

TECHNICAL MEMORANDUM

DATE	31 May 2022	REF	NSWDPE239603
TO	Ms Rose-Anne Hawkeswood – NSW Department of Planning and Environment	REV	0
FROM	Sophie Pape, Earth Systems Jeff Taylor, Earth Systems	PROJECT	Bowdens Silver Mine

INDEPENDENT REVIEW - ACID AND METALLIFEROUS DRAINAGE

INTRODUCTION

The New South Wales Department of Planning and Environment (NSWDPE) has requested an independent review and advice in relation to acid and metalliferous drainage (AMD), water balance modelling and surface water management aspects of the proposed Bowden Silver Mine.

Earth Systems were key authors of the Federal Government's Leading Practice handbooks on "*Managing Acid and Metalliferous Drainage*" (2007) and "*Preventing Acid and Metalliferous Drainage*" (2016).

This Memorandum provides a summary of the documents available for review and the key findings of Earth Systems' independent high level review with a focus on AMD / geochemical characterisation, impact assessment and related management aspects of the proposed mine development. Water balance modelling and surface water management aspects have been reviewed in a separate memorandum.

SCOPE OF REVIEW

Sections of the following reports relevant to AMD / geochemistry were included in the review:

"EIS" documents:

- ▶ EIS Bowdens Silver Project – 2020. 764 pages.
- ▶ Vol 1_Part 3_Materials Charact - May 2020. 562 pages.
- ▶ Vol 5_Part 16A_TSF Design Report - May 2020 (TSF Preliminary Design). 91 pages.
- ▶ Vol 5_Part 16B_Prelim Design - WRE, Oxide Ore (Preliminary Design of PAF Waste Rock Emplacement, Oxide Ore Stockpile and the Southern Barrier). 44 pages.
- ▶ Vol 5_Part 16C_Closure Cover Design – May (TSF and WRE Closure Cover Design). 44 pages.

Submission and Response documents:

- ▶ Submissions:
 - Dr Haydn Washington, environmental scientist, former Experimental Scientist in CSIRO working on heavy metal pollution from mine sites, 16/7/20. 7 pages.
 - Dr Haydn Washington, environmental scientist, former Experimental Scientist in CSIRO working on heavy metal pollution from mine sites, 12/8/21. 10 pages.
 - 4.12. WRE and Leachate Dam. 3 pages.
 - 4.11. TSF leakage risk. 4 pages.
- ▶ Submissions Report - Response to Submissions on EIS - June 2021. 514 pages.

REVIEW FINDINGS

Review Finding	Earth Systems Comment	Recommendation to NSWDP
A "Materials Characterisation Assessment", including static and kinetic geochemistry test work was completed by GCA in May 2020.	<p>The static geochemistry test work undertaken to date is considered preliminary based on:</p> <ul style="list-style-type: none"> ▶ 143 waste rock samples being tested (127 samples in 2012-13 and 16 samples in 2017-18) as a basis for characterising 46.4 million tonnes of waste rock (only 1 sample per 325,000 tonnes of waste rock). ▶ 5 low grade ore and 2 ore samples being tested as a basis for characterising around 30 million tonnes of ore (only 1 sample per 4.3 million tonnes of low grade ore / ore). 	Ongoing static geochemical characterisation test work will be required throughout the Project life to verify the assumptions developed from preliminary test work and inform day to day mine material handling.
	<p>Kinetic geochemistry test work was conducted on 18 samples using weathering columns, and provides some preliminary insights into kinetic geochemical behaviour and components of concern in drainage water quality. However, the use of weathering columns (column leach tests) has a number of limitations as outlined in the Federal Government Leading Practice Handbook "Preventing Acid and Metalliferous Drainage" (DIIS, 2016) and discussed further below.</p>	Additional kinetic test work will be required to quantify pyrite oxidation / acidity generation rates, the "lag time" or delay before onset of acid conditions, and the duration of acid generation from PAF materials.
<p>The static geochemistry test work included:</p> <ul style="list-style-type: none"> ▶ 54 waste rock samples with Total S < 0.3% tested in 2012-13. ▶ 73 waste rock samples with Total S > 0.3% tested in 2012-2013. ▶ 16 samples of fresh waste rock with Total S < 0.3% tested in 2017-18. 	<p>The primary focus of sample selection should be to obtain samples that are representative of the deposit, based on spatial location (position and depth), extent of weathering, lithologies, etc. (eg. DIIS, 2016). However, the sample selection process employed by GCA (2020) appears to be more focussed on Total Sulfur values, with the presumption that an arbitrary 0.3 % Total S cutoff may be appropriate for defining PAF versus NAF materials. However, some waste rock with 0.1-0.3 % S is PAF (see comments below).</p>	<p>Ongoing static geochemical characterisation test work will be required throughout the Project life to verify the assumptions developed from preliminary test work and inform day to day mine material handling.</p> <p>The AMD risk classification system should be reviewed (as per Recommendations below).</p>

