Review of Sepik Development Project Environmental Impact Statement (EIS)

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Summary of my opinion

The proposal to develop a major copper gold mine, encompassing three open-cut pits and a large dam ('Integrated storage facility' or ISF) into which mine wastes will be disposed, presents very significant water quality risks for the areas surrounding and down-stream of the proposed project. These include exposure of the near-mine and downstream environments (Frieda River catchment) to elevated levels of metals - particularly copper, but also aluminium, zinc, cadmium and chromium. This is due to the highly reactive, acid-forming nature of the material that is proposed to be mined, and the proposal to dispose treated mine water, tailings and waste rock into the ISF, which will ultimately outflow to the Frieda River. Water quality impacts that are potentially harmful to ecological communities are predicted to occur in the EIS under the average, planned operating conditions of the mine and ISF, due to discharge of water containing elevated metal concentrations at the ISF outlet. The water quality impacts described in the report also potentially under-estimate actual impacts, due to assumptions and uncertainties in the modelling used to predict copper and other metal concentrations in water bodies surrounding and downstream of the mine.

Because the project is a 'greenfield' site with little or no existing infrastructure or experience with mining, most of the water quality and quantity risks are currently difficult to accurately predict, notwithstanding the pre-development hydrological, hydrogeological and geochemistry investigations that have been conducted and presented in the EIS. While some of this is unavoidable, there are areas where significantly more data collection and interrogation, modelling and critical analysis should have been conducted in order to better understand these impacts. A wider range of possible outcomes based on assessment of model uncertainty and a wider range of climate and operating condition scenarios, should have been presented along with better quality figures which give a clear picture of the full range of possible impacts.

Much of the modelling work completed in the groundwater assessment (Appendix 4) and site-wide load balance (Appendix 6b) is based upon assumptions which are questionable, for example:

- bulk/matrix groundwater flow in a setting where preferential/fracture flow is likely to dominate;
- current day climatic data in water and load balance calculations, without incorporation of future climate change;
- the assumption that sub-aqueous storage of mine wastes will prevent any oxidation of sulphides and acid/metal generation from waste rock in the ISF;
- the assumption that groundwater will not act as a future pathway for contaminant transport from the abandoned pits and ISF, and that groundwater mounding will have limited impact on the flow of potentially contaminated groundwater downstream of the ISF.

The lack of any formal uncertainty analysis in the groundwater modelling or water quality modelling is a serious deficiency of the EIS and prevents an objective assessment of the current level of

confidence in the predictions of key water quality related to various risk pathways during and post-mining.

There is also the prospect of significant additional water quality (and quantity) impacts occurring at the site due to unforeseen events arising during operation and post-closure. This is due to the extreme geographical and hydrological characteristics of the site – it is located within very steep topography, in an area of very high rainfall and with much greater than typical level of seismic risk. These factors create a significantly greater than normal risk of catastrophic events – such as failure of parts of the ISF dam wall and/or other mine infrastructure, overflow of mine water storages, over-turning/mixing of water and sediment in the ISF (leading to oxidation and release of acidity and metals beyond what is predicted), landslides, and associated release of hazardous wastewater and sediment to the environment. While some attempt has been made to investigate and plan against such events (e.g. Chapter 11), the proponent is taking an optimistic view – concluding that there is a 'very low probability' of such events occurring. Analysis and modelling of the possible effects of such events should be included in the EIS given the more than remote possibility of such events.

Post mine-closure, the risks to water quality at the site will persist for many decades (and probably many hundreds to thousands of years), posing an ongoing hazard for downstream communities and the environment. It is unclear how these risks will be managed and controlled after mining of the site is completed, for the necessary timescales required to ensure minimal adverse long-term impact. The EIS should clearly set out how these risks will be managed and controlled following mining. In summary it can be argued on the basis of the water quality impacts predicted in the EIS, and possible additional impacts not captured in the current modelling, that the project is not compatible with the relevant section of the National Constitution PNG that calls for:

1. *wise use to be made of our natural resources and then environment in and on the land or seabed, in the sea, under the land, and in the air, in the interests of our development and in trust for future generations; and*
2. *the conservation and replenishment, for the benefit of ourselves and posterity, of the environment and its sacred, scenic, and historical qualities; and*
3. *all necessary steps to be taken to give adequate protection to our valued birds, animals, fish, insects, plants and trees.*

Introduction

I was asked by the Centre for Environmental Law and Community Rights (CELCOR), to provide an expert report analysing the potential environmental impacts arising from the proposed Sepik Development Project (including the Frieda River copper-gold mine and hydro-power development) ("**project**"), based on a review of the project environmental impact statement (EIS).

My primary expertise is in the areas of hydrogeology, geochemistry and water quality assessment. As such, this report mostly focusses on potential water quality and hydrological impacts associated with the project, analysing Appendix 4 (Groundwater Assessment) and Appendix 6 (Site water balance and Site-wide load balance). Other major chapters of the EIS describing the proposed infrastructure (e.g. Chapter 5) and analysis of extreme natural hazards (chapter 11) were also reviewed and considered during preparation of the report, along with the Information Guideline – Guideline for Conduct of Environmental Impact Assessment & Preparation of Environmental Impact Statement, and Operation Manual of the Environment Act 2000.

While I understand the project is not currently the subject of any court proceedings, I have prepared this report in accordance with Division 23.12 of Part 23 of the Australian Federal Court Rules and the Expert Evidence Practice Note including the associated Annexures ("**Practice Note**"**).** I have read the Practice Note and agree to be bound by it. In particular, in accordance with clause 2 of the Expert Witness Code of Conduct, this report has been provided on the basis that I have a paramount duty to provide advice impartially on matters relevant to my area of expertise.

