actual need.

Measures to reduce the acidity load and hence change the predicted pit water chemistry could include:

- Minimisation of acid rock drainage contribution to the lake (e.g. pit wall passivation, lining, diversion of runoff away from exposed PAF etc.)
- Modifying lake inflows by introducing alkalinity into pit lake inputs (i.e. limestone spreading on pit walls)
- Increasing alkalinity within the pit lake to buffer against on-going acidity contribution via active treatment (i.e. limestone dosing system).
- Backfilling of the pits to reduce exposure of pit walls.
- Backfilling of the pits to above the simulated pit lake water levels to prevent pit lakes from forming

9. Monitoring recommendations

9.1 Groundwater and surface water monitoring

Any management measures should be supported by a surface water and groundwater monitoring program, including water levels and quality during the operational phase, to support the ongoing understanding of risk and as inputs to update any predictive modelling requirements (e.g. closure).

Monitoring should focus on monitoring the groundwater and in-pit water quality in strategic locations to identify potential risks to groundwater both beneath and down hydraulic gradient of the site during operations and post mining.

An outline of the recommended monitoring, which aligns with the previous assessment as reported in SKM, 2014 is summarised in Table 9-1.

There should be a particular focus on water level (as well as water quality) in order to confirm the groundwater modelling and understanding of groundwater recharge as undertaken. This will also confirm the impact of the waste dumps (if any) which are currently not considered in relation to providing an impact (in terms of leachate) to the surrounding groundwater and/or final pit lakes which are expected to function as groundwater sinks.

The baseline monitoring program currently run by Atlas Iron should be continued and expanded to meet Department of Water and Environmental Regulation guidelines and expectations. This also includes the formulation and enhancement of a Groundwater Licence Operation Strategy.

The monitoring program should include regular measurements of groundwater levels. It is recommended that during initial two years of operations the water levels should be monitored monthly, with a potential to decrease the monitoring frequency to quarterly for the majority or selected monitoring locations. It is recommended that pH and EC be measured at the same time.

It would be advantageous to equip some of the monitoring locations with loggers, in particular those that are remote and/or require a more detailed understanding of water level changes in response to rainfall events, dewatering or excess water disposal.

Table 9-1 Recommended groundwater monitoring schedule and analysis (adopted from SKM 2014)

Monitoring Category Monitoring	Monitoring Parameters	Frequency	Targeted Wells
		Pre-Mining	
Groundwater Levels	Groundwater level (as m bgl and m AHD)	Quarterly	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
Groundwater Quality	pH, EC, alkalinity, metals suite[1], major ions[2], chloride	Quarterly (and upon monitoring well installation is required)	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
		During Mining	
Groundwater Levels	Groundwater level (as m bgl and m AHD)	Monthly	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
Groundwater Quality	pH, EC, alkalinity	Monthly	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
	pH, EC, alkalinity, metals suite[1], major ions[2], chloride	Annual	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
		Post Mining	
Groundwater Levels	groundwater level (as m bgl and m AHD)	annually for first 5 years, then 2-yearly for the next 6 years okay	Wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
Groundwater Quality	pH, EC, alkalinity	annually for first 5 years, then 2-yearly for the next 6 years okay	Pit lake and wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)
	pH, EC, alkalinity, metals suite[1], major ions[2], chloride	annually for first 5 years, then 2-yearly for the next 6 years okay	Pit lake and wells targeting areas around pits and down hydraulic gradient of other potential contaminant sources (e.g. waste rock dumps)

Note 1: Metal suite comprises aluminium, antimony, arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, phosphorous, selenium, silicon, silver, strontium, thallium, tin, uranium, vanadium, zinc

Note 2: Major ions suite comprises sodium, magnesium, potassium, calcium, chloride, sulphate, ferric/ferrous iron

10. Conclusion and recommendations

Geochemical modelling was updated to reflect updates to the water balance, groundwater modelling, refined pit shale and calculated exposure areas, additional ABA data, and groundwater quality data.