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<p>Key findings from GCA (2020) include:</p> <ul style="list-style-type: none"> ▶ Most of the waste rock lithologies comprise PAF material, with sandstone being the only lithology that was regarded as NAF. ▶ All lithologies are generally deficient in carbonate materials. Furthermore, where carbonates are present, they are dominated by rhodochrosite (manganese-carbonate) which is not an acid neutralising carbonate and can be associated with elevated manganese in drainage water. ▶ The low grade ore and ore samples were classified as PAF. ▶ The process tailings were classified as PAF. ▶ The soil-clays were classified as NAF. 	<p>The potential for acid and metalliferous drainage (AMD) from sulfidic waste rock, low grade ore, ore and tailings is a significant water quality risk for the Project, in both the short-medium term (during operations) and the long term (post-closure), if not managed effectively.</p>	<p>A stand-alone site-wide AMD Management Plan will need to be developed and a qualified geochemist employed to ensure its effective implementation throughout the mine life.</p>
<p>For the 54 waste rock samples with Total S < 0.3% tested in 2012-13:</p> <ul style="list-style-type: none"> ▶ Most samples were classified as “NAF” based on the classification system in Annexure 5 of GCA (2020). Four exceptions were classified as “Uncertain” though “likely NAF”. ▶ Despite most samples being considered “NAF” by GCA (2020), sulfate-bearing minerals such as alunite and jarosite were identified, which represent another source of acidity and a potential source of water quality impacts. Indeed, a significant proportion of samples (12 out of 54) had pH 1:2 values below 4.5 despite their “NAF” classification. <p>The kinetic test work results demonstrate initial drainage from this material may be slightly acidic (pH 5) but this eventually increases towards pH 6 as trace alunite and jarosite are depleted.</p>	<p>Many of the samples classified as “NAF” could have an impact on water quality due to the presence of sulfate-bearing minerals such as alunite and jarosite.</p> <p>Materials containing alunite and jarosite could be generated throughout the mine life, therefore water quality issues could be expected to occur over a period of at least 15-20 years, if “NAF” materials are not managed effectively.</p> <p>Also, at least one of the four “Uncertain though likely NAF” samples would be regarded as PAF by Earth Systems, based on a NAG pH value of 4.2.</p>	<p>A management strategy will be required for “NAF” mine materials that contain alunite and jarosite, as part of the site AMD management strategy.</p> <p>The AMD risk classification system should be reviewed (as per Recommendations below).</p>

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<p>Elevated metals, in particular manganese (up to 5.2 mg/L after 10 weeks and consistently 1-2 mg/L over ~3 years) were identified in the kinetic test results.</p> <p>Up to ~60% of the Total S was removed over the ~3 year kinetic test program.</p>		
<p>For the 73 waste rock samples with Total S > 0.3% tested in 2012-2013:</p> <ul style="list-style-type: none"> ▶ The sulfur content ranged up to 5.2% and was increasingly dominated by Sulfide S (eg. pyrite and marcasite) with depth in the deposit, however Sulfate S (eg. alunite and jarosite) was also present throughout these samples. ▶ Only 4 of these 73 samples were classified as NAF, therefore the assessment concluded that all such materials should be collectively treated as PAF. ▶ Relatively high manganese concentrations were observed in the kinetic tests (~30 mg/L at the end of testing for a 0.3-0.5 % S sample). Manganese (eg. 10-20 mg/L), zinc (eg. 2-3 mg/L) and arsenic (50-60 mg/L) were identified as the key components of concern in drainage from samples with >0.5% S. ▶ Oxygen Consumption Rates (OCR) were measured for 3 samples and reported as 6.3×10^{-11}, 1.4×10^{-11} and 5.4×10^{-11} kg O₂/kg/s. 	<p>The conclusion that all materials with Total S > 0.3% should be collectively treated as PAF is considered reasonable, but some waste rock with Total S < 0.3 % is also PAF (see comments below).</p> <p>Some PAF waste rock will generate acid and metalliferous drainage (AMD) in the short term, characterised by low pH, elevated dissolved metal concentrations and elevated (sulfate) salinity.</p> <p>Most PAF waste rock will generate near neutral but metalliferous drainage (NMD) in the short term, prior to the onset of acid (low pH) conditions. The delay before acid drainage commences is referred to as the "lag time" or "lag phase".</p> <p>Key components of concern in drainage water quality (NMD) from PAF materials during this "lag time" will include manganese, zinc and arsenic. Following the lag phase, low pH and a wider range of dissolved metals would also be of concern if PAF waste rock is not managed appropriately.</p> <p>For further information on AMD / NMD refer to Attachment A.</p> <p>OCRs will vary with Sulfide S content, oxygen concentration and moisture content, and therefore it is not clear whether the estimated OCR values are representative or not. Furthermore, it is unclear how such figures were used to estimate the depth of an "O₂ diffusion front" at 10 metres in a constructed waste rock dump.</p>	<p>Further kinetic test work on PAF materials is required to understand:</p> <ul style="list-style-type: none"> ▶ Normalised Pyrite Oxidation Rates (POR) that can be extrapolated to other materials based on Sulfide S content, oxygen concentration and moisture content; ▶ The duration of the "lag time" before the onset of acid generation; and ▶ The longevity of pyrite oxidation (acid generation). <p>Field-based kinetic test work will also be required to develop a better understanding of the depth of O₂ diffusion into PAF waste rock (and tailings).</p>
<p>GCA (2020) noted that the majority of the waste rock and ore expected to be extracted from the proposed open cut pit would have Total S > 0.5%. This indicates that most waste rock and ore material is expected to be PAF (and is confirmed by subsequent reports). For example, Advisian (2020a) reports an estimated 57% of waste rock is PAF.</p>	<p><i>Specific comments relating to the proportion of PAF and NAF mine materials is provided below.</i></p>	<p><i>Specific recommendations relating to the proportion of PAF and NAF mine materials is provided below.</i></p>