My background and relevant expertise

I am an Associate Professor in the School of Engineering at RMIT University, Melbourne, Australia. I received my PhD from Monash University in 2011, on the use of environmental isotopes and geochemistry to assess processes controlling groundwater quality. For the last 9 years while employed at RMIT I have taught hydrogeology, geochemistry and groundwater modelling to environmental and civil engineering students, and supervised Masters and PhD projects in applied hydrogeology research. I have been awarded more than $800,000 in research funding as a lead chief investigator on more than 10 research grants, supporting projects examining groundwater sustainability and contamination issues. I have published more than 45 peer-reviewed international journal articles, which have been cited more than 1000 times, and served on the editorial board of the *Hydrogeology Journal* (the journal of the International Association of Hydrogeologists) from 2014 to 2018. I have acted as an expert witness in court proceedings and government inquiries regarding impacts of mining developments on groundwater quality and quantity on multiple occasions. My full academic CV is available upon request.

1. Major water quality and quantity risks associated with mine operations and waste management

Frieda River Limited are proposing to build a major open-cut copper-gold mine (encompassing three pits), and artificial lake or 'Integrated Storage Facility (ISF)' to generate hydropower and dispose of mine waste(s), including waste rock, mine water and tailings. Key risks associated with development of the project include the following:

- Ecological risks due to elevated copper and other heavy metal concentrations in the Frieda River and elsewhere downstream of the mine pits and ISF. Under the base case model, including with the implementation of a treatment plan for open pit mine water, the predicted dissolved copper, aluminium, cadmium, chromium and zinc concentrations downstream of the ISF will exceed ANZECC 95% freshwater ecosystem protection guideline values (See section 5 of Appendix 6b). The exceedance is particularly significant for copper. Heavy metal concentrations in the river are predicted to be greater under low rainfall conditions, as higher flows are expected to dilute metals. However, importantly, the concentration values predicted (based on the site water and load balance modelling) assume that minimal oxidation and release of acidity and heavy metals will occur within the ISF, once waste rock and tailings are disposed into the lake. If mixing events occur in the lake and/or the release of metals from the waste rock or tailings is greater than anticipated (e.g. sub-aqueous storage of wastes does not fully prevent sulfide oxidation) - then the concentrations of copper and other heavy metals will be higher than predicted downstream of the ISF. Additionally, the estimates of water quality in surface water bodies upstream and downstream of the ISF depend on estimates of the pit inflow/seepage volumes, derived from groundwater flow modelling. The modelling methodology used for estimating these volumes provides highly uncertain estimates (see below), meaning there is the possibility of significantly greater (or lesser) volumes of mine water, which in turn could result in higher copper loads in the downstream water bodies and additional challenges with mine pit water management.

- Uncontrolled release of contaminated water and/or sediment with high acid and heavy metal content into the surrounding environment, harming ecological communities and creating health and safety risks. For example, during heavy rainfall events (which are a significant probability in the setting), acidic and/or metal-rich water and sediment may be transported into the creeks upstream of the ISF, or (under extreme conditions) downstream of the ISF at rates greater than predicted in the site water balance. Slope stability issues (e.g. rock or mud-slides) could cause much greater releases of sediment and water into water bodies than is anticipated under the range of operating conditions assumed. The high level of geological faulting and potential seismic risks heighten the potential for short-term, catastrophic impacts of this kind (despite planned engineering measures to withstand such events). The risk of such uncontrolled flow events will be particularly high during the initial construction phase of the project – e.g. before infrastructure to capture and control runoff and ensure site stability are fully developed, as well as in the post-mining phase, when the pits become re-flooded and there is less ongoing maintenance and management of site infrastructure. Because of the very high rainfall throughout the year (approximately 8.5 m), establishment of infrastructure and monitoring regimes to guard against such risks will be significantly more difficult than is usually the case at a typical mine site.

- Transport of acidic, metal-rich water, via groundwater, from the ISF towards the lower-lying regions of the Frieda/Sepik River catchments. Due to the construction of the dam and filling with water and waste material, a significant amount of groundwater mounding is expected to occur (see chapter 6 of appendix 4), which will increase groundwater flow gradients away from the ISF. There is potential for groundwater flow from the ISF to transport contaminants downstream into lower-lying areas, and potentially lead to discharge of contaminated water to the surface – e.g. into the Frieda River or surface seeps. It appears this risk has not been analysed in any detail by the proponent.

- Ongoing, long-term health and ecological risks from the formation of acidic, metalliferous leachate within the mine open pits following closure of the mines. Acidification of groundwater during de-watering for mining and/or recovery of groundwater levels following mining is likely to occur. This is in turn likely to increase the overall load of metals discharging to streams upstream of the ISF and contribute to further water quality impairment within the ISF and downstream of it, particularly following recovery of groundwater levels after mining (see above). This has also received limited attention in the relevant chapters of the EIS and it is unclear how ongoing, long-term impacts of the mine site on water quality will be monitored and mitigated for a timescale commensurate with the likely period of impact, which is likely to be hundreds to thousands of years after mining, based on typical groundwater flow rates and the scale of the project. .

2. Key considerations and issues at the Frieda River site

The following features of the study area need to be carefully considered when examining the environmental and health and safety risks associated with the project, including water quality and quantity effects:

- The project area is one of very high rainfall - e.g. annual rainfall is approximately 8.5 m/year (e.g. see Appendix 4, table 3.2). This will create a significant risk of very large flow or flood events in streams, potential issues with soil and slope stability, the possibility of overflow events in water storage areas and/or overturning or mixing of waters within the ISF, and difficulty covering/containing runoff interacting with mine wastes during construction and operation of the site. A period of extreme, sustained rainfall could lead to unforeseen catastrophic impacts on infrastructure and the nearby and downstream environment during and/or after development and operation of the mine. The risk of such events is likely to increase over the life of the project (i.e., four decades) due to climate change, which is projected to increase both total rainfall and the frequency of major storm events over coming decades. On page 8 of the Site-wide load balance report (Appendix 6b), it is stated that increases in total rainfall, heavy rainfall and flood and storm events are all likely to occur up to the year 2100, however little consideration is given to this in the site water balance or water quality modelling (which are based on existing climate records).

