

Internal Memo

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Greater Paraburdoo AMD and geochemical risk assessment summary to support the 2020 Greater Paraburdoo Iron Ore Hub Proposal Environmental Review Document

Context

A review of the acid and metalliferous drainage (AMD) risks associated with Paraburdoo, Eastern Range and Western Range have been completed to support the 2019 updates to the respective closure plans. Collectively, these areas form part of the Greater Paraburdoo Iron Ore Hub, where Paraburdoo and Eastern Range are existing operations, and Western Range is currently undeveloped. The summary provided in this memorandum supports the *Greater Paraburdoo Iron Ore Hub Proposal Assessment - Environmental Review Document* [RTIO, 2019a], specifically addressing the following required work item numbers as referenced in RTIO [2019a]:

Work Item No. 47: Characterise the geochemical and physical properties of waste rock and waste fines to allow an assessment of the potential risk from waste rock dumps and waste fines storage facilities.

Work Item No. 48: Analyse, discuss and assess potential groundwater and surface water impacts (direct and indirect). The analysis should include [the] presence of potentially acid forming (PAF) materials and risks associated with AMD.

The review of AMD risks considers drillhole and mine planning data, supplemented by geochemical test data, to assess the risks relating to mining in each area. The AMD risk rankings for each area are provided in Table 1, which have been summarised from the closure plans [RTIO, 2019b; RTIO, 2019c; and RTIO, 2019d].

The development of the 4EE deposit involves the mining of PAF material, while waste materials associated with Eastern Range and Western Range are considered low risk with respect to generating AMD. The *Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* [RTIO, 2018a], and the *Iron Ore (WA) Spontaneous Combustion and ARD (SCARD) Management Plan for Operations* [RTIO, 2018b] are

implemented to ensure waste material is adequately geochemically characterised, and that all PAF material is appropriately managed.

Waste fines will continue to be sent to the existing Paraburdoo waste fines storage facility (WFSF), and an opportunity to utilise the existing 4W pit void as an in-pit WFSF is also being investigated. Waste fines are considered chemically inert, however, a saline plume associated with groundwater mounding beneath the currently active Paraburdoo WFSF has been identified. The potential for water quality impacts resulting from the placement of waste fines into the 4W pit has also been undertaken [ERM, 2019] using chloride and salinity as a proxy for other potential parameters; results suggest some migration of solutes towards Pirraburdu Creek may occur.

During operations, it is understood that seepage from the Paraburdoo WFSF and the 4W WFSF (if utilised) would be confined to the cone of depression generated by mine dewatering as indicated in *H3 Detailed Hydrogeological Assessment, Paraburdoo 4-East Extension* [RTIO, 2018c]. An extensive groundwater monitoring network is in place, which considers groundwater quality as well as the spatial extent of the cone of depression. Monitoring data for the 4E and 4W areas are currently collected based on the *Paraburdoo Operations Groundwater Monitoring Strategy* [RTIO, 2016a], and proposed monitoring bores within Seven Mile Creek and to the south of the 4E pit will further refine understanding of groundwater behavior in those areas. The proposed water strategy includes the monitoring of salinity changes over time to further understand groundwater recharge process (and allow for monitoring of seepage impacts from the WFSFs during operations as well as upon closure). Due to the complexity of the hydrogeological and hydrological environment, the conceptualisation and numerical models will be revisited annually to assess performance.

Order of magnitude studies have been conducted to assess the amount and effects of seepage and optimize tailings deposition methods. Seepage from the 4W in-pit WFSF is expected to decline in time and PFS studies are currently underway.

This memorandum presents an overview of geochemical test data to support the AMD risk rankings assigned to each mining area. The focus is on the assessment of AMD risks associated with waste rock exposure and waste fines disposal, pit wall exposures of PAF material, as well as potential impacts resulting from the dewatering of PAF material.

Table 1: AMD risk ratings– summary of findings from AMD risk assessments.