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<p>Follow up static geochemistry test work was conducted in 2017-18 on 16 samples of fresh waste rock with Total S contents of < 0.3%, to assess its potential for use as a construction material or a resource during decommissioning and closure works.</p> <ul style="list-style-type: none"> ▶ 13 of the 16 samples were classified as NAF, therefore 3 samples were PAF (ie. 19% of samples). ▶ Carbonates were detected at least in "trace" concentrations. While some neutralising carbonate was identified (eg. dolomite), other carbonate forms (eg. siderite and rhodochrosite) will not neutralise acidity from the PAF materials or are only partially acid neutralising (eg. ankerite). Indeed, the risk of locally elevated manganese concentrations in drainage from these potential construction / rehabilitation materials was noted. 	<p>Nearly 20% of potential construction / rehabilitation materials tested (fresh rock with Total S < 0.3% S) were identified as PAF.</p> <p>Based on this information, there may be a deficit of geochemically suitable construction materials for the Project. It is unclear if there would be sufficient NAF waste rock from the weathered zone to meet all construction requirements. This is discussed further below.</p> <p>There is also a risk of NMD from "NAF" construction / rehabilitation materials.</p>	<p>The Total S cutoff value of 0.3 % is not suitable for identification of NAF rock for use as a construction material or resource, and should be reviewed (as per Recommendations below).</p> <p>A management strategy will be required for "NAF" mine materials that contain metalliferous carbonates (eg. siderite, rhodochrosite and ankerite), as part of a site AMD Management Plan.</p>
<p>Geochemical characterisation test work has not specifically been conducted for the pit wallrock materials.</p> <p>Section 2.4.2 of the EIS notes that the rim of the main open cut pit varies from 597 m AHD within Blackmans Gully to 652 m AHD on the north-eastern edge (the deepest section of the pit is at 456 m AHD, approximately 180 m below natural ground level).</p>	<p>These figures indicate a pit highwall of up to 55 metres at the time of closure. With an average weathered zone depth of only 20-30 metres, sulfidic wallrock could be exposed within this highwall, representing a potential long term (post closure) AMD risk.</p> <p>Furthermore, the potential for AMD from pit wallrock, including floor rock and highwall materials, during operations was not considered in the GCA (2020) study.</p>	<p>The potential risk associated with AMD in pit water, both during operations and post-closure, needs to be assessed and managed.</p>
<p>Geochemical characterisation test work has not specifically been conducted for the silver/lead concentrate or zinc concentrate products.</p>	<p>Given the sulfidic nature of the concentrates, this test work would be recommended if concentrate was to be stockpiled or exposed to atmospheric oxygen / incident rainfall prior to being transported off site.</p>	<p>Consideration should be given to concentrate storage and handling procedures, and the potential duration of exposure to atmospheric oxygen / incident rainfall (if at all) prior to off site transport.</p>

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<p>A site-specific AMD risk classification system was developed by GCA (2020) based on the samples tested, to inform material types and management options. The proposed classification system is outlined below:</p> <ul style="list-style-type: none"> ▶ Weathered Zone <ul style="list-style-type: none"> • WZ1: Total S < 0.3% = initially sub-neutral (acidic pH) but evolving to NAF over time as “trace alunites” are leached with buffering from interactions with smectites. • WZ2: Total S > 0.3% = PAF (“>” assumed by Earth Systems to mean “≥”). ▶ Primary Zone <ul style="list-style-type: none"> • PZ1: Total S < 0.1% = NAF. • PZ2: Total S 0.1-0.3% within the northern section of proposed main open cut pit = NAF. • PZ3: Total S > 0.3%; Total S 0.1-0.3% distant from the northern section of proposed main open cut pit = PAF. <p>It is noted that the classification system recommended by GCA (2020) for the Project, differs from the classification system used for the assessment of samples by GCA (2020; Annexure 5) which is based on Total S as well as Sulfide S and ANC/MPA ratios.</p>	<p>The AMD risk classification system recommended for the Project by GCA (2020) would be more practical and cost-effective than the system used for the samples tested in 2012-13 and 2017-18, however it may have some limitations associated with:</p> <ul style="list-style-type: none"> ▶ The potential for NMD from some “NAF” materials (ie. NAF materials are not sub-classified into NAF-NMD or NAF-Inert). ▶ Unclear method for demarcation of the “northern” section of the pit and hence PZ2 vs PZ3 materials. ▶ The accuracy of site assay data for Total S (some discrepancies between assay data and GCA data for Total S were noted). <p>Notwithstanding these potential limitations, the system recommended by GCA (2020) does not appear to have followed through correctly to the mine block model and waste rock schedule that form the basis of the waste rock dump design by Advisian (7 May 2020).</p> <p>A simpler classification appears to have been used by Advisian (2020a) – based only on a 0.3 % Total S cutoff – which could result in some PAF material being inadvertently classified as NAF. Similarly, the EIS has used the 0.3 % Total S cutoff (only) which ignores the potential for PAF waste rock in the 0.1-0.3 % Total S range.</p>	<p>The mine block model and waste rock schedule should be reviewed, and Project design implications considered prior to construction.</p>
<p>According to mine scheduling developed by AMC, around 10 million tonnes of WZ1 material would be produced, corresponding to 22% of the total tonnage of waste rock (GCA, 2020).</p>	<p>Estimates for PZ2 and PZ3 materials are considered inaccurate as they are not based on the original classification definitions recommended by GCA (2020). Therefore:</p> <ul style="list-style-type: none"> ▶ For the PZ2 category, there could be significantly lower tonnages of NAF waste rock than 6.3 million tonnes. ▶ For the PZ3 category, there could be significantly higher tonnages of PAF waste rock than 22.5 million tonnes. 	<p>See Recommendation above.</p>