- The site is also one of very steep topography (e.g., Fig 5.3 and Fig 5.9). The high level of topographic relief (along with the very high rainfall) present further challenges in terms of mine construction – e.g. stability of slopes surrounding the mine pits and ISF and maintaining the integrity of infrastructure used to store and contain mine waste materials. The open pit mines will be constructed within the catchments of Ubai and Uba Creeks, which have steep, rocky channels. Rapid flash-flooding in these channels due to the steep topography and high rainfall is likely a significant risk and this could create serious difficulties in containing poor-quality water and sediment during the construction and operation of the site.

- The area is also one of significant known seismic activity, being heavily faulted and located within a tectonic zone known as the PNG Mobile Belt, to the north of the Australian-Pacific plate boundary. This region is one of the most tectonically complex and seismically active zones in the world (e.g. Baldwin et al., 2012). This creates a significantly higher than usual risk of earthquakes within or nearby to the project area, which could lead to catastrophic impacts such as ISF dam wall and/or other site infrastructure failure. This could lead to catastrophic downstream effects (e.g. uncontrolled release of water and solids from the artificial ISF lake, release of copper concentrate or mine tailings from damaged pipelines, rock and/or mud slides, etc.). Such events would pose huge environmental and health and safety risks for human and ecological communities downstream of the site.

All these factors create significant additional risks and challenges for managing water flows, mine wastes and infrastructure, which are much more significant than at typical mine sites (where rainfall, topography and seismicity are far less significant risk factors). Whilst design of the ISF and other mine infrastructure is stated in the EIS to be ‘conservative’, able to accommodate high flow and seismic events, and extreme weather or seismic events are considered low probability, the impact of such events could be of enormous consequence. It is not demonstrated that the site’s proposed infrastructure and management plans will be resilient, in terms of preventing adverse water quality and hydrological outcomes, in the face of these risk factors. The Ok Tedi disaster[1] is one example of the potential short and long-term risks associated with major open cut copper gold mining operations occurring in the steep, high-rainfall and seismically active terrain of Papua New Guinea, and this should be considered an instructive example of what may potentially transpire at Frieda River.

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[1] See Kirsch, 1996: https://quod.lib.umich.edu/j/jii/4750978.0004.104?view=text;rgn=main

3. Analysis of key reports relevant to water quality/quantity issues

3.1 Site load balance report (Appendix 6b by SRK Consulting)

The major focus of the Site load balance report is potential water quality effects associated with operation of the mine open pits and ISF – a large artificial lake with a 187m high dam wall, into which waste rock, tailings and wastewater from the mine will be stored during and following mining. Water from the ISF is proposed to be discharged through the dam wall at controlled rate downstream into the Frieda River (and ultimately, Sepik River) during and after mining operations. This is predicted to result in elevated levels of metals in the Frieda River – especially aluminium, copper, chromium, cadmium and zinc – as well as in the streams that are up-stream of the ISF and which will flow into it (see figures 5.1 to 5.8 and discussion in section 6 of the report for model results).

Geochemical assessments have been conducted on the rock material in previous studies (EGi, 2011 and EGi, 2018), indicating that the vast majority of waste rock will generate significant acidity due to sulphide oxidation, with relatively low acid neutralisation capacity occurring in the material to buffer/neutralise the acid (e.g. see section 2.8). This in turn will result in high levels of metals in leachates associated with the waste rock, and water intercepted within the mine pits. Acidic pit water is expected to develop rapidly within the open-cut mines during excavation. This water will be collected in sumps, treated and sent to the ISF along with waste rock and tailings – transported to the lake via barge and pipeline, respectively. This is predicted to lead to somewhat elevated heavy metal concentrations in the water within the ISF, which in turn will lead to elevated concentrations of copper and other metals released from the outflow into the Frieda River. Water that has contacted the mine pit walls and wastes will be managed through a series of sumps; this will include the use of the smaller mined-out open pits (Ekwai and Koki) as water storages for the larger HIT open pit after years 4 and 7 of mining, respectively.

A water treatment plant and liming regime is planned in order to deal with the water collected in open-cut pit sumps prior to discharge into the ISF. Effluent from the treatment plant is proposed to be discharged into Ubai Creek where it will then flow downstream into the ISF. It is not clear exactly what sort of treatment will be conducted or how this plant will be constructed, operated and managed, as few specific details are provided in the reporting. The very high rainfall and steep topography will make the operation of a conventional water treatment plant significantly more challenging than otherwise, and the very wide range of possible volumes and qualities of water potentially requiring treatment (which have not been fully characterised or considered, see below) will add a further level of difficulty.

It is hypothesised (e.g. page 15) that sub-aqueous storage of the waste rock within the ISF artificial lake will result in limited oxidation of the waste rock, and therefore limit the generation of acidity and heavy metals within the artificial lake (and thus downstream environment in the Frieda River catchment). This assumption underpins all the predictions of water quality in water bodies downstream of the ISF in the load balance modelling. If higher rates of oxidation than are anticipated occur (e.g. due to mixing processes in the lake and/or oxidation more rapid and extensive than predicted during transit and disposal of waste rock to the lake), then significant additional metal loads will occur in the ISF and Frieda River (potentially also impacting the downstream Sepik River).