Mining Area	Pit Domain	AMD risk ranking
Paraburdoo	5W, 11W, 14-16W, 20W, 27W, 18E, NLC	Low
	4W	Low-Moderate
	4EE (includes 4E)	High
Eastern Range	23E, 24E, 32E, 37E, 42E, 42EE, 47E	Low
Western Range	36W-50W, 55W-66W	Low

Background Information

The risk assessment process utilised is outlined in *Geochemical Risk Assessment Process for Rio Tinto's Pilbara Iron Ore Mines* [Green and Borden, 2011]. A risk-based approach is used to identify those rock types which require specific management to mitigate the impacts associated with AMD. In terms of the assessment of AMD risk, Rio Tinto's approach of making informed decisions to proactively manage chemically reactive mineral waste (e.g., black shale in waste dumps and exposed on pit walls) is further detailed in Green *et al.*, [2018]. The strategies outlined in this paper supported Rio Tinto's Iron Ore Pilbara Operations as a recipient of INAP's *International ARD Best Practice Award* in recognition of best practice in the identification, planning and management of potentially reactive materials at a mining site.

It is recognised that AMD includes *acidic drainage* (elevated concentrations of metals at low-pH), *neutral metalliferous drainage* (elevated concentrations of metals at near-neutral to alkaline pH) and *saline drainage* (generally low concentrations of metals, but moderate concentrations of sulfate, magnesium and calcium, at neutral to alkaline pH) [INAP, 2009; DIIS, 2016]. With the presence of potentially acid forming (PAF) rock types associated with sulfide or some sulfate minerals, it is understood that neutral metalliferous drainage requires, at a minimum, low-pH conditions on a microscopic scale as a mechanism to initially solubilise contaminants. If the PAF rock also has sufficient acid neutralising capacity (ANC), the acid generated is neutralised. However, as a result of this reaction, concentrations of some contaminants (e.g., As, Cd, Mn, Ni, Sb, Se and Zn) do not precipitate at near-neutral pH, and remain in solution, resulting in poor-quality drainage [DIIS, 2016]. An analysis of total sulfur in mineral waste will help infer the likelihood for the rock type to generate acidity which may lead to poor quality drainage characterised by either low-pH or near-neutral pH.

Rio Tinto has undertaken an extensive program of geochemical testing over several years to understand the potential for AMD to occur as a result of exposing various waste rock types common to Pilbara mining operations. The geochemical characterisation process considers sulfur content and elemental abundance as an indicator of acidic and neutral metalliferous drainage potential, and is supported by static (acid base accounting) and, if appropriate, kinetic testing of target materials. It is understood that poor quality drainage may also result from low-sulfur waste rock containing compounds that do not require acidic conditions to maintain elevated concentrations of parameters of concern. For instance, the dissolution of readily soluble salts may mobilise minor and trace elements into pore water that may then be transported into the surrounding environment via surficial or internal drainage. This risk is assessed by considering elemental data collected during routine and extra analysis of drillhole samples, and the results derived from a phased and risk-based approach involving the selection of fit-for-purpose leach extract tests (e.g., Green *et al.*, [2019]). General methodologies used by laboratories to undertake geochemical test work are attached in Appendix A.

The results of geochemical test work and interpretation are applied to the geological and mining models to ensure materials posing potential geochemical risks are identified prior to mining and managed appropriately. This work is in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* [RTIO, 2018a] and the *Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan* [RTIO, 2018b].

The most significant geochemical risk posed by mining iron ore deposits in the Pilbara is associated with the sulfide mineral pyrite, which can form sulfuric acid when exposed to

oxygen and water. The unoxidised (black) Mount McRae Shale is most commonly associated with pyrite and AMD, however, pyrite can also occur within other stratigraphies, including black shale in the Mount Sylvia Formation (MTS) as well as in the Wittenoom Formation (WF). Black shale in the MCS has been exposed historically at Paraburdoo (in the 4E and 4W pits), and is expected to be exposed further during mining of the proposed 4EE deposit.

Sulfate minerals such as alunite and jarosite can also cause a geochemical risk, albeit the risk of this “elevated-sulfur” material is lower due to do self-limiting chemical processes. While black shale is not expected to be exposed during mining at Eastern Range or Western Range, the presence of elevated-sulfur material is indicated by drillhole data within both those areas.

The assessment of elevated-sulfur material is inherently conservative because of the assumption that all sulfur is present as alunite ($KAl_3(SO_4)_2(OH)_6$), where sulfur is likely also derived from other non-acid forming minerals such as gypsum ($CaSO_4$). The acidity potential of elevated-sulfur waste rock expected to be mined from Eastern Range and Western Range was found to be negligible compared to the neutralising capacity of co-disposed waste rock. On-going geochemical test work is required to validate this assessment; further test work will be completed during the feasibility study, as well as during operations. The aim of this test work is to assess the potential for neutral mine drainage, and also to confirm that potential low levels of acid release from elevated-sulfur waste rock will be effectively buffered by the inherent neutralising capacity of the expected surrounding inert waste rock.