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<p>Tonnages for the other material categories (WZ2, PZ1, PZ2 and PZ3) were not specifically reported by GCA (2020) but were documented in Section 2.5.2 of the EIS, as summarised below:</p> <ul style="list-style-type: none"> ▶ WZ1 – 10 million tonnes of NAF waste rock. ▶ WZ2 – 4.1 million tonnes of PAF waste rock. ▶ PZ1 – 3.5 million tonnes of NAF waste rock. ▶ PZ2 – 6.3 million tonnes of NAF waste rock. ▶ PZ3 – 22.5 million tonnes of PAF waste rock. 	<p>Therefore, while the EIS / Advisian (2020a) indicate that approximately 57% of waste rock is PAF and the remaining 43% is NAF, the proportion of PAF waste rock may be under-estimated as it is based on the incorrect assumption that all waste rock with <0.3 % Total S is NAF (whereas GCA identified some waste rock with 0.1-0.3 % Total S as PAF). This is a concern given that:</p> <ul style="list-style-type: none"> ▶ “NAF” waste rock (some of which may be PAF) is planned to be used for the TSF embankment raises, acoustic barrier, waste rock dump haul road and final cover of the waste rock dump and TSF. Furthermore, the potential for acidic drainage (associated with alunite and jarosite) or NMD from NAF rock has not been addressed in the waste rock dump design. ▶ The waste rock dump is designed to accommodate 26.6 million tonnes of PAF waste rock, and may not have sufficient capacity to accommodate additional PAF waste rock. 	
<p>To address the potential for elevated manganese (around 1-2 mg/L) in drainage from WZ1 waste rock materials, GCA (2020) suggested:</p> <ul style="list-style-type: none"> ▶ Site wide application of agricultural lime (ie. crushed limestone). ▶ Ensuring that the outermost section of the Southern Barrier has < 1,000 mg/kg Mn. 	<p>Limestone would not produce a high enough pH to remove all manganese from solution. Additional treatment may be required. It is unclear whether the second recommendation would be practical in terms of both (i) waste rock scheduling and (ii) field-based classification and segregation of waste rock.</p> <p>Notwithstanding the above, neither of these recommendations were adopted in the waste rock dump design (Advisian, 2020a).</p>	<p>A clear strategy to manage this potential water quality risk (NMD from WZ1 “NAF” waste rock material) is needed.</p>
<p>To address the potential for elevated manganese in drainage from PZ2 waste rock materials, GCA (2020) suggested:</p> <ul style="list-style-type: none"> ▶ Consider screening highly siliceous volcanic breccia to +50mm to remove the fines which are considered a greater manganese risk due to their higher surface area. ▶ Develop sub-variants of the PZ2 classification, with a 0.1% Mn cutoff use to segregate Low/High manganese rock. 	<p>As noted above and acknowledged by GCA (2020) the logistics, economics and indicative volumes of such sub-variants are unknown.</p> <p>Notwithstanding this, neither of these recommendations were adopted in the waste rock dump design report (Advisian, 2020a).</p>	<p>A clear strategy to manage this potential water quality risk (NMD from “NAF” PZ2 waste rock material) is needed.</p>