Rescan (1989) conducted a review of sub-aqueous mine waste disposal and examined conditions under which this strategy is likely to be more or less effective in limiting oxidation of reactive sulfide materials. Importantly, the report highlighted that sub-aqueous disposal was not a ubiquitously effective way to prevent oxidation of sulfide-bearing mine wastes (as appears to have been largely assumed in the project EIS), and that analysis of a range of site-specific factors, and lab-based testing could be conducted to better establish this:

> "Various factors, sometimes acting synergistically, determine the potential for mine wastes deposited underwater to generate acid and, consequently, the potential for biological impacts. These factors include, among others, the natural chemistry of the receiving environment, physicochemical conditions which may help limit concentrations of dissolved metals, hydrochemical conditions that may increase heavy metal solubility and the composition of the mine wastes being deposited. Of the range of predictive tests available to evaluate potential for acid generation (Section 2.3), the kinetic shake flask test appears somewhat suitable for subaqueous storage of reactive mine wastes.
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> The complex processes of bioavailability of metals in lake-bottom sediments and bioaccumulation in the freshwater food chain are not well understood, particularly with regard to reactive mine waste disposal. To help improve the level of understanding, lake studies should be conducted whereby post-depositional reactivity of submerged wastes is evaluated to determine if benthic effluxes of selected metals, i.e. Cu, Pb, Zn, Cd, Mn, Fe, As, and Hg are present and to what extent they are obviated by the gradual deposition of a veneer of natural sediments. Apart from potential impact, other biological effects of underwater disposal include turbidity, sedimentation on lake bottoms and toxicity to aquatic organisms." (Rescan, 1989).

The assumption that minimal oxidation of waste rock will occur in the ISF is not tested or demonstrated through any clear empirical evidence – e.g. trials to examine the level of oxidation, pH and metal concentrations occurring during exposure and sub-aqueous storage of waste rock material in an analogous environment. While it is stated that 'Sub-aqueous waste disposal and storage is the only proven method' to prevent oxidation of sulphide-bearing mine waste, no supporting references or empirical data are provided. All the geochemical testing described in Appendix 6b (based on laboratory experiments outlined in EGi, 2011) indicate that the rock material and tailings are subject to rapid oxidation, release of sulphate and mobilisation of acidity and metals following exposure to air and/or leaching with oxygenated water (e.g. page 13-15).

As discussed in Chapter 11 of the EIS, there is a possibility of extreme climatic conditions (strong winds, abnormal temperatures, sustained, high-rainfall events) causing disturbance at the lake bottom, stirring up material and causing additional mixing and oxidation of sulphides beyond what is predicted (i.e., minimal oxidation). Such events would result in significantly increased acidity and metal concentrations occurring in the ISF water and thus downstream environment in the Frieda River. No modelling or prediction of such a scenario is provided in the EIS, and as such the full potential range of water quality impacts downstream of the ISF is unclear. At present there is limited contingency or ability to prevent such events or respond in such a way as to prevent them from causing major downstream water quality impacts beyond those outlined in the water quality modelling.

Long-term plans to monitor and manage water quality upstream and downstream of the ISF are unclear. It is mentioned that treatment of water is expected to be required for at least 50 years following closure of the mine. However, there is no detailed proposal outlining how this will be done, whether the timescale of 50 years is commensurate with the timescale of impacts, how such work will be funded and what possible future contingencies need to be planned for given the challenges associated with post-closure recovery of groundwater levels and filling of the pit lakes. In terms of impacts related to the transport of potentially contaminated water into the surrounding area via groundwater flow, this timescale is unlikely to be sufficiently long to properly monitor and mitigate against impacts – given the large scale of the site and generally relatively low flow rates for groundwater in the types of materials being mined (Freeze and Cherry, 1979).

3.1.1 Methodology: Mine water balance and water quality monitoring

GoldSim – a commercial software package used to model mine site water balances and geochemical effects – has been used to produce stochastic estimates of water flows within and around the mine site, which in turn were used to model water quality impacts upstream and downstream of the ISF (in the Frieda River), at a series of surface water monitoring points (shown in Fig 2-3). The results of the stochastic modelling are outlined in section 5 of the report. Deterministic modelling was also conducted and is briefly summarised in section 6 of the report. Predicted flow volumes at the 13 nominated surface water monitoring points vary by 5 to 6 orders of magnitude depending on climate, indicating huge variation in flow volumes over time in the surface water bodies within and surrounding the site. This presents both significant challenges in terms of managing the range of flows likely to be experienced, and significant uncertainty in the water balance and thus heavy metal load predictions.

There are a significant number of uncertainties and assumptions which affect the confidence with which predicted water quality impacts are estimated using the adopted methodology. The most significant of these are described below. Given these uncertainties and assumptions, the EIS currently does not, in my opinion, give a full picture of the range of possible water quality effects that may occur during and following mining operations at the site.

- It is acknowledged in the report (e.g., page 20) that the historic climate datasets used to generate the range of flows and water balance parameters in the stochastic modelling is limited, and may not capture significantly wetter or drier conditions, which may plausibly occur during the life of the mine. No climate change scenario modelling was included in these simulations (only historic climate data were used), and the range of results is presented in terms of the average, 10th and 90th percentile model predictions. Presumably, extreme events (e.g. above the 90th percentile or below the 10th percentile) are when the risk of adverse water quality events are greatest, and as such these should also be modelled, considered and presented in the EIS, along with possible climate change scenarios. Considering this, the water quality modelling should not be considered conservative – e.g. it is unlikely to capture possible ‘worst case’ scenarios at the very wet or dry end of the climate spectrum.

- Background monitoring of water quality was carried out to establish baseline conditions (e.g. section 2.7) against which to compare the future impacts of mining. This monitoring has mostly been conducted on a quarterly basis (e.g. 4 sampling events per year). It is acknowledged that this does not give a comprehensive idea of the full variability in baseline water quality, as this is likely to be highly dependent on rainfall (which is extremely high and very variable). As is noted in the report, seasonal changes or monthly average values were not able to be included in the baseline data due to this relatively low sampling frequency. At least monthly sampling and possibly, additional strategic sampling seeking to sample following periods of particularly high and low rainfall to obtain a wider indication of water quality under different climatic conditions would be more appropriate.