The Avon Pit lake water quality is predicted to be acidic in the long term with an increase in the concentration of TDS over time, which is dominated by sulphate. The Murray Pit lake water quality is predicted to be neutral and less acidic (compared to the Avon Pit lake) post closure with a lower proportion of PAF runoff relative to other pit lake inputs. Modelling suggests there is some potential for the Murray Pit lake to remain acidic in the long term, however it is considered that based on the conservative nature of the modelling undertaken, this scenario is regarded as unlikely.

As ultimately the pits are predicted to be terminal sinks to groundwater, the risk of pit lake water quality to the regional groundwater is considered to be low based on the current groundwater assessment. The findings of the updated geochemical modelling in relation to pit quality and risks to environmental receptors are considered to align with the 2014 SKM geochemical assessment.

The range of modelled results represents a high degree of uncertainty involved in the prediction of pit lake water quality and this is accentuated by predictions far into the future (10+ years in pit lake evolution). The volume of acidity and associated trace element leaching is potentially one of the largest uncertainties when estimating the ultimate pit lake water quality.

Further refinement of the modelled pit wall acidity load (via surface runoff) could focus on additional characterisation of the identified pit wall shale material by targeted sampling and characterisation analysis (ABA and trace element analysis). This data can then be compared to the samples utilised in the kinetic testing with sulphate oxidation rates adjusted to better reflect specific pit wall characteristics. This could be carried out in conjunction with pit wall wash testing during pit development phase with representative runoff collected and analysed to confirm likely runoff water quality and actual oxidation rates.

Specific recommendations relating to managing acidic inflows will depend on the risk (and perceived risk) to the surrounding environment and acceptable pit lake water quality by relevant stakeholders. If required, potential management could consist of a combination of efforts to minimise acidity load, modify inflows or modify the pit lake water levels and quality.

Groundwater monitoring as outlined by SKM (2014) and recommended by H3 hydrogeological report and Groundwater Licence Operating Strategy (GHD, 2020a) will provide a basis to confirm, and update where necessary, the findings of groundwater and geochemical modelling and to improve the current estimates on the ultimate fate of the pit lakes as groundwater sinks.

11. References

AECOM (2013a) McPhee Creek Iron Ore Project, Phase 2 Groundwater Investigation, 20 May 2013

AECOM (2013b) McPhee Creek Floodplain Mapping Report, 3 September 2013

Bagas, L. (2005) Geology of the Nullagine 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 33p. Perth: Geological Survey of Western Australia, 2005. ISSN 1321–229X.

Campbell & Associates (2013) McPhee Creek Project: Kinetic testing of hale-waste-bedrock samples to assess acid-generation dynamics and metal-solubility behaviour. 9th July 2013.

Castendyk and Webster-Brown 2006. Geochemical prediction and remediation options for the proposed Martha Mine Pit Lake, New Zealand.

Garvie, A; Chapman, J; Linklater, C.M; Green, R. 2014. Oxidation and solute accumulation in pit wall rock: Limiting changed to pit lake water quality.

GHD (2021a) McPhee Creek Iron Ore Project – Water Management Studies, H3 Hydrogeology Report. October 2021

GHD (2021b) McPhee Creek Iron Ore Project – Water Management Studies, Water Balance Assessment. October 2021

MWH (2012) McPhee Creek Excess Mine Water Disposal Options, 3 August 2012

SKM (2014) McPhee Creek AMD Investigation. Summary Report. Rev 2. May 2014.

Warner and Potter (2012). An Updated Stratigraphy for the McPhee Creek Iron Ore Deposit

Appendices

Appendix A - AMD laboratory testing results

Appendix B – Laboratory certificates of analysis

GHD

Level 10
999 Hay Street
T: 61 8 6222 8222   F: 61 8 9463 6012   E: permail@ghd.com

12520160-93561-38/C:\A_GHD Projects\McPhee Creek\PFS\Revised Mine Plan\Report Finalization\2021 Reports_Final\Pit Lake WQ\12548901-REP_ McPhee_ Ck_ Pit_Lake_Review_06102021_Final.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	T Mulliner C Hillman	P Hamer E Young		E Young		30/10/2020
Final	T Mulliner C Hillman	P Hamer B Wijers		B Wijers		6/10/2021

www.ghd.com