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<p>To address the potential for AMD from WZ2 and PZ3 waste rock materials:</p> <ul style="list-style-type: none"> ▶ GCA (2020) suggested: <ul style="list-style-type: none"> • Construction and development of the waste rock dump to prevent pervious, preferential pathways (resulting from segregation of larger cobbles and boulders) which are conduits for rapid ingress of air and water, which enhance sulfide oxidation rates and AMD generation. • Placement of low permeability material over the footprint of the waste rock dump, to prevent seepage to groundwater and surface discharge to downstream watercourses. ▶ From the preliminary waste rock dump design report (Advisian, 2020a) the dump would be developed in a staged fashion via cells and with a bottom-up method of lift construction via paddock dumping. Each 10 m lift would comprise 2 m layers of compacted waste rock. 	<p>It is positive to note that the proposed method of PAF waste rock placement is consistent with current leading practice (eg. INAP, 2020) although large-scale laboratory test work and/or field trials with appropriate instrumentation are needed prior to construction to demonstrate that these construction specifications will sufficiently limit air entry to PAF waste rock and allow water quality objectives to be achieved.</p> <p>The predicted O₂ diffusion front of 10 metres (GCA, 2020) indicates that AMD generation could still be an issue from the outer layer of PAF waste rock that remains exposed to air entry during operations / post closure. This is a particular concern for post-closure given that PAF waste rock appears to extend to the near-surface in the final waste rock dump landform.</p> <p>A store-and-release cover was designed (Advisian, 2020b) based on “current best practice” with reference to MEND (2004) guidelines, but the MEND (2004) guidelines are considerably out of date and while store-and-release cover systems may still be an appropriate from a revegetation perspective, they are not considered leading practice from an AMD risk management perspective. Earth Systems is unaware of any store-and-release cover systems that have proven to be successful for AMD control.</p>	<p>Large-scale laboratory test work and/or field trials are required to support the proposed PAF waste rock placement method.</p> <p>As noted above, field-based kinetic test work will also be required to develop a better understanding of the depth of O₂ diffusion into PAF waste rock (and tailings).</p> <p>Additional management measures will be required for the outer layer of PAF waste rock (eg. O₂ diffusion front of 10 metres as reported) that remains exposed to air entry during operations / post closure.</p> <p>Near-surface PAF waste rock in the final waste rock dump landform should be avoided.</p> <p>An AMD management strategy for PAF waste rock should avoid reliance on a store-and-release cover system for long term control of infiltration and oxygen ingress to waste rock.</p>
<p>Regarding the management of low grade ore stockpiles, which are expected to be PAF, GCA (2020) notes that this material would either be processed, or capped in a method similar to the waste rock dump.</p>	<p><i>The comments above for PAF waste rock are equally applicable to low grade ore stockpiles.</i></p>	<p><i>The recommendations above for PAF waste rock are equally applicable to low grade ore stockpiles.</i></p>
<p>An “oxide ore” stockpile is discussed by Advisian (2020a), however this material was not specifically characterised by GCA (2020). A total of 1.78 million tonnes of oxide ore would be produced over the mine life, and this may be integrated into the final waste rock dump landform if it is uneconomical to process.</p>	<p>Oxide ore is generally a lower AMD risk than sulfidic ore, but could have comparable water quality issues to WZ1 or WZ2 waste rock.</p> <p>It is positive to note that oxide ore would be placed “in accordance with the methodology presented in Section 3.2” for waste rock (Advisian, 2020a).</p>	<p>Geochemical characterisation of “oxide ore” material is required.</p> <p><i>The recommendations above for WZ1 and WZ2 waste rock could be applicable to “oxide ore” stockpiles.</i></p>

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The outer slope of the flood protection bund extends into the modelled 1:100 AEP flood area, and this bund would be removed during rehabilitation and closure of the waste rock dump (Advisian, 2020a).	It is therefore conceivable that at some stages post-closure, extreme floodwaters could come into contact with PAF material in the base of the waste rock dump. The potential implications for both flood water quality and stability of the waste rock dump have not been specifically discussed.	Consideration should be given to the potential implications for both flood water quality and stability of the waste rock dump.
A section of the southern barrier encroaches on the current alignment of Blackmans Gully, resulting in the need to create a zone of permeable fill to reduce the impoundment of water from the upstream catchment (Advisian, 2020a).	The potential implications for impoundment water quality in contact with "NAF" material (eg. manganese or other NMD issues) have not been specifically discussed.	Consideration should be given to the potential implications for impoundment water quality in contact with "NAF" material (eg. manganese or other NMD issues).
The waste rock dump capping layer will comprise a 1 metre thick layer of "oxide PAF" to create a smooth cushion layer above the "general PAF" (Advisian, 2020a).	Earth Systems assumes "oxide PAF" corresponds to WZ2 material. As this would be mined earlier than "general PAF", this would require separate temporary stockpiling and double-handling of "oxide PAF", although this doesn't appear to have been considered. Notwithstanding this, near-surface PAF material in the final waste rock dump landform remains a concern, as noted above.	Near-surface PAF material in the final waste rock dump landform should be avoided.
A number of additional studies were recommended by Advisian (2020a) for the next phase of the design process.	Earth Systems supports their inclusion in Project consent conditions. They are however limited to water management, physical / geotechnical properties and stability of the waste rock dump, rather than geochemical stability / water quality issues outlined above.	Future studies should focus on geochemistry / water quality aspects as well as water management, physical / geotechnical stability aspects of the waste rock dump.
Tailings are expected to be PAF but GCA (2020; Annexure 2) suggested that near-saturated conditions will suppress pyrite oxidation and that PAF tailings beaches will not remain exposed for longer than several months. This implies that AMD from PAF tailings will not be an issue during operations, hence there is currently no AMD management strategy for PAF tailings within the TSF design report (ATC, 2020).	This assumption is considered optimistic and cannot be verified without kinetic geochemistry test work on representative tailings material (to quantify the "lag time" before the onset of acid generation) which has not been conducted to date.	Kinetic geochemistry test work needs to be conducted on representative PAF tailings materials. An AMD management strategy for PAF tailings is required.