Total Sulfur Analysis of Drillhole Samples

The deposits within the Greater Paraburdoo Iron Ore Hub contain bedrock formations from the Fortescue Group, Hamersley group and the Wyloo Group. Iron ore mineralisation occurs mainly in the Dales Gorge Member (DG) and the Joffre Member (JOF) of the Brockman Iron Formation, but also occurs in the Marra Mamba Iron Formation in some pits at Paraburdoo.

Waste rock may include the overlying detritals (DET), dolerite dykes and sills (DOR), and waste-grade banded iron formation (BIF) and shale associated with the Brockman Iron Formation and the Marra Mamba Iron Formation. Adjacent stratigraphies include the Wyloo Group (WYL), Weeli Wolli Iron Formation (WW), Yandicoogina Shale (YS), Mount McRae Shale (MCS), Mount Sylvia Formation (MTS), Wittenoom Formation (WF) and Fortescue Group (FOR), where associated rock types include BIF, shale, dolerite and dolomite.

A sulfur cut-off value of 0.1% is generally relevant to waste rock types associated with the Greater Paraburdoo iron ore deposits. In addition, material associated with elevated-sulfur in the form of sulfate (where sulfur values may range from 0.1% to greater than 1%) is also considered to be potentially acid forming in a low capacity.

The analysis of total sulfur content in drillhole data was undertaken to help identify the rock types which require further investigation relating to AMD risk. The risk is assessed by considering the relative percentage of drillhole samples with total sulfur content greater than 0.1% against the total number of samples measured for total sulfur. This task was completed for all mining area drillhole samples, with a focus on waste drillhole samples. Results are summarised in Table 2, and documented in further detail in RTIO [2019b], RTIO [2019c] and RTIO [2019d].

Table 2: Summary of waste drillhole sulfur analysis (reporting relative percentage of all waste drillhole samples assayed for total sulfur).

Mining area	Pit area	Approx. no. of samples	Rel.% with S>0.1%	Rock types associated with PAF material and management strategy
Paraburdoo	4E (4EE)	67,600	5%	Black shale in MCS, MTS, WF (estimated 14 Mt); encapsulation in waste dumps in accordance with <i>Iron Ore (WA) SCARD Management Plan</i> ; ongoing refinement of 4EE water balance and geochemical pit lake model in relation to PAF pit wall exposures.
	4W	11,300	5%	Black shale in MCS; encapsulation in waste dumps in accordance with <i>Iron Ore (WA) SCARD Management Plan</i> ; backfill strategy to encapsulate current PAF pit wall exposures.
	NLC	8,000	5%	Black shale in MCS and WF underlies pit shell designed to avoid exposure.
	11W	7,700	2%	Black shale in MCS underlies pit shell designed to avoid exposure.
	18E	7,700	6%	Black MCS and sulfidic NAM BIF have not been exposed during mining.
	5W	1,500	5%	Potentially sulfidic FOR has not been exposed during mining.
Eastern Range	14-16W, 20W, 27W	7,800	3%	Black shale in MCS underlies pit shells designed to avoid exposure.
	23E, 24E	55,600	3%	Elevated-sulfur samples associated with DOR and WS waste - ongoing testing to confirm low AMD risk.
	32E			Black MCS underlies pit shell designed to avoid exposure; elevated-sulfur samples associated with WS waste - ongoing testing to confirm low AMD risk.
	37E, 42E			Elevated-sulfur samples associated with WS waste.
42EE, 47E	None.			
Western Range	36W-50W, 55W-66W	44,000	3%	Black shale in MCS underlies pit shell designed to avoid exposure; elevated-sulfur samples associated with oxidised MCS and DOR - ongoing testing to confirm low AMD risk.

Geochemical Analysis of Samples – Standard Tests

Understanding the geochemistry of waste materials can assist with more environmentally sound waste management. Within the Greater Paraburdoo area, drillhole samples have been regularly analysed for the major chemical element suite of Al, Ca, Fe, K, Mg, Mn, P, S, Si, and Ti. Many samples have also been tested for the minor chemical suite of As, Ba, Cl, Co, Cr, Cu, Na, Ni, Pb, Sn, Sr, V, Zn and Zr.