- Estimates of mine water inflow volumes are based on groundwater modelling, which contains significant uncertainties and assumptions (see further discussion of this topic below in section 3.2 of this report). For example, seepage inflow volumes are estimated using a matrix-dominated, single porosity flow model, whereas the dominant flow mechanism at the site (given the complex geology) is dual or multi-porosity fracture flow. As such, both the volume and quality of water seeping into the mine pits and requiring treatment are currently poorly constrained and could be highly variable – e.g. beyond the ranges used within the modelling. This has not been factored into the modelling of water quality upstream and downstream of the ISF.

- Solute (e.g. metals) concentrations in water interacting with the mine pit walls are calculated using the assumption that sulphate and metal concentrations are limited by the rate at which oxygen can diffuse into exposed rocks. It is conceded in the methodology section (page 34), that these estimates are uncertain and that factors such as the depth of fracturing, porosity and level of saturation are relatively unknown variables. As such, greater degrees of oxidation and solute generation from pit wall rocks cannot be ruled out - e.g. again, the modelling of water quality should not be considered conservative with respect to the possible rate and amount of acidification and metal mobilisation.

- There are a number of other large uncertainties related to the estimation of solute release rates (and total amounts) for mine pit water and waste rock that is proposed to be sent to the ISF after mining. Limiting the time between excavation and disposal of waste rock is proposed to be one of the major mitigation strategies to minimise water quality impacts. However, the release rates and time-lags involved are still poorly understood, other than acknowledgement that oxidation of sulphides occurs rapidly (page 14). Using an average value of exposure time (12 weeks) and release of sulphate/metals over this time period may not give the full potential range of effects. The surface area of crushed blasted rock and effect of exposure on solute release for typical waste rock particles is assumed (e.g. not actually observed in experimental work), as the experimental test work used smaller than particles than are anticipated during mining. The metal release rates are based on sulphate release rates – e.g. not actual measurement of metal concentrations following sulphide oxidation to varying degrees. Alternative/additional methodologies (e.g. outlined in Rescan, 1989) would provide better information in this regard. Without such data it is not clear how applicable this assumption is as the oxidation pathway(s) involved and trace/heavy metal element contents of different material in the waste rock may be variable. The specific reactions involved, and associated range of pathways, rates and total acidity have not been predicted based on geochemical modelling (for example).

- Solute concentrations in groundwater inflow to the pits are based on AGE (2018) – Appendix 4 (see below). It is not clear how representative these values are likely to be for the true seepage of groundwater that is likely to enter the mine pits during operation (e.g. they likely represent ambient, baseline groundwater quality conditions in a wider area than will be mined, and many will be more diluted and less affected by contact with sulphide-mineral bearing rocks than what would be expected in the vicinity of mining, particularly given the disturbance of these materials). Mobilisation of acidic, metal-rich leachate into groundwater and infiltration of this as groundwater discharge into the pits appears not to have been factored into water quality modelling (and hence pit water quality may be of optimistically high quality) or water treatment plan. The disturbance created by open-cut mining – e.g. excavation and blasting work, dewatering and ultimately, recovery of groundwater levels, all have the potential to oxidise greater amounts of sulphide and impair the quality of water intercepted by the pits and sent to the treatment plant and ISF beyond the base case predictions. Notably, the Groundwater Assessment (Appendix 4) does not propose any monitoring of groundwater quality immediately surrounding the mine pits – instead relying on sampling of seepage/inflow to the pits.

- Tailings water quality input into the ISF is estimated based on data from a previous study by EGi (2011), however no detailed justification or analysis of this data is provided. The use of averaged values, without considering and presenting the full possible range of water qualities is again likely to preclude assessment of the full possible range of water quality impacts.

3.1.2 Results

The modelling results indicate significant exceedance of ANZECC 95% freshwater ecosystem protection guidelines, due to the anticipated high metal concentrations within and downstream of the ISF. This is particularly pronounced if untreated open-pit water is discharged into the ISF (Figs 5-1 to 5-4), but it is also true under the modelled scenario involving treatment of mine pit water prior to discharge to the ISF (Fig 5.8 to 5.10).

Dissolved copper concentrations in the Freida River are predicted to exceed ANZECC freshwater ecosystem 95% protection guidelines by 7 to 8 times, even with the pit water treatment plan implemented (although details of this treatment plan are not extensive in the reporting). Other constituents such as aluminium, cadmium, zinc and chromium also exceed these guideline values to varying degrees, depending on the level of flow, and implementation (or not) of the treatment plan (section 5).

TSS values are also expected to be highly variable, and particularly in the early stages of mining will be at times highly elevated (notwithstanding relatively high background TSS levels in Freida River at present). Total metal concentrations (e.g. Al, Fe, Cu) may become significantly elevated in conjunction with elevated TSS events. At present there is limited basis to predict and understand these relationships.

Notably, the range of predicted impacts does not consider the many uncertainties and assumptions outlined in the previous section, and therefore does not capture the full possible range of water quality impacts. Under certain situations, which are plausible – e.g. greater than anticipated oxidation of waste rock in the ISF, poorer quality and/or greater quantity of mine pit inflow than anticipated, more extreme climatic conditions – significantly poorer water quality could be expected in the Frieda River catchment than is presented in the results.

All of the predicted impacts also assume standard operating conditions, assuming no infrastructure failure throughout the life of the mine. Given the extremely high rainfall/runoff characteristics of the site, the risk of seismicity and the (unknown) potential for mixing/overturn events in the ISF, there is considerable risk that standard operation may be impaired at some stage(s) during the project, leading to water quality outcomes that are significantly worse than the predicted range of impacts presented.

3.1.3 Further issues

Elevated background levels of aluminium (up to 32 mg/L) and copper (up to 0.17 mg/L) were observed at the Freida Base Camp monitoring site (Table 2-3), as reported in the baseline data. The possible reasons for these elevated values are not discussed in the report. The data indicate that existing water quality may be impacted by anthropogenic disturbance, for example, during mining exploration activities at the site. In Appendix 4 (Groundwater Assessment) it is stated that there are exploration bores that have been drilled at the site which are artesian, and discharging groundwater freely at the surface. The influence of these and/or other pre-existing disturbances which have led to water quality impacts should be carefully analysed and discussed in the report. Such analysis could give an indication of expected water quality changes occurring during early-stage construction of infrastructure at the site - this data may for example indicate that mobilisation of metals during mining construction works is probable in the short-term, requiring additional runoff control and other management measures in the early stages of mining beyond those currently planned.