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Despite the predicted near-neutral drainage, GCA (2020) noted that tailings pore water manganese concentrations could be 10-30 mg/L (ie. during the lag phase before the onset of acid generation) and TSF seepage control would be required.	Seepage collection and recovery during operations is addressed by ATC (2020) from a water management perspective only, however the likely requirement for treatment of TSF seepage water (and decant water) is not specifically discussed by GCA (2020) or ATC (2020).	An AMD management strategy for PAF tailings should consider the potential need for treatment of AMD / NMD in TSF seepage and decant water.
The potential need for management of TSF seepage post-closure has not been considered.	This could become an increasing water quality concern as the tailings are allowed to naturally drain post-closure, leading to pyrite oxidation and AMD generation.	An AMD management strategy for PAF tailings should consider the risk of AMD in TSF seepage post-closure.
For the closure phase, GCA (2020) recommended a TSF cover system to restrict both infiltration and oxygen ingress to the tailings. A store-and-release cover was designed (Advisian, 2020b) based on "current best practice" with reference to MEND (2004) guidelines.	<i>See earlier comments regarding store-and-release cover systems.</i>	An AMD management strategy for PAF tailings should avoid reliance on a store-and-release cover system for long term control of infiltration and oxygen ingress to tailings.
The TSF has been designed as a water-holding structure for the operations phase (only).	<p>A water-holding TSF structure is positive from an AMD risk perspective as it will enable a significant proportion of PAF tailings to remain saturated, thereby limiting the extent of pyrite oxidation (notwithstanding the concerns regarding beached tailings noted above) at least during operations.</p> <p>It is unclear whether consideration was given to maintaining the TSF as a water-holding structure post-closure, and whether this would be practical under the post-closure water balance conditions. If feasible, this could potentially avoid the risk of AMD generation as the tailings progressive drain over time post-closure.</p>	Consideration should be given to the potential for a permanent water-holding TSF to be part of the AMD management strategy for PAF tailings.
Around 2.9 million m ³ and up to 1.3 million m ³ of NAF rock would be required for the TSF and waste rock dump cover systems (Advisian, 2020b). NAF rock is also required for the TSF embankment (3.3 million m ³), waste rock dump construction (assume ~0.3 million m ³) and satellite pit backfill (assume ~1.0 million m ³). This equates to ~8.8 million m ³ of NAF rock required. Around 10 Mt of WZ1 material (5.99 million m ³) and ~3.5 Mt of PZ1 material (1.90 million m ³ at 1.84 t/m ³) would be produced ("NAF Oxide"; Advisian, 2020a).	Notwithstanding the concerns above regarding (i) store and release covers for TSFs and waste rock dumps; and (ii) the potential for acidic drainage or NMD from some "NAF" materials, these quantities indicate a potential shortfall in suitable NAF waste rock (ie. that meets both geochemical and geotechnical requirements) for construction and rehabilitation purposes, which will depend on the proportion of PZ2 material that is actually NAF and can be readily segregated during mining.	Predicted quantities of suitable NAF rock for construction and rehabilitation purposes need to be reviewed, and Project design implications considered prior to construction.

KEY CONCLUSIONS AND RECOMMENDATIONS

The majority of waste rock, low grade ore, ore and tailings generated from the Project is expected to be potentially acid forming (PAF). Acid and metalliferous drainage (AMD) is therefore a significant potential water quality risk for the Project, that is likely to commence during operations and continue into the long term post-closure, based on the current AMD management strategy. Key concerns are summarised below:

- ▶ Geochemical characterisation work conducted to date is considered to be preliminary only. Much more static geochemistry data are required to establish a reliable and practical AMD risk classification system for the Project.
- ▶ The behaviour of sulfidic mine waste materials over time is poorly understood and additional kinetic test work is required to address this. From the test work conducted to date, it has not been possible to quantify the rate of pyrite oxidation / acidity generation processes, the “lag time” before acid conditions will develop, or the longevity of AMD generation from PAF waste rock or tailings.
- ▶ The AMD risk classification system is considered inappropriate for this Project, resulting in inaccurate predictions of PAF and NAF material tonnages. This will affect waste rock dump design and the availability of non acid forming (NAF) materials for construction / rehabilitation requirements. The mine block model and materials schedule will need to be updated to better quantify tonnages based on geochemistry / water quality risk and suitability for construction or rehabilitation.
- ▶ There appears to be a significant potential for acidic drainage (associated with alunite and jarosite) or neutral and metalliferous drainage (NMD) from mine materials that have been classified as “NAF”. The EIS appears to assume that “NAF” waste rock is benign and drainage water quality will be suitable for discharge without treatment / management. A clear strategy is required to address these potential water quality risks from “NAF” waste rock.
- ▶ Earth Systems has little confidence in the current AMD management strategy for waste rock and tailings. For example:
 - The waste rock dump design is unproven and appears substantially problematic, with initial indications that the site could be establishing the need for water treatment in perpetuity. Large-scale laboratory test work and/or field trials with appropriate instrumentation are needed prior to construction, to demonstrate that waste rock placement methods will sufficiently limit air entry to PAF waste rock and allow water quality objectives to be achieved. Additional management measures are required for the outer layer of PAF waste rock (eg. 10-metre oxygen diffusion front as reported) that remains exposed to air entry during operations / post closure. Additional measures are required to manage other water quality risks from “NAF” rock. Near-surface PAF material in the final waste rock dump landform should be avoided.
 - More detailed assessment of potential AMD impacts from tailings during operations and post-closure is warranted. AMD from the tailings (surface water and seepage) could become a particularly significant issue post-closure as the tailings are progressively drained. Kinetic test work and a strategy for management of PAF tailings is required.
 - Store-and-release covers are used widely, but almost never in recent years for the purposes of AMD control. The proposed store-and-release cover systems are not considered an appropriate strategy for PAF waste rock or PAF tailings management.
- ▶ Pit lake water quality issues associated with AMD generation within the pit wallrock, including floor rock and highwall materials, have not been considered for the operations or post-closure phases of the Project. Potential AMD impacts on pit water quality should be assessed and a management strategy developed.

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Attachment A

Background to Acid and Metalliferous Drainage

Background to AMD

Key Geochemical Principles for Environmental Management

In order to understand AMD and associated risks, it is important to consider the mechanism of AMD generation in some detail. AMD refers to the acidic, saline and metalliferous water that can occur as drainage from mine waste stockpiles, TSFs, pit walls, underground workings (if any) and potentially other mine infrastructure such as Run Of Mine (ROM) pads and road embankments. AMD is a common problem for mines worldwide and one of the most significant obstacles to pollution prevention and minimisation during operations and post-closure.

AMD commonly occurs when previously water-saturated sulfide mineral bearing rocks or sediments are excavated and stored in an unsaturated setting, as is typical in mining operations that store mine waste materials and tailings in unsaturated or partially unsaturated piles and impoundments. Desaturation of in-situ rocks / sediments (eg. associated with mine dewatering) can also generate AMD.

The key terms and processes involved in the generation, release and treatment of AMD are described in the following sections.

Sulfide Oxidation

AMD can be produced when reactive sulfide minerals such as pyrite (iron sulfide, FeS_2) are disturbed or dewatered as part of mine operations. Many sulfide minerals, particularly pyrite but also chalcopyrite (copper sulfide, CuFeS_2), pyrrhotite (iron sulfide, FeS) and some others, naturally undergo oxidation when exposed to atmospheric oxygen and moisture. Oxidation of sulfides results in decomposition of the mineral to release sulfur in the form of sulfuric acid (H_2SO_4), and soluble metals such as iron, which contribute to 'mineral acidity'. The acid conditions and soluble iron generated during pyrite oxidation can attack and dissolve other minerals, resulting in elevated soluble concentrations of other metals such as aluminium, manganese, copper, lead, zinc, nickel, cobalt, cadmium, chromium, arsenic, antimony and mercury.

Under oxidising conditions, sulfide oxidation continues until all reactive sulfides have been converted to acid and metals. Different sulfides oxidise at different rates. It is not unusual for sulfide oxidation (and hence AMD issues) to persist for hundreds of years. The amount of acid produced by sulfide oxidation per year tends to decrease over time as the bulk concentration of source sulfides decreases (eg. within an overburden pile).

Some sulfide minerals, such as galena (PbS), sphalerite (ZnS), arsenopyrite (FeAsS) and stibnite (Sb_2S_3), are relatively geochemically stable (unreactive) and slow to oxidise. However, these minerals can be dissolved by exposure to acid conditions and dissolved iron, resulting in the release of soluble metals, which contribute to acidity.

Secondary Acid Sulfate Minerals

Acidity generated as a result of sulfide oxidation can react with silicate minerals to form secondary acid sulfate salts such as melanterite, jarosite and alunite. Melanterite is highly soluble in water, jarosite is sparingly soluble, and alunite is approximately ten times less soluble than jarosite. Acidity stored in these minerals is released by dissolution in water, and is not sensitive to oxygen availability.

Depending on the rate of sulfide oxidation, jarosite (or alunite) formation as a result of sulfide oxidation can proceed faster than the rate of jarosite dissolution, resulting in an accumulation of jarosite in stockpiles

of potentially acid forming (PAF) materials. Melanterite, if formed, is highly soluble and does not tend to accumulate in non-arid environments.

Acid Neutralisation

Certain carbonate minerals, primarily calcium- and magnesium-bearing carbonates such as calcite (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$), can neutralise the acidity produced by sulfide oxidation. The neutralisation potential of a rock or sediment as determined through test work is referred to as its acid neutralisation capacity (ANC). Iron- and manganese-bearing components of carbonates have no net contribution to ANC, as the metals oxidise and hydrolyse, thereby contributing to acidity.