The extent of enrichment of a drillhole sample can be reported as the Global Abundance Index (GAI), which relates the actual concentration with average crustal abundance on an

adjusted log 2 scale [Bowen, 1979]. The GAI is typically expressed in integer increments where a GAI of zero indicates the element is present at a concentration similar to, or less than, the average crustal abundance, and a GAI of 6 indicates approximately a 100-fold enrichment above the average crustal abundance. The main purpose of the GAI is to provide an indication of elemental enrichment that may be of environmental importance. As a general rule, a GAI of 3 or greater signifies enrichment that warrants further examination, while a GAI of 1 or 2 indicates the element may be elevated.

Drillhole data from the Greater Paraburdoo area were assessed to determine the geochemical characteristics of rock types likely to be exposed during operations and upon closure. The results of the detailed assessment have been summarised in RTIO [2019b], RTIO [2019c] and RTIO [2019d], and indicate most rock types are enriched in iron, correlating with the iron mineralisation, and enriched/elevated in arsenic and tin. In addition, the following elements have been identified as being enriched or elevated in some samples tested: Cl, Co, Cr, Cu, Mn, Ni, Pb, S, V and Zn. In particular, the following rock types may be associated with elevated-sulfur: DOR, WS and oxidised MCS, as well as black shale in MCS, MTS and WF (as expected).

It should be noted that whilst concentrations of some elements (e.g., As and Sn) may be enriched, these elements will not necessarily mobilise into groundwater. Arsenic is commonly enriched in ore and waste for many Hamersley Group deposits, and iron oxy-hydroxide minerals such as hematite and magnetite have high sorption capacities for arsenic. Tin, likely to be in its oxidised form, is unlikely to solubilise under the near-neutral conditions expected. In any case, it is important to understand potential long-term contaminant release under a variety of conditions (i.e., associated with acidic, neutral or saline drainage), and subsequent geochemical testing of samples is undertaken to investigate the potential for contaminant release from all rock types.

Geochemical Analysis of Samples – Supplemental Tests

In addition to the standard chemical suite, select samples have also been tested for Ag, B, Be, Cd, F, Hg, Mo, N, Sb, Se, Th and U. As part of this supplemental test work, liquid extract tests are conducted by mixing solid samples thoroughly with deionised water. The sample liquor generated by this process is filtered and analysed for the full suite of water quality data including: pH, electrical conductivity (EC), Ag, Al, As, B, Ba, Ca, Cd, Cl, Co, Cr, Cu, F, Fe, HCO₃, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, SO₄, U and Zn.

To date (March 2020), up to 342 samples representing a variety of rock types from the Greater Paraburdoo area have undergone this supplemental testing, where results have been summarised according to rock type in Appendix B. Some wasterock types (e.g., DET, YS, FWZ, MCS, MTS, WF, where MCS, MTS and WF samples include black shale) may be considered enriched in Hg, Sb and Se. Liquid extract tests indicate these elements would not be readily leached when the (non-pyritic) samples were contacted with deionised water, and the final pH in the leach extracts for those samples was generally measured near neutral. Leachate concentrations of Al, Cd, Co, Cu, Ni and Se were relatively higher for black MCS samples, which is expected.

Geochemical Analysis of Samples – Acid Base Accounting

The static acid base accounting (ABA) tests evaluate the balance between acid generation processes and acid neutralising processes. The acid generation potential depends on the oxidation of sulfide (and in some cases sulfate) minerals while the neutralising capacity of the sample depends on the presence of carbonate or silicate minerals.

Samples are typically assessed for total sulfur content via the LECO method. The maximum potential acidity (MPA) for a sample is determined by considering the total sulfur content and conservatively assumes that all of the measured sulfur is fully oxidised to generate sulfuric acid. As previously discussed, sulfur may be in the form of the sulfate mineral alunite, and the form of sulfur is typically investigated. It was found that routine ABA tests such as the hydrochloric acid (HCl) digest may under-estimate the sulfate-sulfur content of samples when alunite or jarosite are present, as these minerals do not dissolve in the digest, and that chromium-reducible sulfur (CRS) test results should be considered to confirm the sulfide-sulfur content of the sample [e.g. see Linklater *et al.*, 2012].

Acid formed by the oxidation of sulfide minerals (or the dissolution of sulfate minerals) will to some extent react with acid neutralising minerals (e.g. carbonates and aluminosilicates) present in the sample; the measured inherent acid neutralising capacity (ANC) of the sample considered relative to the calculated MPA of the sample will provide an indication of the potential for the sample to generate acidity. If available, the total inorganic carbon content, as well as the results of the acid buffering characteristic curve (ABCC) test, should be considered to refine the understanding of whether the measured ANC is readily available in the sample.