It does not appear that any detailed analysis or investigation of the relevant geochemical reactions occurring during oxidation of sulphides and other constituents (e.g. iron) in the waste rock or tailings material has been done, for example through geochemical modelling (PHREEQ) and/or the use of mineral-aqueous phase redox stability diagrams for key species (Appelo and Postma, 2005). The potential range of reaction pathways occurring during oxidation of sulphides can be complicated and vary due to a range of factors including redox, temperature and pH conditions, presence and abundance of particular mineral phases involved in the reaction sequence, and competing reactions. Given the significance of the sulphide oxidation process in controlling water quality, such analysis should be conducted to improve understanding of the likely timing, rates and extent of oxidation, acid generation and metal mobilisation in the system.

3.2 Groundwater assessment (Completed by AGE – Appendix 4)

A groundwater assessment is included as Appendix 4 of the EIS. This assessment is predominantly focussed on groundwater quantity impacts, such as the effects of the proposed mine on groundwater levels and baseflow to streams in the area. However, the assessment also has important water quality implications (see above), as both baseline groundwater data and groundwater modelling outputs are used in the site water balance and load balance modelling in Appendix 6 (discussed above).

Major impacts associated with mining that relate to groundwater include:

- Drawdown (reduction in groundwater levels) occurring during and after mining – this is expected to influence an area of 5 to 6km away from the mine pits.
- Loss of baseflow (groundwater discharge) into streams, leading to ecological impacts – e.g., streams in the area are expected to experience losses in baseflow ranging from negligible change to 100% of current baseflow (e.g. in Ekwai Creek) which may impact aquatic ecosystems.
- Inflow of groundwater to the mine pits, which will require careful management in order to prevent issues with slope stability and pit water quality management; approximately 10 to 30 ML/day of water is expected to flow into the pits during operations.
- Loading effects resulting from the damming/filling of the ISF, which will lead to rising groundwater elevations and hydraulic gradients away from the dam, and result in potential stability issues and/or leakage and sub-surface transport of contaminated water from the storage facility into the surrounding region. Some of this water may ultimately discharge to streams and/or elsewhere at the surface (e.g. as seeps). This has received minimal attention or consideration in the groundwater and water quality assessments.
- Groundwater contamination. The groundwater assessment contains minimal analysis and discussion of groundwater contamination risk due to the project, however, this is likely to be a significant consequence of mining, as is common in copper and gold mines worldwide (e.g. Gestring and Hadder, 2017). The assessment includes baseline groundwater quality data but no analysis of likely changes to groundwater quality arising during the project. The risk of enhanced sulphide oxidation, leading to release of metals and acidity into groundwater during de-watering and/or recovery of water levels has not been explored in detail in the assessment (for example, through hydrogeochemical modelling). This issue is of significance, irrespective of whether groundwater is currently used be people and/or ecosystems in the area, as contamination of groundwater is likely to have flow-on effects for mine-pit water

quality (see above) and possibly surface water, due to discharge of groundwater to streams. Due to the lack of analysis of likely changes to groundwater quality caused by mining and during post-mining recovery, these issues are currently poorly understood.

3.2.1 Methodology

Most of the assessment of the groundwater-related issues described above is based on baseline groundwater level and quality monitoring and a numerical groundwater flow model, which has been used to simulate the drawdown and water budget impacts of the project during and after mine development. The model has been developed using a range of site-specific field data (e.g. analysis of drill cores and groundwater level monitoring carried out at the site over recent years), and the modelling code MODFLOW-USG – an industry standard code used for groundwater flow modelling problems.

It should be acknowledged that all the groundwater impacts discussed in this section of the EIS suffer from a significant level of uncertainty, due to:

a) the highly heterogeneous nature of the geological material – e.g. heavily deformed and metamorphosed rocks, with significant development of fractures and geological faults, and;
b) the fact that the mine is a 'greenfield' site, with no existing experience of mine related drawdown, inflows or water level recovery, anywhere near the magnitudes expected.

As a result of these and other factors (discussed below), the predicted impacts of the project on groundwater, and related issues (e.g. surface water quality) should be viewed with caution and a degree of scepticism at this stage. Unfortunately, there is no formal uncertainty analysis reported in conjunction with the groundwater modelling to better inform an understanding of the degree of uncertainty that is associated with the model's major predictions. Such analysis has become standard practice in the mining industry – e.g. the Australian Groundwater Modelling Guidelines include a formal uncertainty analysis as part and parcel of the groundwater modelling process (Barnett et al., 2012).

Specific issues affecting the current level of confidence with which the groundwater impacts described above can be determined are further discussed below:

3.2.1.1 Drawdown and Post-mining water level recovery

Predictions of the amount of groundwater drawdown caused by mining (see Fig 6.1 and 6.2) are informed by the numerical modelling, which is in turn informed by water level monitoring and hydraulic parameter data collected from the site (e.g. packer and falling head tests to estimate hydraulic conductivity). There is a reasonable coverage of baseline groundwater level data from monitoring bores and vibrating wire piezometers at the site (e.g. Fig 4.1, Fig 4.9), although this is biased towards the deeper aquifer(s), with more limited data regarding hydraulic properties and water levels in the shallow regolith and alluvial/colluvial material. This means the estimates of changes to groundwater levels and flow in shallow groundwater, and by extension baseflow in streams, are less well constrained by existing monitoring data than the response in the deeper units.