Acid produced by sulfide oxidation can also react (slowly) with common silicate minerals, partially neutralising acidity and storing some acidity in precipitated secondary minerals such as jarosite or alunite. Due to the slow rate of reaction, relatively long acidity contact times are required to induce silicate neutralisation, which can be achieved by ensuring slow water migration rates.

Acid and Acidity

In determining AMD risk, it is important to take into account both acid (H^+) and dissolved metals (latent mineral acidity) concentrations as a combined measurement of 'acidity' in units of milligrams of calcium carbonate (equivalent) per litre ($\text{mg CaCO}_3/\text{L}$). The measurement of acidity is equivalent to the amount of neutralising agent (such as calcium carbonate) that would need to be added to the affected water to raise the pH to 8.3. Observations of pH alone, while a reasonable qualitative indicator of water quality, are insufficient to estimate total acidity. For example, water with a pH of 3.0 can have an acidity of as low as 50 $\text{mg CaCO}_3/\text{L}$ and as high as 10,000 $\text{mg CaCO}_3/\text{L}$ or more.

Kinetics of Sulfide Oxidation

Sulfide oxidation occurs at a rate that is determined by the intrinsic geochemical and physical properties of the sulfide minerals (eg. mode of formation, geological history and crystal size), the grain size of the rock, temperature, moisture availability, oxygen availability and bacterial activity.

Sulfide oxidation is a first-order decay reaction that can be described in terms of a percentage of the sulfides that oxidises each year. For example, if the sulfide oxidation rate is 50 wt.% sulfide / year, half of the sulfide exposed to atmospheric oxygen would be oxidised (to form acid and soluble metal ions) in the first year, and then half of the remaining sulfide (25% of the starting total) would be oxidised in the second year. The rate of acid generated by this process decays over time accordingly. The rate of oxidation can be determined through kinetic geochemical tests such as oxygen consumption cell tests and column leach tests.

The kinetics of sulfide oxidation can therefore be used to estimate the duration or longevity of sulfide oxidation and acid generation (before neutralisation reactions).

For materials or sediments of the same geological characteristics (ie. from the same lithological unit) and grain size, the rate of sulfide oxidation is largely uniform and independent of absolute sulfide concentration. This means that oxidation rates (in wt.% sulfide/year) determined through kinetic geochemical test work can be applied to rocks of the same lithology for any sulfide-sulfur content. The sulfide oxidation rate is typically normalised to pyrite equivalent units for convenience (ie. wt.% FeS_2 / year).

Lag Period

Once the sulfide oxidation rate has been determined, the annual acidity generation rate (AGR) and ANC can be used to determine the lag time before the onset of acid conditions. In materials or sediments that contain reactive carbonate minerals (as ANC), any acidity generated as a result of sulfide oxidation will be neutralised until the effective ANC has been exhausted.

If the ANC of the material is less than the total acid generating potential of the sulfides, acid conditions will eventually develop. The net acidity generation rate (NAGR) is the amount of acidity released after neutralisation reactions. The evolution of NAGR can be predicted over time using the sulfide oxidation rate and ANC.

Depending on the balance of Maximum Potential Acidity (MPA) and ANC, sulfidic materials or sediments can display three general lag-related behaviours:

- ▶ No lag period with immediate onset of acid conditions ($ANC = 0$, $MPA > 0$).
- ▶ A discrete lag period followed by the onset of acid conditions ($MPA > ANC$).
- ▶ Onset of acid conditions unlikely to occur ($ANC \gg MPA$).

In the second case described above, drainage will be near-neutral, but may be metalliferous and / or saline, during the lag phase. This is referred to as neutral metalliferous drainage or saline drainage (see following sections).

Neutral Metalliferous Drainage (NMD)

Neutral metalliferous drainage (NMD), also referred to as or neutral mine drainage, can occur when there is sufficient ANC to neutralise the acidity produced by sulfide oxidation, but the drainage still contains elevated dissolved and/or total metal concentrations and (sulfate) salinity.

Some metals, particularly manganese (Mn), cadmium (Cd) and arsenic (As), as well as others, remain in solution even at elevated pH. Neutralisation of AMD by carbonates can raise the pH of the drainage to near-neutral levels (eg. pH 6–8), but this can be insufficient to precipitate all metals, leaving a certain metalliferous component in solution. This is referred to as NMD.

Furthermore, some metals in some scenarios, such as zinc, can precipitate at elevated pH, but can remain suspended in drainage and resist sedimentation. This can result in elevated total metal concentrations, with implications for regulatory compliance.

Saline Drainage

Saline drainage can occur when there is sufficient ANC to neutralise the acidity produced by sulfide oxidation and the resulting drainage does not contain metals at toxic concentrations. The sulfate salinity of the neutralised drainage depends on the relative proportions of calcium and magnesium in the neutralising minerals. Due to the high solubility of magnesium sulfate, higher salinity is likely to occur in deposits where magnesium is a significant component of the neutralising material. Conversely, if calcium is the dominant component of the neutralising material, gypsum precipitation may contribute to lower salinity (sulfate) levels.