The net acid producing potential (NAPP) is a calculation ($NAPP = MPA - ANC$) considered to indicate whether material has the potential to generate acid. A positive NAPP indicates the sample may be acid generating, while a negative NAPP indicates that the sample may have sufficient neutralising capacity to prevent acid generation. It should be noted that this calculation assumes that all sulfur is conservatively fully oxidised to generate sulfuric acid, and also assumes that all neutralising capacity is readily available, and this is not necessarily the case for all material.

The net acid generation (NAG) test results are considered in association with the NAPP calculations to classify the acid generating potential of samples. During the NAG tests, acid generation and neutralisation can occur simultaneously, resulting in a direct measurement of the net amount of acid generated by the samples.

The acid forming potential of a sample is classified on the basis of total sulfur (i.e. calculated MPA values), measured ANC values, the resulting calculated NAPP values and the measured results of the NAG test [AMIRA, 2002]. Non-acid forming samples (NAF) are considered unlikely to be a source of acid drainage. A sample classified as potentially acid forming (PAF) will likely generate acid drainage when exposed to oxidising conditions. Those PAF samples with measured low acidities are considered to be potentially acid forming in a low capacity (PAF-LC).

The measured ANC can also be used with the sample's MPA to derive the neutralisation potential ratio (NPR), where $NPR = ANC/MPA$. This ratio provides an indication of the relative margin of safety with regards to net acid generation (or lack thereof) within a material [AMIRA, 2002]. In general, an NPR greater than 2 signifies that there is a likely likelihood that the bulk material in waste dumps will remain near-neutral in pH.

To date (March 2020), 340 samples representing a variety of rock types from the Greater Paraburdoo area have undergone ABA test work, where results have been summarised according to rock type in Appendix B. Considering the NPR method, most samples would be classified as non-acid forming based on the low sulfur content and excess neutralising capacity, and also taking into account the conservative assumption that sulfur is present as pyrite, which is not the case for clearly oxidised samples. The collection of ANC data, in

particular, supports the knowledge base used to assess the inherent neutralising capacity for various rock types used to encapsulate PAF material in waste dumps.

Geochemical Analysis of Samples – Kinetic Column Leach Tests

In addition to completing static ABA testing for Greater Paraburdoo samples, testing has also been completed on analogous material from the Turee Syncline area. A total of 66 drillhole samples representing five rock types (JOF, WS, DG, FWZ, black MCS) were tested. A supplemental phase of testing involved two of these 66 samples (representing the FWZ and MCS rock types) which underwent kinetic column leach testing. Details of this test work and analysis are provided in the following reports:

- *Geochemical Characterisation of Material from Turee Syncline* [SRK, 2013]; and
- *Geochemical Characterisation of Material from Turee Syncline - Long Term Kinetic Leach Testing* [SRK, 2014].

Results indicated the samples are enriched or elevated in major elements Fe, Mn and S where minor elements As, Au, B, Bi, Cr, Hg, Sb, Se, Tl may also be enriched in some rock types. Whilst static leach extractions cannot determine potential full-scale outcomes, the short-term leach test results suggest that none of these elements would be readily leached at neutral pH [SRK, 2013].

Kinetic leach tests were carried out on two samples: one from MCS and one FWZ sample. Both of these samples are classified as PAF, containing total sulfur contents of 9.8% (MCS) and 2.7% (FWZ). Both samples generated strongly acidic solutions which remained relatively constant over the test duration, favouring dissolution of minor/trace elements. The black MCS sample gave rise to the highest solute release rates with Ag, As, Ba, Bi, Cd, Fe, Mn, Mo, Pb, Sb, Sn, Sr, Ti, Tl, and Zn released at more than twice the rate than from the FWZ sample.

Geochemical Analysis of Tailings Samples

To-date (March 2020), geochemical test work was also carried out on up to nine tailings samples from the Paraburdoo area, where results are summarised in Appendix B and provided in the following reports:

- *Paraburdoo Mine Operational Tailings Sample Testing 2017* [Knight Piesold, 2017];
- *Further Geochemical Analysis of Elevated-sulfur Tailings Samples – Paraburdoo* [RTIO, 2016];
- *Geochemical Assessment of Tailings from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J* [EGi, 2014]; and
- *Paraburdoo Geochemical Characterisation and ARD Assessment of Fine Tailings from Paraburdoo* [EGi, 2007].