The predictions of drawdown in any groundwater model are highly dependent on the hydraulic parameters adopted in the modelling, particularly hydraulic conductivity (K) and storage coefficients (Ss, Sy). While Fig. 4.9 shows that there is a reasonable amount of data to inform appropriate hydraulic conductivity values for the major rock units at the site, it is also acknowledged (e.g. p. 22) that most of the rock material is highly fractured and heterogeneous, and the K values are not representative of dual or multi-porosity flow (e.g., via fractures) which is likely to be the dominant flow regime in the area. Importantly, the modelling code used – MODFLOW – is suited to single-porosity, constant parameter ‘matrix’ flow (e.g. porous media as opposed to fractured rock) and is not well adapted to modelling fracture flow processes. This creates a high level of uncertainty in the predictions of drawdown, particularly at the local scale. Alternative codes (such as HydroGeoSphere – Therrien) are available to simulate multi-porosity flow, although modelling is not always the most appropriate approach – often in such settings it is more valuable to increase the amount of site-based observation data to compensate for the generally high level of uncertainty in predicting groundwater flow in fractured rock environments.

No field data to inform estimates of storage coefficients (e.g. specific storage) are available (p. 24). Storage coefficients are key to controlling the relationship between extraction (or injection) of groundwater, and the rate at which drawdown or recovery of water levels occurs. It is noted in section 4.2.3 that many of the points where groundwater levels have been monitored over time show significant temporal variability (e.g. significant water level changes over time). At this stage, it is not well understood whether such changes reflect variability in groundwater recharge, or pressure loading effects (e.g. p. 21). The predictions of drawdown and recovery of groundwater levels during mine operation and closure must be seen in the context of this parameter and conceptual uncertainty with respect to transient responses.

As a result of these issues, the estimates of the extent and rate of drawdown and recovery occurring during and after mining should be viewed as preliminary guidance and the actual case may depart from predicted values significantly. The statement on page 38 that the model calibration and RMS value obtained (5.2%) provide ‘confidence in the ability of the model to be fit-for-purpose for the impact assessment’ is potentially misleading in this context. As is well recognised in the groundwater modelling community, a well-calibrated model does not in itself indicate confidence in the model’s predictions (Rojas et al., 2008; Hunt et al., 2019). This is particularly true where there are multiple poorly constrained parameters - as is the case for this particular model - which may compensate for one another in order to achieve a high level of calibration fit. The lack of any formal uncertainty analysis in the groundwater model again means that it is not possible to properly assess or understand the level of certainty in the model predictions or wider range of possible outcome arising due to the project. In this sense, similar to the modelling of water quality effects, the EIS is not a conservative representation of potential impacts.

3.2.1.2 Changes to baseflow in streams

Predictions of the reduction in baseflow (groundwater flow to streams) occurring due to mining are also made based on the numerical groundwater model. Because the baseline groundwater level data in the shallow material is relatively sparse compared to deeper aquifers (see above) and there is limited monitoring of groundwater levels adjacent to streams, these estimates should also be seen in the context of significant potential uncertainty. The use of baseflow recession or other stream-hydrograph methods for estimating current baseline quantities in the stream network are of limited value (as discussed in section 4.6.1), due to the very persistent high rainfall at the site. The usefulness of these estimates as calibration targets in the groundwater modelling (e.g. p. 33) should thus also be viewed with caution/scepticism.

The above issues mean that the estimates of baseflow changes occurring during mining are not well constrained. Notwithstanding, the modelling indicates the potential for significant baseflow reductions during mining – particularly in the Nena River and Ekwai Creek (e.g., Figure 6.4). It is unclear what level of ecological impact the disturbance of flow regimes caused by these changes might occur.

3.2.1.3 Pit inflows/seepage

Seepage of groundwater into the mine pits is a common issue during open-cut mining which requires careful management, to prevent issues with pit-wall stability and water quality. The model predicts approximately 28 ML/day of water seeping into the mine pits (a combined total across the three pits) at peak operating conditions (Fig 6.3). This seepage will require ongoing treatment and management, in order to allow the progression of mining. Pit inflows will be managed according to the protocols outlined in the site load balance assessment (appendix 6b), which include treatment and discharge to the ISF.

The issue of a high degree of fracturing and deformation of the rocks that will be intersected by mining, and the impact of this on seepage of water into the pits has not been carefully analysed, considered or discussed. The pit seepage estimates simulated in the model and presented in Section 6.2 are based on matrix flow as opposed to fractured rock flow (which is likely to be the dominant flow mechanism), and uniform porosity/hydraulic parameters within a given layer, contrary to the rock material encountered at most of the site (which is heavily fractured). Seepage of water to the pits is likely to be highly heterogeneous and follow preferential pathways such as fractures. Intersection of fractures that provide preferential flow during mining may lead to sudden and rapid inflows of water at specific points in the mine walls, that are well above those considered typical or average rates, based on the modelling.

No field studies or verification/calibration datasets for seepage inflows in any excavated areas are currently available with which to assist model development and calibration for the purpose of inflows predictions. As such, the model is not well equipped to provide accurate estimates of pit seepage, and the estimates presented may be misleading. This has significant flow-on implications for other parts of the site water and load balance modelling – e.g. estimation of pit water volumes and mine water quality requiring treatment prior to discharge to the ISF. The pit inflows estimates have been used to calculate the total loads of acidity, sulphate and metals (e.g. copper) being discharged into the ISF (Appendix 6), which will in turn control the down-stream concentrations of copper and other heavy metals in the Frieda River. It is plausible that much higher pit inflows may be experienced, and this could increase the copper and other heavy metal loads discharged from the ISF beyond those predicted in Appendix 6b – however at present this is highly uncertain.

3.2.1.4 Mounding of groundwater

The issue of mounding of groundwater (rising water levels in response to surface loading) beneath and surrounding the ISF is mentioned on page 39 of the report, although no in-depth analysis of this issue has been undertaken. It is predicted, based on the numerical modelling, that the filling of the artificial ISF lake will result in groundwater levels increasing up to 150m higher than the surface elevation of the Frieda river. This will potentially lead to:

a) geotechnical issues (e.g. ground and slope stability challenges)
b) potential pathway(s) for groundwater contamination – e.g. via seepage of water from the base or sides of the ISF into the surrounding areas - possibly emerging as discharge of contaminated groundwater to surface water.