Results indicate the samples are non-acid forming. While individual samples may be considered enriched in As, Fe, Mn, Sb and Se relative to the average crustal abundance, average values calculated from all samples indicate relatively lower concentrations (see Appendix B). Static leach tests were undertaken using deionised water and saline solution, where results indicate little difference between the two extractions, where relatively higher concentrations of Ca, K, Mg and Sr were measured with increasing salinity, while the concentrations of Al and Fe were lower in the saline extracts compared to the deionised

water [EGi, 2014]. In general, the results indicate tailings, as represented by the samples provided, are unlikely to result in low pH conditions or metals leaching under oxidising conditions [e.g., EGi, 2014; EGi, 2007], however, As, Se and Sr were considered to be slightly soluble in surface samples relative to concentrations found for samples collected from depth [EGi, 2007]. In general, concentrations of constituents of potential concern are low in the leachate based on average values calculated from all samples tested (see Appendix B).

Metallurgical tailings samples associated with 4EE and Western Range will also be tested in 2020. Ongoing characterisation of future generated tailings will be undertaken in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* [RTIO, 2018a], where results will be considered in model updates associated with WFSF salinity plume assessments.

Assessment of Pit Wall Exposures to Support Pit Lake Modelling at 4EE

Mining of the 4EE pit will result in the exposure of PAF material (i.e., sulfidic black shale) located on the north wall. Based on the predicted post-closure groundwater level, PAF material will remain exposed on the pit wall above a permanent pit lake.

A model of the water balance and water quality has been undertaken [SRK, 2018] which considered the results of site-specific geochemical test data as inputs into the model. Pit wall exposure modelling was completed to inform on the relative proportions of rock types expected to be exposed on the 4EE pit shell upon closure. Results of the modelling indicate the formation of a pit lake approximately 200 m deep. Water quality modelling indicates a circum-neutral pit lake which is predicted to be a terminal sink (i.e., the stable pit lake level is lower than the pre-mining water level and therefore groundwater flows are continually towards the pit lake). As a result, the influence of evapoconcentration is predicted to generate high concentrations of TDS and analytes such as Na, Cl, Mg and SO₄ by the end of the 1000-year model. As a terminal sink, water is expected to be confined to the immediate proximity of the pit rather than forming a plume with the potential to impact downstream groundwater.

Assessment of Potential Impacts from Dewatering PAF Material

With regards to dewatering PAF material, Rio Tinto has assessed the AMD risks related to the development of unsaturated areas of PAF material during dewatering activities. It is understood that the oxidation of this material may depend on a number of factors including the degree of de-saturation which would occur depending on the characteristics of this material, as well as the duration for which the groundwater table remains lowered. At Paraburdoo, pyritic black shale is associated with fresh basement material (i.e., MCS, MTS, WF) with a low hydraulic conductivity (i.e., the porosity of the matrix is considered to be extremely low, and relatively higher within fractures); this indicates the rate of oxygen transport (likely via diffusion) from the pit wall to the underlying PAF material will be low. Further information on the AMD risk related to dewatering of PAF materials is presented in Garvie *et al.*, [2014].

The *Paraburdoo Operations Groundwater Operation Strategy (GWOS)* [RTIO, 2016] covers management of abstraction with the aim that the water quality does not deteriorate below its beneficial end use. The current objective of the 4W and 4E dewatering borefield is to locally deplete the orebody aquifer; however, for mining in the 4EE pit, abstraction will reduce groundwater levels in the adjacent WF aquifer [RTIO, 2018c], therefore an update to the GWOS would include water quality monitoring strategies and contingency plans to

address potential risks related to dewatering PAF material which may be present in the MCS/MTS/WF geological units.

Recommended Further Work

It is recommended that further work be undertaken to address gaps in the current knowledge base, including:

- Review the 4EE water balance and geochemical pit lake model to predict how the pit lake and its water quality will evolve over time, and refine the inputs, outputs and reactions that occur in a pit lake.
- To support the ongoing review of the pit lake model, review additional resource/hydrogeological drilling data as they become available for the 4EE pit to refine the understanding of PAF material geochemistry (via column leach tests) and modelled exposures/volumes expected.
- Characterise the geology underlying the locations of PAF waste dumps to refine the assessment of transport pathways and receiving environments which may be impacted by AMD.
- It has been demonstrated that the acidity potential of elevated-sulfur (sulfate) waste material present at Eastern Range and Western Range is negligible compared to the neutralising capacity of co-disposed waste rock; on-going geochemical test work is required to validate this assessment with the aim to assess the potential for neutral mine drainage, and also to confirm that potential low levels of acid release from elevated-sulfur waste rock will be effectively buffered by the inherent neutralising capacity of the expected surrounding inert waste rock.

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Appendix A – Summary of Geochemical Test Work Methodologies

RTIO-PDE-0174239 - Methodologies used for geochemical test work:

<http://iodms/iodms/drl/objectId/090188a380bd490e>

(memo attached)

Appendix B – Summary of Geochemical Test Work Results

Table C-1: Summary static ABA data for Greater Paraburdoo samples. ^a

Rock type	Sample Count ^b	Average of EC (µS/cm)	Average of pH (pH units)	Average of ANC (kgH ₂ SO ₄ /t)
ALL+DET	19	*3,029	*7.34	180
DOR	22	139	8.24	19
WW	12	*1,069	*7.35	3.8
YS(+WYL)	4	*2,493	*7.24	8.8
JOF	16	*987	*6.80	1.9
WS	8	*1,802	*6.67	2.5
DG	20	612	5.87	8.40
FWZ	9	*368	*7.18	1.9
MCS-OX	53	616	6.98	5
MCS-BK	112	916	6.07	19
MTS	21	634	7.37	49
WF	15	500	5.80	10
MM	2	*1,631	*7	2.5
FOR	5	*528	*7.48	9.8
TAILINGS	22	2,487	7.8	3

^a data compiled from RTIO geochemical database *Database_Leach_200224*.

^b sample count considers those samples that have been measured for ANC.

* Indicates the value has been measured from the leachate during the liquid extract test.

Table C-2: Summary of extra elemental concentrations (average values) relative to the average crustal abundance for Greater Paraburdoo samples. ^{a, b, c}

Rock Type	Count	Ag (ppm)	B (ppm)	Be (ppm)	Cd (ppm)	F (ppm)	Hg (ppm)	Mo (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)
DET	8	0.21	36.00	0.77	0.10	130.00	0.67	1.40	3.66	0.54	3.66	2.16
DOR	24	0.05	15.35	1.16	0.07	248.95	0.02	0.44	1.55	0.38	1.77	1.54
WW	14	0.05	12.36	0.78	0.04	113.50	0.06	0.81	1.57	0.10	2.29	2.19
YS(+WYL)	8	0.04	18.88	1.15	0.05	125.75	1.41	1.49	3.32	1.04	6.75	3.75
JOF	54	0.05	18.60	1.05	0.06	58.00	0.02	0.58	1.47	0.10	2.15	1.16
WS	29	0.07	23.08	1.85	0.07	117.33	0.03	2.26	1.82	0.44	7.00	2.77
DG	51	0.08	17.71	1.20	0.08	64.21	0.04	1.30	1.12	0.82	2.86	1.38
FWZ	10	0.04	13.00	0.68	0.02	50.30	0.03	1.64	0.75	0.09	1.00	0.96
MCS-OX	39	0.22	48.08	1.66	0.10	945.97	0.08	5.39	3.84	1.49	7.35	3.21
MCS-BK	33	0.42	68.41	1.71	0.16	1088.18	0.63	6.53	6.25	3.34	9.65	4.31
MTS	13	0.13	31.69	1.07	0.09	389.46	0.11	3.64	3.53	1.48	6.17	1.92
WF	14	0.11	23.00	1.29	0.08	313.00	0.10	1.34	3.43	2.55	8.18	2.88
MM	29	0.11	16.21	0.84	0.13	61.07	0.16	0.94	1.31	0.13	1.82	0.94
FOR	5	0.06	10.00	1.71	0.22	170.80	0.06	0.51	0.33	0.07	1.76	1.40
DUMP	2	0.05	10.00	1.75	0.10	50.00	0.01	0.25	1.20	0.25	2.50	1.25
TAILINGS	9	0.07	50.00	2.09	0.05	117.50	0.03	1.06	1.99	0.49	4.35	2.66

^a data compiled from RTIO geochemical database *Database_Leach_200224*.

^b highlighted cells represent enriched concentrations relative to the average crustal abundance [Bowen, 1979].

^c values measured less than the limit of detection have been included in the calculations as half the limit of detection.