Due to the regional scale of the modelling and lack of certainty regarding hydraulic parameters, flow pathways, groundwater quality and other baseline groundwater data surrounding the ISF, it is currently unclear what level of risk groundwater mounding at the site presents. This would require significant further investigation and modelling work (e.g. hydrogeochemical modelling – see Appelo and Postma, 2005). Results of particle tracking simulations, to explore the potential transport of groundwater from the ISF to surrounding areas are shown in Fig 6.6. These results indicate likely flow of water from the ISF towards the Frieda River occurring in the long term (on a 2000-year timescale), which would presumably increase contaminant loads in the river as groundwater discharges into it. Again, the timescale and pathways for potentially contaminated groundwater migrating from the ISF to downstream receptors via such pathways should be considered highly uncertain, given the issues discussed above (e.g. inappropriateness of the modelling code for simulating fracture flow, high level of parameter and conceptual uncertainty).

3.2.1.5 Groundwater quality

Analysis of baseline hydrochemical data (section 4.4) indicates that groundwater is generally relatively fresh, and the hydrochemical composition is controlled by:

a) dissolution of anhydrite or gypsum (leading to Ca-SO4 type water) and
b) some local oxidation of sulphide minerals in the rock, resulting in low pH and significantly elevated SO_4 concentrations (Fig 4.15).

The baseline groundwater quality data in section 4.4 include a relatively sparse number of groundwater quality data points (given the size of the project area) – see Fig 4.13 and 4.15, and not all analytes that should be considered (in terms of assessing potential water quality threats) have been analysed. For example, there are no data regarding the oxidation state of the groundwater – e.g. field Eh/ORP measurements, measurement of dissolved gases (e.g. hydrogen sulfide) or dissolved organic carbon concentrations. Given the oxidation of sulphides is the key process that will control ground and surface water quality evolution at the site, these parameters should have been included in the baseline data and should be part of any future ongoing monitoring program. Collection of redox potential data (e.g. Eh/ORP) would allow for the plotting of redox stability diagrams and/or geochemical modelling, to examine the most likely state(s) for key mineral phases and ion complexes under different aqueous conditions. Such information is required to properly characterise likely groundwater and surface water quality evolution in response to mining (see above).

Drawdown of groundwater associated with mining is likely to result in significant additional oxidation of sulphide-bearing minerals in the rock, which will likely lead to increased acidification and release of metals into the groundwater. Depending on the pathway(s) by which groundwater moves during and following mining activity, this could lead to additional acidification and contamination of surface waterways (e.g. those which receive groundwater discharge/baseflow), as well as impairment of the groundwater quality itself (creating additional challenges managing the mine pit water quality). Little to no discussion or analysis of this risk is provided in the groundwater assessment or site load balance report, and it does not appear to have been factored into the modelling of surface water quality in the site load balance report (Appendix 6b). Geochemical modelling to explore likely changes to groundwater quality resulting during de-watering and recovery, and associated sulphide oxidation should be included in the analysis of groundwater impacts from the project to better inform assessment of these risks.

In general, there is limited integration of the findings of the two studies (site load balance and groundwater assessment) to inform a proper groundwater contamination risk assessment or analysis of ground-surface water interaction and the resulting water quality effects. As discussed in section 7 of Appendix 4 (Groundwater assessment), there is currently no proposal to monitor groundwater quality immediately surrounding the proposed open-pit mines; water quality will only be monitored as seepage/pit inflows once discharged into the pit. Monitoring groundwater quality (and levels) immediately surrounding the pits is a key mechanism to better characterise and understand water quality evolution and assess and mitigate water quality risks during the progression of the project.

Collection and analysis of such data would allow for a much more data-driven and risk-driven approach to water quality issues – e.g. if rapid changes in groundwater quality can be detected prior to this water discharging to the mine pits, it can be more pro-actively managed and treated to prevent downstream water quality impacts. Monitoring around the edge of the pits will also give a clearer indication of the evolution of water quality (and levels) during the recovery phase of the project (e.g. after mining), allowing for more pro-active assessment of likely down-gradient water quality impacts (e.g. movement of contaminated groundwater towards streams).

4. General comments on report quality

- Figures are generally of poor quality/resolution throughout the EIS. The maps in Appendix 6b showing the details of site layout (Figs 2-1 & 2-2) and mine development plan (Figs 3.3-3.5) are of such poor quality that the labels and legend can’t be read, precluding a close analysis of site features, some of which are relevant to the assessment of potential water quality/quantity impacts.
- Integration of results between the different reports is limited – e.g. there is no proper consideration of the likely effect of mining on groundwater quality, and integration of such information into the water quality modelling and management plans. Consideration of the water quality implications of ground-surface water interaction is minimal, as is consideration of water quality changes and challenges related to groundwater recovery in the post-mining period.
- There is a lack of formal analysis of uncertainty in the groundwater modelling predictions and water quality modelling results (although in the case of the latter, a probabilistic method is used, providing some limited indication of uncertainty), and a lack of consideration of how uncertainties in the groundwater modelling (which are likely to be very significant) propagate as additional uncertainty in the water balance/water quality modelling used to predict impacts on surface water bodies in the region.
- In general, there is a lack of consideration or modelling of potentially rare but extreme magnitude climatic or seismic events, which could cause catastrophic water quality/quantity impacts. While these impacts are acknowledged in Chapter 11 of the EIS, there is little to no consideration or prediction related to these integrated into the groundwater assessment and site load balance predictions. Such events may be of far greater importance from the ecological and human health and safety perspective than the ongoing, base-case operational scenarios and thus should be a far greater focus in the analysis of impacts and threats from the project.

5. References

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