Table C-3: Summary of static leach data for Greater Paraburdoo samples, indicating average concentrations in leachate. ^{a, b}

Rock Type	Sample Count	pH (pH unit)	Al (mg/L)	As (mg/L)	B (mg/L)	Cd (mg/L)	Co (mg/L)
DET+ALL	7	7.34	0.59	0.005	0.33	0.0002	0.01
DOR	24	7.32	0.07	0.001	0.24	0.0004	0.002
WW	14	7.35	0.04	0.001	0.26	0.0002	0.001
YS(+WYL)	8	7.24	0.01	0.002	0.32	0.0002	0.003
JOF	54	6.80	0.03	0.002	0.12	0.001	0.003
WS	29	6.67	0.02	0.002	0.14	0.0004	0.004
DG	48	6.96	0.08	0.003	0.16	0.0001	0.02
FWZ	10	7.18	0.01	0.001	0.13	0.0002	0.001
MCS-OX	35	6.89	0.07	0.01	0.32	0.01	0.01
MCS-BK	33	4.98	59.94	0.06	0.40	0.03	2.46
MTS	13	7.23	5.00	0.01	0.28	0.01	0.54
WF	12	6.84	0.78	0.01	0.16	0.0002	0.36
MM	29	7.11	0.12	0.003	0.16	0.0001	0.005
FOR	5	7.48	0.01	0.0001	0.18	0.0003	0.0001
Dump	2	7.00	0.06	0.003	0.08	0.0001	0.01
TAILINGS	7	7.59	0.03	0.003	0.17	0.0001	0.001

Rock Type	Sample Count	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Mn (mg/L)	Mo (mg/L)
DET+ALL	7	0.01	0.005	0.28	0.0007	0.01	0.004
DOR	24	0.004	0.005	0.23	0.0002	0.81	0.01
WW	14	0.004	0.005	0.07	0.0001	0.18	0.003
YS(+WYL)	8	0.004	0.003	0.02	0.0003	0.04	0.01
JOF	54	0.003	0.003	0.42	0.0003	0.11	0.002
WS	29	0.003	0.003	0.02	0.0004	1.04	0.002
DG	48	0.003	0.004	0.34	0.0003	8.07	0.01
FWZ	10	0.005	0.005	0.03	0.0001	0.28	0.002
MCS-OX	35	0.01	0.01	0.53	0.0002	0.10	0.01
MCS-BK	33	0.18	1.08	128.77	0.0002	29.19	0.03
MTS	13	0.01	0.03	4.66	0.0002	14.73	0.01
WF	12	0.01	0.03	1.15	0.0003	14.37	0.001
MM	29	0.002	0.003	1.27	0.0006	0.27	0.003
FOR	5	0.01	0.01	0.33	0.0001	0.01	0.01
Dump	2	0.001	0.003	0.55	0.0005	0.19	0.003
TAILINGS	7	0.01	0.01	0.23	0.0001	0.01	0.0002

Rock Type	Sample Count	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Se (mg/L)	SO ₄ (mg/L)	U (mg/L)
DET+ALL	7	0.01	0.01	0.01	0.01	1229	0.14
DOR	24	0.01	0.003	0.001	0.005	223	0.001
WW	14	0.01	0.002	0.0002	0.001	316	0.0003
YS(+WYL)	8	0.01	0.004	0.001	0.02	70	0.0003
JOF	54	0.01	0.004	0.001	0.003	30	0.0003
WS	29	0.01	0.004	0.0004	0.003	30	0.0003
DG	48	0.02	0.01	0.001	0.03	71	0.0004
FWZ	10	0.01	0.01	0.0001	0.001	9	0.0002
MCS-OX	35	0.01	0.01	0.006	0.01	46	0.001
MCS-BK	33	3.03	0.03	0.02	0.07	988	0.03
MTS	13	0.67	0.01	0.01	0.05	701	0.001
WF	12	0.27	0.004	0.001	0.003	111	0.002
MM	29	0.01	0.01	0.001	0.003	21	0.001
FOR	5	0.01	0.001	0.0001	0.0004	18	0.00003
Dump	2	0.01	0.01	0.001	0.003	22	0.001
TAILINGS	7	0.01	0.001	0.0001	0.02	245	0.0004

^a data compiled from RTIO geochemical database Database_Leach_200224.

^b values measured less than the limit of detection have been included in the calculations as half the limit of detection.